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New World Situation: New Directions in Concurrent Engineering

Proceedings of the 17th ISPE International Conference on Concurrent Engineering

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Preface

The proceedings contain papers accepted for the 17th ISPE International Conference on **Concurrent Engineering**, which was held in Cracow, Poland, September 6-10, 2010.

Concurrent Engineering (CE) has a history of over twenty years. At first, primary focus was on bringing downstream information as much upstream as possible, by introducing parallel processing of processes, in order to prevent errors at the later stage which would sometimes cause irrevocable damage and to reduce time to market.

During the period of more than twenty years, numerous new concepts, methodologies and tools have been developed. During this period the background for engineering/manufacturing has changed extensively. Now, industry has to work with global markets. The globalization brought forth a new network of experts and companies across many different domains and fields in distributed environments. These collaborations integrated with very high level of profesionalism and specialisation, provided the basis for innovations in design and manufacturing and succeeded in creating new products on a global market.

Although CE has diversified in many ways, its idea and methods are now prerequisites for every engineer and company now. No matter how diversified the current CE may be, there is certainly a direction common to all these CE researches and applications. The reader will find it as a main stream of most of the papers contained in this book that they are looking into the direction of a human, i.e., designer as a human, engineer as a human, customer as a human, and even a knowledge engineer as a human, although each paper deals with different issues. This main stream is reflected in session organization as well, design knowledge utilization and knowledge engineering, product design and development: lean product development, human centric product design and development, advanced manufacturing and mass customization, advanced manufacturing.

The conference is titled "**New World Situation: New Directions in Concurrent Engineering**". "New World Situation" is a fact. "New Directions in Concurrent Engineering" is our hope to establish new directions in the greatly and rapidly changing world of CE. We sincerely hope the book will serve to our readers to find CE in his/her new direction which will work in his/her own environments.

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Part I
Advanced Manufacturing

A Novel Bio-inspired Approach for Adaptive Manufacturing System Control

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Abstract. The trend towards a global market and the increasing customer orientation impel the manufacturing discipline to seek new paradigms. As biological organisms are quite capable of adapting to environmental changes and stimulus, bio-inspired concepts have been recognized much suitable for adaptive manufacturing system control. This paper, therefore, proposes a novel concept of NeuroEndocrine-Inspired Manufacturing System (NEIMS). The proposed NEIMS control architecture is inherited from neuro-control and hormone-regulation principles to agilely deal with the frequent occurrence of unexpected disturbances at the shop floor level. From the cybernetics point of view, the control model of NEIMS has been described in detail. And a test bed has been set up to enable the NEIMS simulation.

Keywords. Adaptive Manufacturing System Control, Bio-inspired Manufacturing System, Neuroendocrine System, Neuro-control, Hormone-regulation

1 Introduction

Nowdays, facing more complex and significant trends of cultural diversification, lifestyle individuality, activity globalization, and environmental consideration, manufacturing companies are forced to have manufacturing systems that can support the agile response to the emergence and changing conditions in manufacturing environments[1].In order to meet the new requirements, several manufacturing paradigms have been proposed for next generation manufacturing, such as agent-based manufacturing system [2], fractal manufacturing system[3], holonic manufacturing system[4], etc. These types of architectures are considered to be suited for developing distributed intelligent systems in an open and dynamic environment.

As we know, biological organisms naturally can be capable of adapting to environmental changes through self-recognition, self recovery, and evolution. The manufacturing paradigms of Multi-agent Manufacturing system, HMS, and FrMS embody more or less the characteristics of biological organisms. In a biological

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body, the neuroendocrine system is also one of the major physiological systems and has some special modulating mechanism for better control adaptability and stability [5]. But few relative researches have been done on manufacturing system control based on the neuroendocrine-inspired idea. By referencing the biological organization structure and the neuroendocrine mechanism, a new bio-inspired architecture for manufacturing system control is proposed in this paper. The aim of this research is to improve the intelligence, controllability, and adaptation of the manufacturing system by utilizing the mechanism of neuro-control and hormone-regulation, thus consolidating and deepening the BMS theory and fundamentals.

The remainder of the paper is organized as follows. Section 2 presents a new BMS model designated by NeuroEndocrine-Inspired Manufacturing System (NEIMS), and describes its architecture in detail. From the cybernetics point of view, section 3 gives the control model of NEIMS and especially explains the hormone-regulation mechanism of NEIMS. Section 4 describes a pilot test bed for simulating the neuroendocrine-inspired manufacturing control system and discusses the adaptive and dynamic behavior of the proposed manufacturing system. Section 5 concludes the paper and points out the next step research.

2 NeuroEndocrine-Inspired Manufacturing System (NEIMS)

In the biology area, as we all known, the neuroendocrine system is quite critical in initiating life sustaining adaptive reactions to internal and external (environmental) stressors. Based on the general concept of Bionic Manufacturing System (BMS), hereby we consider the manufacturing system as a living organism. To be different with other BMS researches, a bio-inspired manufacturing system is presented based on the general principles of neuroendocrine system. In this section, we will propose a novel architecture of NeuroEndocrine-Inspired Manufacturing System.

2.1 Bio-Inspired Manufacturing Cell (BIMC)

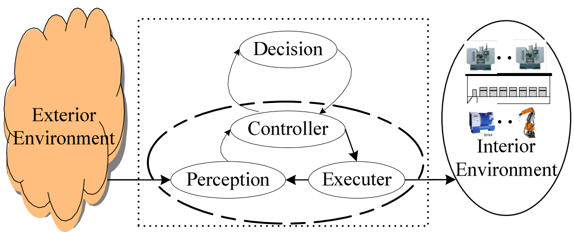


Figure 1. Basic Structure of Bio-Inspired Manufacturing Cell (BIMC)

To biologically describe such architecture, the composing unit of NEIMS is defined as Bio-Inspired Manufacturing Cell (BIMC). The basic structure of BIMC is shown in Figure 1. Like biological sensory neurons, each BIMC contains the functional components of controller, decision-maker, executer, and perceptron. A BIMC is defined as an autonomous entity that can perform some tasks and achieve the goal autonomously, and can regulate itself when facing non-predeterministic changes in manufacturing environments. The autonomy in the definition does not mean a BIMC must be fully independent, but means that it can automatically ask for assistance and services from other BIMCs whenever necessary. The BIMC facing complexities comes from two aspects: interior environment and exterior environment. The BIMC deals with exterior and interior complexities by perceptron and controller respectively, keeps balance between control function and perceptional function simultaneously, and then makes a decision.

2.2 Architecture of NeuroEndocrine-Inspired Manufacturing System

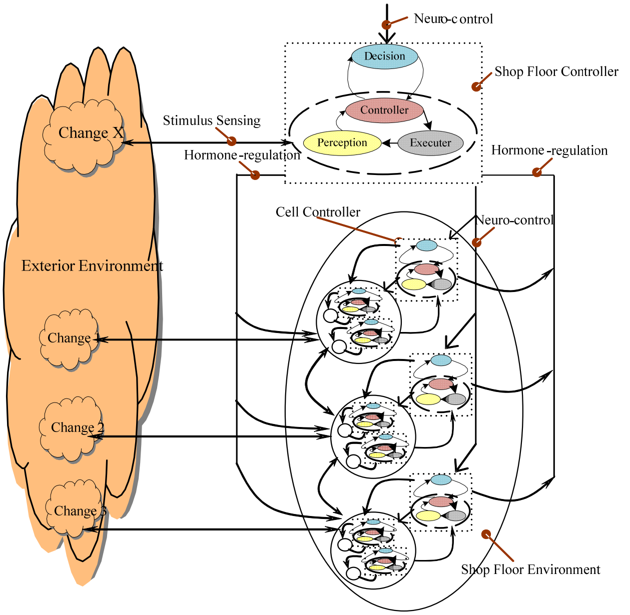


Figure 2. Architecture of NEIMS

Biological body is a whole entirety, though each biological cell has its special physiological function, they are dominated by the neuroendocrine system. Based on the BIMCs which has been defined firstly, a new architecture of bionic manufacturing system is proposed in Figure 2.

Inspired by the principles of neuroendocrine system, NEIMS conducts neuro-control in a normal state, and applies hormone-regulation in an emergent state. In the normal state, the BIMCs at different levels are organized in a hierarchical structure, and the shop floor controller (similar to central nervous system(CNS)) elaborates and sends optimized schedule plans (similar to signals) to the cell controllers of BIMCs. BIMCs at different levels follow the received command and conduct their own stationary operations (just like the heart pumping blood with a normal rhythm). In this state, NEIMS can get a global optimization of the production process with a maximized resource (equipment) utilization rate and optimum task schedule.

If unexpected events occur in the shop floor, the system will deviate from planned, and regulation is necessary for adaptation. In such case of emergent context, NEIMS adopts the hormone-regulation mechanism to agilely adjust the behaviors for recovery. The hormone-regulation is to control the hormone release to keep a well-balanced biochemical environment in the blood vessel. In the emergent state, it is no doubt that the resource shall be re-organized, and/or the original task schedule plan shall be adjusted for re-schedule. Taking the task schedule and resource (equipment) utilization as hormones of NEIMS, a hormone regulation model is set up and illustrated in following section. The basic principle is to modulate the resource utilization to obtain an optimized task re-schedule. The BIMC which detects the disturbance initiates the recover locally from the emergence by sensing the concentration oscillation of hormone (such as machine failure will negatively affect the resource utilization). Meanwhile, the initiated BIMC interacts with other ones for cooperation, as its disturbance surely affects the original task schedule. The cell controllers conduct the role of pituitary, and the operational devices are similar to the glands. The hormone release control mechanism is used to make a balance between resource utilization and task re-schedule. The shop floor controller still acts as central nervous system. It doesn't directly deal with the disturbance, but receives the feedback of the interaction among the involved BIMCs, and then continues elaborating the task allocation for recovery.

Furthermore, the recursivity of NEIMS is reflected not only on the system structure, but also on the control and regulation mode.

3 NeuroEndocrine-Inspired Control Solution

The harmonic control mechanism plays a critical role in the system performance in terms of agile response to disturbance. In order to enables the agility and reaction to unexpected changes and guaranteeing the global optimization, an adaptive control approach using the hormone-regulation mechanism has been developed to react to disturbances in the emergent state. In this section, the control model of NEIMS is illustrated with a focus on the hormone-regulation.

3.1 Biologic Hormone Regulation Mechanism

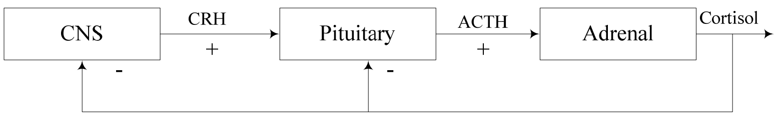
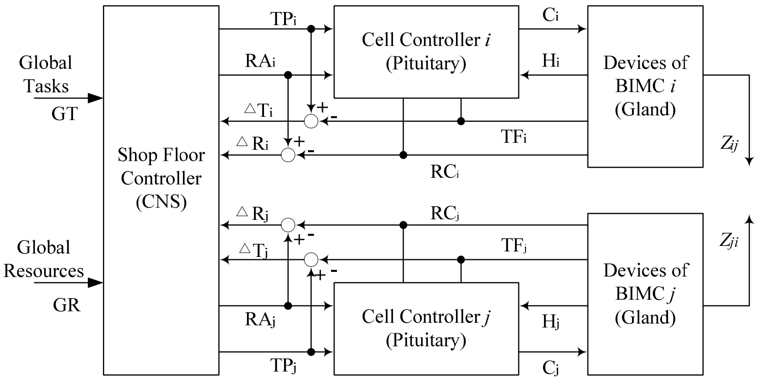


Figure 3. Negative feedback control model of hormone-regulation

The endocrine system is made up of a series of ductless glands that produce chemical messages called hormones. A number of glands that signal each other in sequence are usually referred to as an axis, for example, the hypothalamic-pituitary-adrenal axis. In this sub-section, a feedback-controlled ensemble model of the stress-responsive hypothalamo-pituitary-adrenal axis[6] is used to explain the hormone-regulation mechanism and related control model. This neuroendocrine ensemble exhibits prominent time-dependent dynamics reflected in vividly pulsatile and 24-h rhythmic output. Episodic secretion is driven by hypothalamic neuronal pacemakers of CNS, which secrete the pituitary signaling peptides CRH (ACTH-releasing hormone). These agonists singly and synergistically stimulate ACTH (adrenocorticotropic hormone) synthesis and secretion (feedforward), which in turn promotes the dose-responsive biosynthesis of cortisol. Cortisol feeds back to inhibit CRH and ACTH production via concentration-dependent and rapid, rate-sensitive mechanisms. A typical control model of hormone regulation is shown in Figure 3, which exhibits the characteristic of negative feedback.

To sum up, the hormone-regulation involves the interaction of two types of hormone. Suppose that the secretion rate HA of hormone A does not depend explicitly on the time t and is controlled by the hormone B (cortisol), we write, HA=HA(CB(t)) where CB is the concentration of B (cortisol). In the sequel, HA is called a control function which is monotonous and nonnegative.

3.2 Hormone-Regulation Model of NEIMS



GT: global task of original plan
GR: global resource capacity of original plan
TPi: task plan to BIMC *i* in the original plan
RAi: resource allocation to BIMC *i* in the original plan
TFi: task finished by BIMC *i*
RCi: resource capacity consumed by BIMC *i*
ΔRi: resource capacity deviation of BIMC *i*
ΔTi: task deviation of BIMC *i*
Ci: control order to BIMC *i* from cell controller *i*
Hi: state of BIMC *i*
Zij(Zji):machine skill similarity (0-1) between BIMC *i* and BIMC *j*

Figure 4. Control model of NEIMS

Inspired by the biologic hormone-regulation mechanism, a control model of NEIMS for coordination is proposed in Figure 4. Mimicking the hormone-regulation principle, there are three types of entity, namely, the shop floor controller (CNS), the cell controller (pituitary), and the devices of BIMC (gland). Taking the resource utilization and task schedule as two types of hormone, the level of hormone concentration of BIMC i can be indicated as ΔR_i and ΔT_i. During the schedule plan, the information of resource utilization contains machines' type, capability, and number of machine units; and the task schedule refers to the operations assigned with the required amount of time for processing on the specified type of machines. Therefore the resource utilization and task schedule are interdependent on each other. Suppose that the resource hormone is controlled by the task hormone. If $\boldsymbol{\Delta T_i}$ is not equal to zero, it means unexpected events occur in the manufacturing system, and the hormone-regulation will be triggered for system equilibrium through resource regulation. The resource regulation is to re-organize the resource allocation for re-scheduling, and regulated resource capacity $\boldsymbol{\delta R_i}$ (like the secreted hormone for biological regulation) will be assigned to BIMC *i*.

In the biological hormone-regulation mechanism, normally the release of one type of hormone is up-(down-) regulated by another type of hormone. Inspired by such mechanism, it is considered the resource capacity regulation is controlled by the task deviation, and the relationship between them is $\boldsymbol{\delta R_i = K_R * \Delta T_i}$, where $\boldsymbol{\delta R_i}$ is the regulated resource capacity of BIMC i, $\boldsymbol{K_R} > 0$ is the regulation coefficient. To quantitatively describe the regulated resources and task deviation, $\boldsymbol{\delta R_i}$ is expressed with the number of type *x* resource units, $\boldsymbol{\Delta T_i}$ is expressed with the required amount of time originally planned for processing on type *y* resource, and $\boldsymbol{K_R}$ is expressed with unite time resource.

With the hormone-regulation mechanism, the resource regulation is trying to minimize deviations from the initial plan. There are many sources of uncertainty in real-world manufacturing system, which trigger disturbance events in dynamic manufacturing system. Generally speaking, there are two types of disturbances, namely, resource-related disturbance, and source-related disturbance [7]. Resource-related disturbance refers to the disturbance caused by unreliability coming from resources (machines) in the shop, including machine breakdown and machine recovery. The unreliability is expressed in terms of mean time between failure and the mean time to repair. Source-related disturbance refers to the disturbance caused by the changes in production orders, including new order/job arrival. In such context, the cell controller i will act as a resource activator to release affordable resources. One way of resource activation is to utilize the redundant resources of BIMC i. Another way is to ask resource help from other BIMCs with similar machine skills.

After the execution of local resource regulations performed in a distributed manner, it is necessary to synchronize and optimize the global schedule. The synchronization is conducted by the shop floor controller under the global resource constraint, which is described as

$$\left.\begin{array}{c} TF(TF_1, TF_2, ..., TF_n) \rightarrow Max \\ s.t. \sum_{1}^{n} RC_i \leq GR \end{array}\right\}$$

where TF_i is the task finished by BIMC i, RC_i is the resource capacity consumed by BIMC i, GR is the global resource capacity of original plan. After the recovery from the disturbance, the cell controllers end the resource regulation, and the system is evolving to a new control state. The shop floor controller returns to its neuro-control function, and continues elaborating and proposing the allocation of work orders to the cell controllers of BIMCs.

4 Test Bed for NEIMS Simulation

In order to simulate the operating mechanism of NEIMS, a test bed consisting of an ARM controller, several singlechips, several AGVs, Virtual machines, a LCD Monitor and an automated storage/ retrieval system (AS/RS) has been set up. The structure of the best bed is shown in Figure 5 , and the physical scenario of test bed is shown in Figure 6.

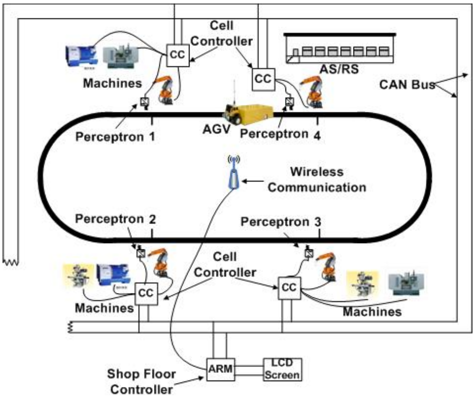


Figure 5. Simulation structure of NEIMS

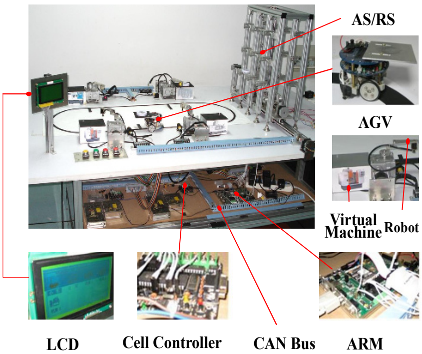


Figure 6. Physical test bed of NEIMS

On the test bed, the ARM controller is responsible for the role of central nervous system. The AGV, the manipulator and the Virtual Machines can be looked as biologic cells, and a BIMC is consisted of different cells. Several singlechips act as the cell controllers of BIMCs. These controllers are linked through CAN (Controller–Area Network) bus which is a vehicle bus standard designed to allow microcontrollers and devices to communicate with each other within a vehicle without a host computer. Here the CAN bus acts as the neurotransmitter to transmit production orders from the shop floor controller to the cell controllers. A LCD monitor screen can monitor the machines' status and show the real time operation situation of the whole system.

Based on the principles of neuroendocrine system, a BIMC is autonomous entity which can operate by itself. A BIMC can apperceive the change of the exterior environment and has an ability to self-diagnose and take actions to fulfill the task by ultra-short feedback loop. If the local task can not be better resolved by adjusting some control parameters (theses parameters can be looked as internal hormone concentration of different glands), then the BIMC's controller transfers the information to other BIMCs' by quasi-humoral regulation and normal feedback. Consequently there is no need to be coordinated by the ARM controller (quasi-neural regulation). When there are resources conflicts arising between different BIMCs, the ARM controller will re-schedule the resources rapidly and communicate with related BIMCs through the CAN bus. In such a context, the entities of relevant BIMCs will be temporarily reorganized into a dynamic manufacturing cell to adapt to the change requirements. When the task is finished, the dynamic manufacturing cells dismiss themselves automatically. Meanwhile, if there is a malfunction during the system operation process, the related operational entity will release pheromone to its BIMC. Then the BIMC propagates such pheromone to other BIMCs' controllers to cope with the malfunction cooperatively.

5 Conclusion and Outlook

In the current manufacturing paradigms, most of the popular coordination mechanisms are kinds of direct negotiation mechanisms in which exist the limitation in communications overhead[7]. Especially when the system becomes complex, the deadlock phenomenon may occur. Bio-inspired concepts seem much suitable for adaptive manufacturing system control, and biologic manufacturing system (BMS) has been a hot concept now. In the biologic filed, it has been recognized that the neuroendocrine system plays a quite important role to control and modulate the adaptive behaviors of biological organisms using neuro-control and hormone-regulation principles. This paper, therefore, proposes a novel concept of NeuroEndocrine-Inspired Manufacturing System (NEIMS). Aiming at attaining high level adaptability of manufacturing system, the author has concieed a NEIMS control architecture which imitates the principles of neuro-control and hormone-regulation to agilely deal with the unexpected disturbances at the shop floor level, and a test bed for NEIMS simulation and verification is developed. In further work, the NEIMS will be improved in order to attain the self-learning mechanism to identify the situations and the way to evolve.

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Ongoing Research on Adaptive Layered Manufacturing from Overtraced Freehand Sketch

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Abstract. Freehand sketch on a paper is commonly seen being used as it is an effective convenient way to express rough ideas. The sketch is typically transformed to be a 3D CAD model by a designer for subsequent operations such as rapid prototyping process where a physical prototype is fabricated from a 3D CAD model. To speed up the realization of an idea, a research called adaptive layered manufacturing from overtraced freehand sketch has been being developed as an attempt to shorten steps from having a sketch drawing to obtaining a physical prototype. Presented in this paper is the current progress of the research. A single line drawing identification module is being developed to transform a paper-based overtraced freehand sketch to be a single line drawing. This module is required to generate more information about the sketch (i.e., the number of lines and their starting points and endpoints) since the initial information is limited to a batch of points. The algorithms developed for this module have been implemented on LabVIEW program. Some examples of sketch to a single line drawing transformation are also presented in this paper.

Keywords. Paper-based overtraced freehand sketch, single line drawing.

1 Introduction

Product design and development (PDD) is critical to the success of manufacturers, especially, in today's high competitive market where voice of customer is as important as manufacturer's capability. The trend of product development has changed from manufacturer-oriented to customer-oriented [1]. In the early days, tools and techniques limited manufacturer's capability to offer simple products. Advancement in technology has opened up a market. High competition has made voice of customer louder. It is arguable that the only way for the manufacturers to be competitive in the market is to adopt a customer-driven strategy [2]. Today, customer needs are even more sophisticate. They demand faster and better responsiveness [3]. The earlier introduction of a product creates momentum that could not only increase product's sales but also extend them much further into the

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future. Therefore, goods and services must be met or exceeded customer expectation and delivered quickly.

Rapid prototyping (RP) has been introduced and become an important technology that allows designer-customer realize and experience their ideas rapidly. It can help reduce 30-50% of manufacturing time for product development [4]. RP is a technology for fabricating complicated physical prototype without molds and dies. A 3D CAD model is translated into a stack of 2D contours which are used to generate machine commands for constructing a prototype layer by layer. Typically, a rapid prototyping process starts with obtaining a 3D CAD model, which can be created on any CAD software. Since the data formats are different among the software, the created model will be converted to a common format, called Stereolithographic (STL) file. The STL model is then sliced, and based on these sliced layers, machine commands are generated to build a physical prototype layer by layer. Post processes may be required depended upon the selected RP technique.

Besides creating a 3D CAD model on commercial software, today's technologies make it happens for the 3D CAD model to be created from its physical object as well as engineering drawing when they are available. Manufacturer can use reverse engineering, RE, to reconstruct a CAD model directly from a product that customer brings in, and by coupling RE with RP its physical prototype can be delivered back to customer in a short period of time. Several researchers have tried to improve and to realign steps in both processes to make their direct integration work more effectively [5-6]. The similar idea has been extended to reconstruction a physical prototype directly from orthographic views drawing, used universally for a long time for communicating designer's ideas to part manufacturing on a shop floor [7].

Another media that customer can use to communicate with manufacturers is sketch. Freehand sketch is a quick rough drawing for portraying ideas, and commonly used during the conversation to elaborate an explanation. Typically, a sketch is started with single lines, also known as non-overtraced strokes. Unless these lines unambiguously represent idea, additional lines are drawn repeatedly over the existing lines. This is known as a sketch with overtraced strokes [8]. So far, geometrical reconstruction has been researched to support reconstruction of 3D CAD model from online sketch on a tablet PC [9-11] and a non-overtraced sketch on a paper [12-14] while a paper-based overtraced freehand sketch is commonly found in practice.

Therefore, there should be a system that allows 3D model to be reconstructed from a paper-based overtraced freehand sketch. Furthermore, it is foreseen that direct interfacing a paper-based overtraced freehand sketch with RP will shorten product development time.

Presented in this paper is an ongoing research on direct fabrication of a physical prototype from a paper-based overtraced freehand sketch. In the next section, the system overview is presented, and followed by the current state of the research and implementation. The conclusion and future work are addressed in the last section.

2 System Overview

Although a paper-based overtraced freehand sketch is simple and convenient, its extended applications are limited. To be workable in subsequent operations, a designer is required to translate lines and to create a 3D model manually. For constructing a prototype, the obtained CAD model is fed into a typical RP process that will first convert a 3D model to be an STL model before being sliced. This tessellated model is only an approximation that its accuracy and file size are dependent upon the number and sizes of all triangular facets [15]. Several researches have been conducted to minimize errors from STL conversion [16] and even further avoiding it with direct slicing concept [17].

In order to support a fabrication of a physical prototype from a sketch, “direct interface between a paper-based overtraced freehand sketch and RP” is being researched. This system is intended to bypass 3D model reconstruction and STL conversion to speed up process. Sliced file will be generated directly from a paper-based overtraced freehand sketch. This system composes of two key modules: single line drawing identification and contours generation. The input to the system is the image of an overtraced freehand sketch that the number of overlapping lines and their starting points and endpoints are unknown, since available information is limited to a batch of points. Therefore, the first module is being developed for transforming a paper-based overtraced freehand sketch to be a single line drawing such that additional information can be extracted. The obtained single line drawing will be sent to the second module that will be developed to generate a stack of contours. An algorithm will be developed to analyze the complexity of the appeared object on the drawing, to identify acquisition position, and to construct a contour at that position. The result of the second module is a stack of contours that will be used to generate commands directly for fabricating a physical prototype layer by layer.

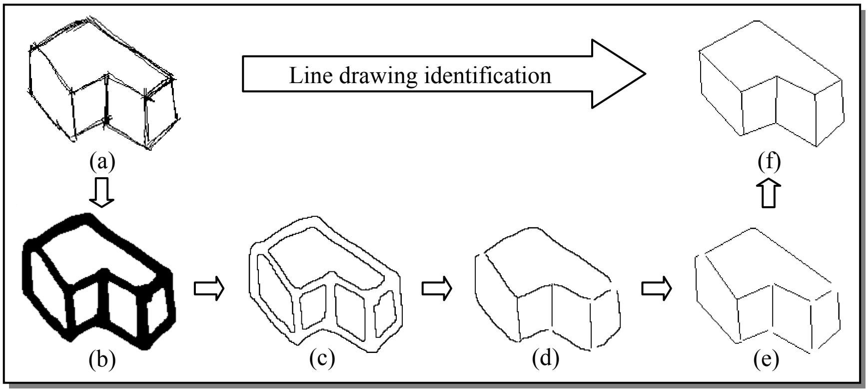

Figure 1. The current state of single line drawing identification (a) an overtraced sketch, (b) a thick line sketch, (c) a dual line sketch, (d) a segment sketch, (e) a fitted segment sketch, and (d) a single line drawing

3 The Current State of the Research

This section presents the progress of this research. Currently, this research focuses on the first module to identify a single line drawing from a paper-based overtraced freehand sketch. Our first attempt to identify a single line drawing from an overtraced freehand sketch was developed based on the assumption that the point density is higher at corners than on edges [18]. Vertices-then-edges identification approach was pursued. The developed algorithm filled overtraced lines to form thick line sketch; filtered out the low density areas; and identified vertices from the centroids of the remaining high density areas before forming edges. However, the algorithm did not guarantee that all corners would always have higher point densities than edges; and some imaginary lines created were not marked on the original image, although the representative points were found. As a result, a new approach has been introduced. As illustrated in Figure 1, this new approach tries to obtain edges first [19]. Similar to previous approach, the new algorithm first combines overtraced lines to form a thick line sketch, but instead of seeking for corners, boundary extraction is applied. That results in a dual line sketch (Figure 1c). Segments representing edges can be obtained by expanding internal contours and/or shrinking external contour simultaneously. The obtained discrete segments will then be connected to form line drawing of the sketch.

Since it was first introduced, the algorithm has been improved. The time-consuming vector scan method has been replaced by morphological dilation and erosion operations for expanding and shrinking activities. The line drawing creation part has also been updated. The steps taken in the four main activities: thick line sketch creation, contour boundary extraction, segments identification, and line drawing creation are presented in Figure 2.

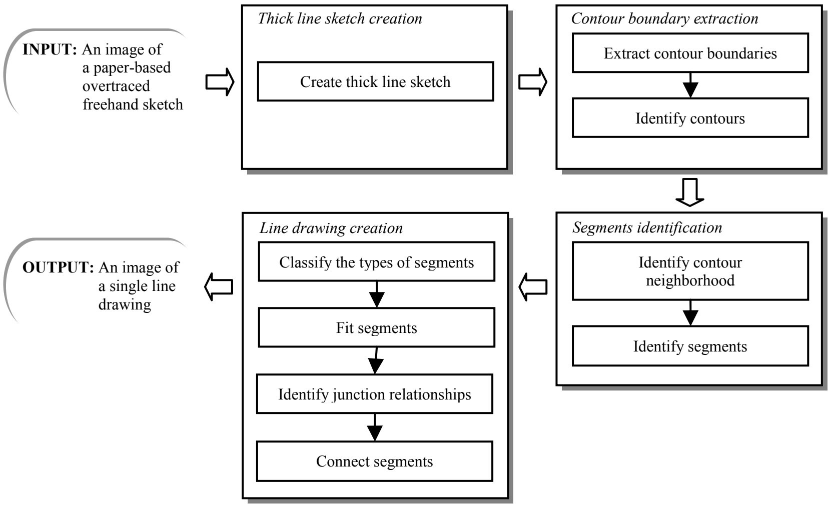

Figure 2. The overview of single line drawing identification

3.1 Thick Line Sketch Creation

A binary image of an overtraced freehand sketch, an input to the system, will be transformed to be a thick line sketch in this step. The process starts with acquiring data points in the window with size about the largest gap between overtraced lines in the sketch. This window is slid along the sketch image from left to right and top to bottom. At each position, the center point of the window is recorded on a new image, if the number of data points inside the window is greater than or equal to an assigned threshold value. By overlapping the windows, these recorded points will form a thick line sketch.

3.2 Contour Boundary Extraction

After the thick line sketch is created, the next step is to extract contour boundary and to identify contours. This process applies morphological operation to erode data points on the image. A 3×3 window is slid on the image of the thick line sketch from left to right and top to bottom. The center point of the window is drawn on the new image, if eight pixels exist in the window including the center. This operation results in a dual line sketch which always gives a set of closed contours. A contour tracing algorithm [20] is then applied to obtain ordered sequences of external contour and internal contours.

3.3 Segments Identification

This process starts from identifying contour neighborhood. The segments are determined from every two contours that are said to be neighbor. By resizing these contours toward each other, segments can be formed. Morphological dilation and erosion operations are applied to expand internal contours and shrink external contour respectively. During resizing process, points on segments in the narrowest gaps will appear first. All points will appear after points in the largest gap area meet. The wide span from the first iteration the meeting points appearing to the last iteration may result in a line segment with more than 1-pixel-wide. Therefore to achieve a 1-pixel-wide line segment, stopping condition, formulated statistic values representing the average and standard deviation of the shortest distances between points on the two contours, is applied. The obtained segment sketch is sent to the next process for creating line drawing.

3.4 Line Drawing Creation

The segments, obtained from contour expanding and shrinking technique, can be classified into three types: straight line segments, intersecting line segments and curve segments. For identifying types of segments, linearity analysis is performed first to separate segments into two types: straight line segments and non-straight line segments. A segment is a straight line, if mean square error (MSE) between the observed data and the fitted data is less than or equal to a threshold value which is 4 according to our experiments. For obtained straight line segments, linear least square fitting is applied. In case of non-straight line segments, a local maximum curvature is applied to divide each of the segments into sub-segments at dominant points where a segment changes its direction. Starting from one end of the segment, dominant point candidates are assigned for every five consecutive points. Tangent angles are calculated for all candidates. The points that the angles exceed the acceptable range will be dominant points. Linearity test is performed again on each of sub-segments. Unless it is a straight line sub-segment, Sturges's rule is executed to identify the number of control points before interpolation is applied. Sub-segments belonging to the same segment are then connected.

After beautifying all segments, their junctions are identified. A junction is defined as a single point where at least three segments are met. A matrix is created to represent relationships among all contours. To reduce the computation time, combination method is then applied to only internal relationships to generate all possible candidates for internal junctions. The internal segments are checked against the obtained junctions and those segments that still have free end will be connected to the external segments. The junction identification steps are illustrated in Figure 3.

To form a junction, the associated segments are extended (extrapolated) to intersect with each other. Ideally, they will meet at one location, and that point will be a junction. In practice, however, they often meet at different locations and form a triangle. In this case, the centroid of the triangle is used to represent the junction. A single line drawing is created after all junctions are connected.

4 Implementation

All algorithms, developed for the four steps, have been implemented on LabVIEW program and have been linked to form the first module. Illustrated in Figure 4 is the front panel screen of a single line drawing identification module. To execute this program, a user is asked to upload a binary image of an overtraced freehand sketch. This input is displayed on the top-left side of the screen. The four images in the right side of the screen show work in process. A single line drawing, an output of this program, is shown at the bottom-left corner. The program has been tested with several examples. The examples are shown in Figure 5.

5 Conclusions

This paper presents an ongoing research on adaptive layered manufacturing from overtraced freehand sketch with the objective to direct interface a paper-based overtraced freehand sketch with RP. At the present state, a single line drawing idnetification module is being developed and implemented. This module transformes an overtraced freehand sketch to be a single line drawing. For the future work, an algorithm will be developed to analyze and acquire the information of a single line drawing to generate commands for fabricating a phyiscal prototype.

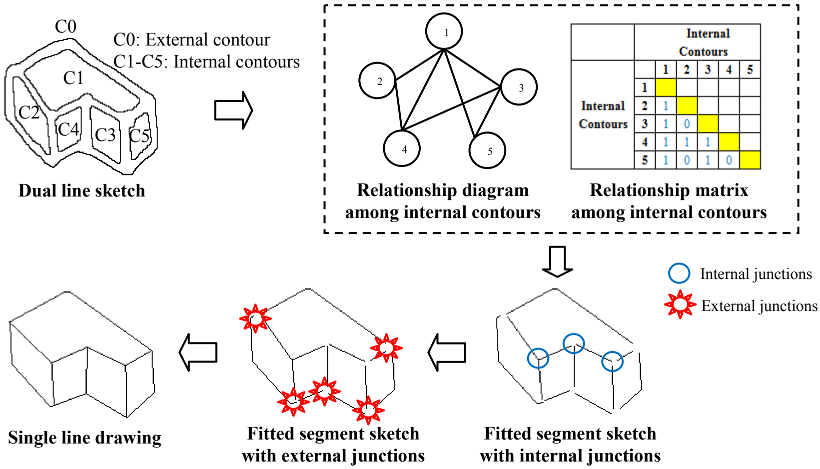

Figure 3. Junctions identification

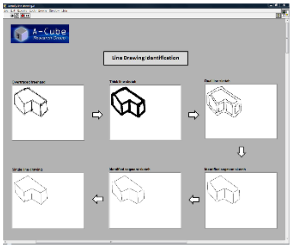

Figure 4. The front panel of single line drawing identification program

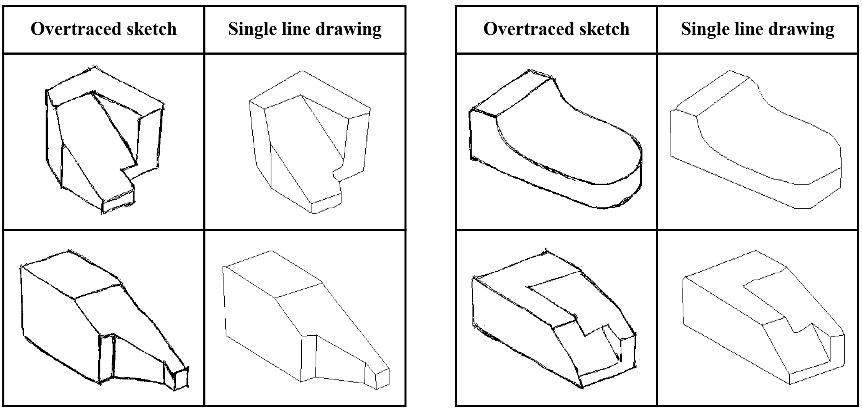

Figure 5. Examples of single line drawing identification

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An Application of Neural Network in Recognizing of the Tooth Contact of Spiral and Hypoid Bevel Gears

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Abstract. The special computer system KONTEPS for calculation of spiral and hypoid bevel gears generally supports technology for the conventional and CNC machines (milling machines). In this system environment, the special computer application generates solid or surface models of gears by cutting simulation. Other computer application, based on Matlab functions and methods of artificial intelligence, supports the tooth contact development. The special classifiers which allow to recognize the tooth contact, select the first, second and third order of changes and support the technologist in manufacturing process. This paper describes computerized integration of design and manufacturing of the spiral and hypoid bevel gear which belongs to CE, supported by the artificial intelligence.

Keywords. Neural network, bevel gears, tooth contact

1 Introduction

The tooth contact analyses is one of the important elements during development process of the spiral and hypoid bevel gears. The size, orientation and shape are the main features of the tooth contact [1,4]. This analysis can be done in CAD environment when CAD system is used to generate solid models of gears by the cutting simulation [5,6] or by numerical methods supported on Litvin theory [3]. In each case there are the theoretical solutions in computer environment without any errors which exist during cutting on the milling machines as kinematic errors of the machine, setup errors, fixture errors, blank errors, cutter errors etc. These factors are the reasons that the tooth contact of the cutting gears is different than the theoretical approach. In order to correct the tooth contact, the first, second and third order of changes are introduced. The first order of changes (proportional changes) are used during cutting by a technologist in the machine setup without special calculations, based on practical recommendations and experiences only, obviously supported on the theory of gears. Second order of changes are used when the first order changes are not effective. Third order of changes require the

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new geometrical and technological calculations. It means, that they will have new geometrical dimensions of gears which are slightly different from the previous geometry such as tooth proportions, addendum and dedendum angle, pressure angle, etc. In this case the gears follow the same procedure in a development process: first , second and third order changes. Steering of tooth contact requires in depth knowledge and experience about the spiral bevel gears.
Tooth contact development and identification of tooth bearing can be transferred to artificial intelligence area supported by a neural network. Observed tooth contact on the testing machine by digital cameras (Figure 1) is saved in *.bmp standard or *.jpeg standard. Testing machine it is typical machine as example G513, in which the digital cameras have been mounted. Each camera observes during testing (gears rotate under slightly load) one flank of tooth, it means convex and concave side of tooth. The bmp or jpeg files are saved in the computer and they are analyzed by special Matlab application, which it is call classifier.

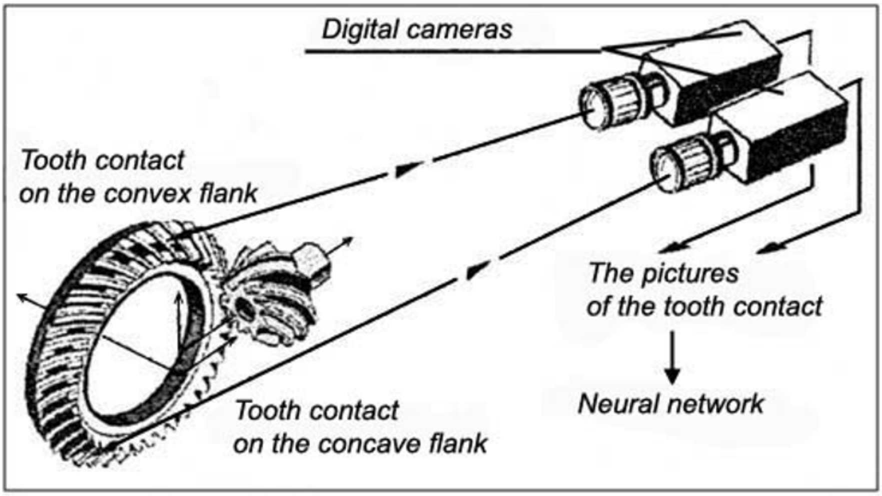

Figure 1. An idea of the tooth contact recognition

The tooth contact picture is analyzed by a special program and after its identification ascribed to the proper classes. The practice of tooth contact development allows to differentiate thirteen classes, which are connected with size, shape and position of the tooth contact. Ascribing the tooth contact to the proper 13 classes (Table 1) means activation of a suitable correction procedure, which gives proper changes in pinion machine setup. This program is an external program which reside on the PC computer and most often use the Matlab environment.
An observed by the digital camera the tooth contact is not a homogeneous area as a texture and it has not well-defined border lines. This is because the tooth surface is rather as free form surface and consists the ellipses of temporary contacts. Besides, the tooth surface is the result of generation movement of the cutting edges. In each normal section along the tooth, a profile consists of micro-segments, which sizes depend on the feed rate velocity. Pictures of tooth contact which are observed by digital camera are shown in the Figure 2a (correct tooth contact) and Figure 2b

(too short tooth contact). In both cases it is very difficult to precisely determine the limits (borders) of area of tooth contact, hence in Table 1 the samples of the tooth contact do not have well-defined line which delimit the area of the mismatch.

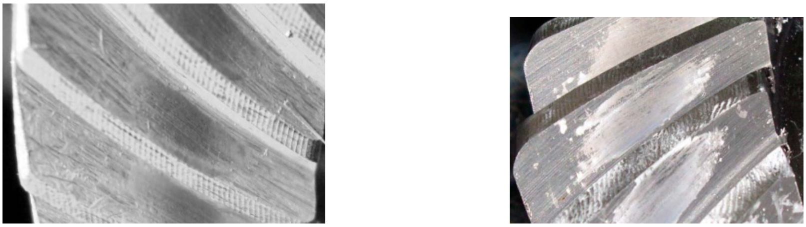

Figure 2. Observed by the digital camera tooth contact: correct tooth contact(left), to short tooth contact (right)

2 The features of the tooth contact

Classification to the proper classes depends on the features of tooth bearing. The analysis of the features of tooth bearing has been done in Matlab environment. A special procedure “features.m” based on function “regionprops” allows to determine the features of tooth bearing. For the Matlab function “regionprops” thirteen (13) features has been chosen. Some of the features are as vectors and therefore in this way the number of features of tooth bearings increase to seventeen (17). The features “Centroid” and “BoundingBox” have together six constituents. In the result, it is examining seventeen (17) features which will identify the tooth bearing. These features are mentioned below as the vectors value and the scalar value:

- Area – scalar – the number of pixel in investigated tooth bearing,
- BoundingBox1,2,3,4 – vectors – the smallest polygon included investigated tooth contact,
- ConvexArea – number of pixels in ConvexImage,
- Perimeter – the length in pixels of perimeter of tooth bearing,
- Centroid1,2 – vectors, the center of mass of the region,
- MajorAxisLength – scalar – the length in pixels of major axis of ellipse,
- MinorAxisLength – scalar – the length in pixels of minor axis of ellipse,
- Orientation – scalar – the angle between major axis of ellipse and horizontal axis,
- EquivDiameter – diameter of circle which includes the same numbers of pixels as investigated bearing,
- Solidity – scalar – the relationship between number of pixels in Area to the total number of pixels,
- Eccentrity – scalar – relationship between the distance of ellipse centers (in pixels) to major axis length (in pixels),
- Extent – scalar – relationship number of pixels in tooth contact to number of pixels limited by BoundingBox,
- FilledArea – scalar – number of pixels in tooth contact limited by boundingBox.

Table 1.

Class No	Type of tooth bearing	Tooth bearing Toe Heel
1	Correct bearing	
2	Bias in	
3	Bias out	
4	Short bearing	
5	Long bearing	
6	Wide bearing	
7	Narrow bearing	
8	Toe bearing	
9	Heel bearing	
10	High bearing	
11	Low bearing	
12	Diamond bearing I	
13	Diamond bearing II	

3 The classifiers of the tooth contact recognition

Approximately two hundred nine (209) different pictures of the tooth contact which belong to thirteen (13) classes (see Table 1) have been prepared in order to learn about the neural network. In the initial phases of this experiment the SVM Classifier of Matlab environment has been used. Based on the analysis of many tooth contacts including comparisons of their features, it has been noticed, that some of the features have very closely values, for example: the correct or wide tooth contact had similar number of pixels as the toe or heel bearing. Therefore, the SVM classifier has been identified its by NBV classifier [2]. During the analysis of many tests for the correlation coefficient equal c=1 it was noticed, that the 2-dimentional set (feature/feature) is very strongly correlated with other several features, for example: the feature number # 12 with # 13 and # 14 and also # 13 with # 14. It means, that the features may have similar value and that the tooth contact may be ascribed to the different classes. The correlation factor "c" was decreased to c=0.95 and analysis of the features has been done again. The result of analysis is that the features number # 5 (BoundingBox) and # 13 (Perimeter) are strongly correlated. It is possible to start the next analysis in which the arrangement of vectors in observation space is studied. The arrangement vectors, these are the vectors describing the layout of classes in a function of chosen features. To make such analysis easier and to determine the direction of further studies, it is enough to take 2 features (2-dimensional coordinates) but the complete analysis include in this case the 13-dimensional space. Selection of the features of n-dimensional observation space based on evaluation of the features or group of the features leads to finding subset of the M-futures, it is m –dimensional subspace. The subset of the M-features must be subspace which optimize criteria of the classes separation. Therefore, it means evaluation of the classes separation based on two criteria: Criterion of Average Scatters (CAS) and Criterion of the Number of Prototypes of classes (CNP). From the number 2N-1 combinations of the observation subspace, using criteria CAS and CNP, the best subspace has been chosen: CAS=0.361 and CNP=151. This selected subset of the futures of 2-dimensional observation space is shown in the Figure 3, it means that the features Centroid1 and BoundingBox3 decide in which class is tooth contact. Running the next analyses for the next features is seen, that is no clear group of classes. There is (Figure 3) dissipation and confusion of classes. It means, that is very difficult to put down investigated tooth contact to one of the thirteen classes. The classes intermingle because for strongly correlated features of the tooth contact, classifier can not synonymously to put down the tooth contact to the proper class. Neural network can recognize usually two classes but in this task are 13 different tooth contacts (13 classes) with sometimes very similar features.

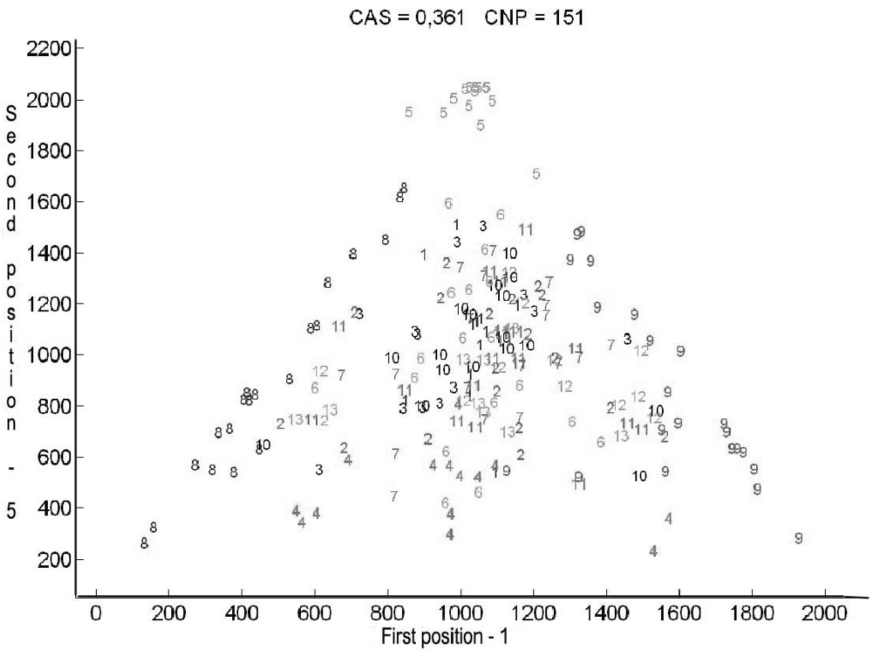

Figure 3. Arrangement of the vectors in observation space for the feature 1 and 5 (Centroid1 and BoundingBox3)

3.1 The NBV I classifier

This problem can be solved based on k-classifiers, it means that should be prepared committee which consists k-classifiers. Thus tooth contact recognition is the multiclass problem. Then is necessary to build the submodels which will be the smaller group of classes. The same set of 13 classes has been divided on five classes. As criterion of partition were taken prediction direction of the tooth contact movement, similar as technologist make a decision during tooth contact development introducing the I and II order changes. In the first class numbering all tooth contact are situated centrally and symmetrically with regard to the middle point of tooth surface. Therefore, in the first class are correct and not correct tooth contacts as bias in, bias out, wide, narrow, short and long. The first classifier should be recognized independently to the size and shape of bearing, all tooth contacts are in the middle of tooth ,toe bearing, heel bearing, low and high bearing. Studying correlation of the features for coefficient c=1 of all 17 features for less numbers of classes (5 classes) still a very strong correlation between ConvexArea , FilledArea and EquivDiameter have been noticed. Such strong correlation influences arrangement of vectors in the observation space where criteria CNP and CAS are not satisfied. Similarly as before this correlation of the features for coefficient c=0.9 and arrangement of subspace observation have been verified. The best subspace of the observation subspace where CAS=0.65 (Criterion of Average Scatters) and CNP=34 (Criterion of the Number of Prototypes) has been chosen. It means that features Centroid1 and Centroid2 decide in which class the tooth contact is located. An areas of the 5 classes have been shown by solid line (Figure 4). Continuing such classification problem is necessary in order to define the next classifier which will recognize the next five classes. Second classifier should recognize: correct tooth contact (class 1), wide tooth contact (class 2), narrow tooth contact (class 3), short tooth contact (class 4) and long tooth contact (class 5).

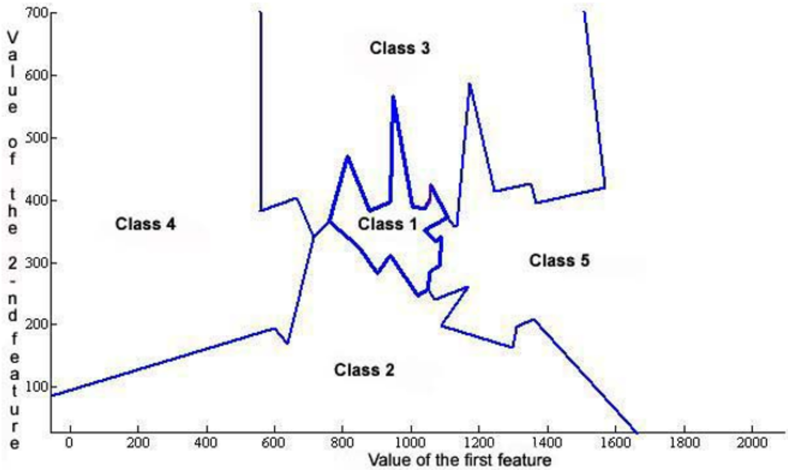

Figure 4. An illustration of the I classifier for five classes

3.2 The NBV II classifier

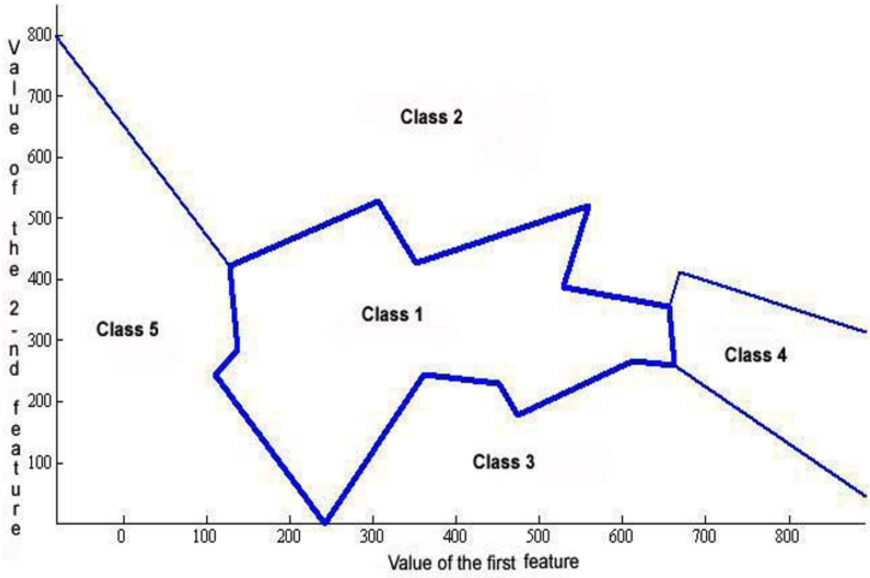

Figure 5. An illustration of the II classifier for five classes

This classifier will recognize tooth contacts which are in the central area of the tooth flank. Certainly, II NBV classifier is based on the same features as I NBV classifier. Taking the same correlation factor as before for the I NBV classifier (c=0.9), the observation subspaces criteria have been analyzed. Subspace has advantageous values: CAS=0.762 and CNP=15. For this observation subspace and arrangement of vectors in the observation space and areas of classes has been made in the Figure 5.

3.3 The NBV III classifier

Running classification problem is necessary in order to define the next classifier which will recognize next three classes. The next classifier number III NBV will recognize: correct tooth contact (class 1), bias in (class 2) and bias out (class 3). Activity of third classifier focuses on the tooth contact which is in the middle of tooth flank however it has correct length, width and bias out or bias in. The III classifier NBV analyse the same 17 features. The subspace has advantageous values according to CAS and CNP criteria: CAS=1.39 and CNP=3. An arrangement of vectors in the observation space for the Third NBV classifier (3 classes) shows well-defined group of classes. The two dimensional graph of the arrangement of vectors in the observation space for features Orientation and Extent illustrates clear divided areas of classes (Figure 6).

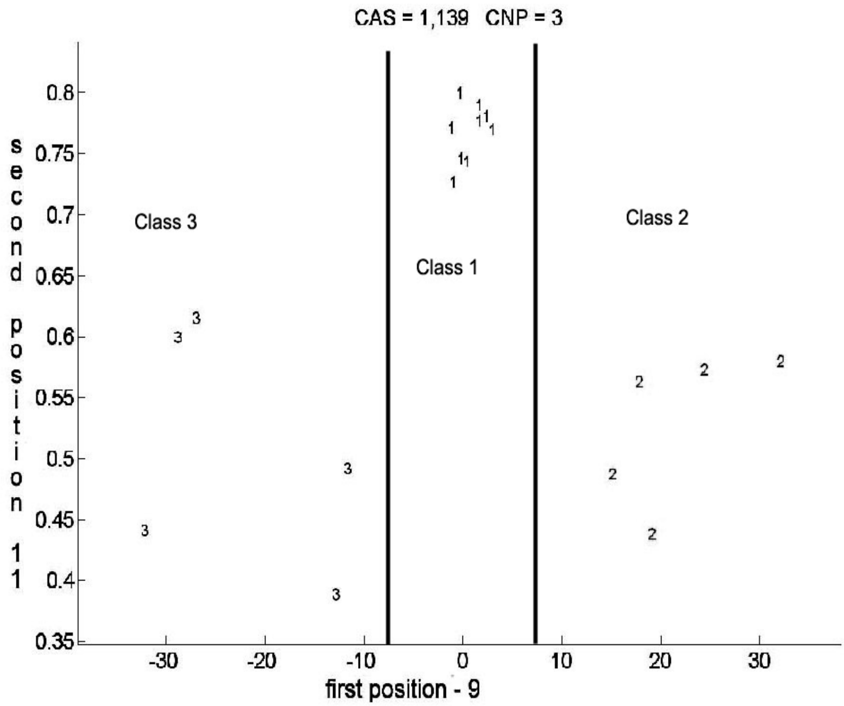

Figure 6. An illustration of the III classifier for three classes

4 Conclusion

Verification of classifiers has been done accepting the same conditions as in production of the spiral bevel gears. Taking the tooth contact as a short and in the heel position, I NBV classifier identifies it according to the principle of recognizing to the fifth (5) classes. After applying of II order changes (increasing the eccentric angle and cradle angle) and cutting the pinion, the tooth contact was in the middle of tooth but moved down toward the dedendum. For this tooth contact the I order change has been used meaning the head setting was increased. After the finally cutting, the tooth contact was in the middle of tooth and it had correct size and shape (ellipse). It means, that all three classifiers are correct and they satisfied requirements of the technologist.

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Integration of Time Management in the Digital Factory

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Abstract. This paper reflects the current work on the integration of Time Management in the Digital Factory. To eliminate deficits in the integration of leading planning tools, a methodical approach was established in order to develop application protocols based on a systematic basis for the Digital Factory. Therefore, a joint project with both industrial and research partners has been initiated. Beside the fundamental methodology for the standardisation in the Digital Factory as further important result an interface between the software products Teamcenter Manufacturing and TiCon will be developed.

Keywords. digital factory, time management, application protocol, STEP, PLM services

1 Initial Situation

Today globally operating companies face due to the increasing complexity of processes and products, the growing demands on flexibility and the shortened development cycles additional challenges. This leads more than ever to a conflict between time - cost - quality in design, development, acquisition and commissioning at different locations. Furthermore these plants represent independent organizational units within affiliated groups, which have grown with hierarchically self-sufficient IT and staffing. An approach to handle this situation is the introduction of production systems, such as adaptations of the Toyota Production System (TPS). This methods, designed and established in the mid of 1990's allow the standardization of the production of enterprise-equitable and corporate assembly-groups, aggregates and finished products in worldwide locations to a large extent. As an example one engine architecture for heavy-duty engines from Daimler Trucks is planned and manufactured by Detroit Diesel (Detroit, USA), Mercedes-Benz (Mannheim, Germany) and partially by Mitsubishi Fuso (Kawasaki, Japan). The introduction of such standardized methods and processes abet the implementation of the digital factory as an additional approach to encounter the new challenges. Today the concept of the digital factory is used in

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industrial enterprises in order to plan and secure the manufacturing of products with the necessary processes in the early phases of product development, and to optimize existing processes. The digital support of these planning processes includes methods, models and tools that enable the integrated planning of production processes [1]. Thereby the traceability, validation and optimization of existing processes are secured, the planning quality will be increased and the planning cycle on the whole noticeable shortened. The implementation of the digital factory and therefore the digital production planning is not yet well advanced in many companies. But such an integrated IT environment is the base of the parallelization of development and planning processes necessary for the efficient use of concepts such as the simultaneous and concurrent engineering. This IT integration is well implemented in the product development. In the planning departments the corresponding system environment, the digital factory lacks of integration and standardization. The reasons for this are multifaceted and partly founded in the necessary requirements for the implementation of the digital factory in companies.

2 Requirements and need for action

In this situation, where global operating manufactures have varying processes, methods and standards in different locations, also the existing systems of the digital factory often differs from location to location. Even same or similar IT environments can lead to different data processes and structures, due to the supported variability. Apart from these different data structures various data sets and planning states must be taken into account in parallelized planning processes also with respect to the increasing globalization. In addition, partner companies planning data are also supposed to be integrated into the own system at any time. The system landscape of the digital factory differs between two partners for example in an OEM and supplier partnership. In order to make it possible for international planning and production departments to learn from each other and participate in the planning of consistent and uniform production lines there are valid processes, methods and standards all across the group required which has to be implemented in the production planning department. The foundation for this is the usage of digital models and a network of methods, standards and tools for the consistent and integrated data management. Due to this challenges where conventional planning methods often reach their limits the implementation of the integrated digital factory as the central resource for the production planning is the approach to fulfill these requirements. For many OEMs as well as the Daimler Trucks the introduction of the integrated Digital Factory is an important strategic research and development goal in the next few years. Crucial to the development of a Digital Factory and the successful use of digital design tools is a continuous process support for the production and factory design. Because usually a variety of planning domains are involved in the production and because their results must be matched with each other and exchanged, it is necessary to have a continuous integrated planning process across the entire Product Emergence Process (PEP). Because of this requirement of a distributed planning process in a world wide concurrent engineering approach the associated data exchange is necessary and via standardized interfaces reasonable. With the development and implementation of such standardized interfaces the companies achieve the ability to flexible the applications of the Digital Factory in the company specific, heterogeneous system environment This standardization is lacking in many areas of the Digital Factory. Today often there are isolated applications which has to be connected with great effort.

3 Approach

The joint project ADiFa ("Application Protocol for the harmonization process in the Digital Factory") is developing a system to allow the standardized exchange of planning data in the Digital Factory. In a basic system concept several planning domains such as time management, logistics or the layout planning shall be supported. After the system is developed it should be possible to evaluate a process model for unifying the used processes as well as a data model for exchanging planning data for each planning domain of the Digital Factory. The procedure is orientated at the standard series ISO 10303 (STEP).

Within the project ADiFa the technical focus is on time management. The process model allows a common understanding and points to possible interfaces between systems that are used to support the planning process. Therefore exemplary interfaces are implemented of the software vendors involved in the project. For the integration with other systems implementation guidelines for the interface development will be elaborated. The application protocol is validated with the help of several practically relevant use cases from the user. In this publication, the current status of the work will be presented with the following priorities:

- Conceptual methodology
- Development of a process model to analyze the possible interfaces between the IT systems
- Development of a data model to exchange time data (e.g. for assembly planning).
- Implementation of the application protocol for data exchange
- Validation of the various project phases

3.1 Conceptual methodology

The project consists of two parts built up on each other; the basic system concept and the application protocol. The basic system concept sets the frame in which different application protocols for different technical domains of the Digital Factory can be created (fig.1).

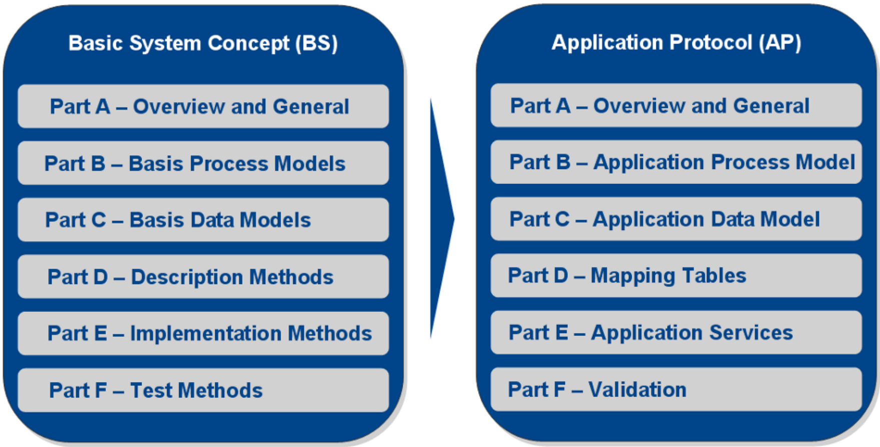

Figure 1. Conceptual structure of ADiFa

Basic system concept setup

The basic system concept is composed of a total of seven sub-sections (part A to part G) [2].

The first part provides a general overview of the basic system's functionality and structure. It introduces the systematic approach to the development of application protocols and explains the use of the basic system for the application protocol development.

The second part describes a universal process model. This model will set the foundation for application-specific process models, which then determine the technical focus and the scope of validity of each application protocol.

Part C represents the basic models, the basic system's main components. Application-specific data models of an application protocol can be defined, based on the basic data model. The data structures within the basic data models are defined in such a way that they are suitable for a variety of applications within the Digital Factory. Basic data models consist of objects and structures from the application protocol 214 of the ISO standard STEP and on this basis the OMG standard Product Lifecycle Management (PLM) Services 2.0. This enables the use of already existing and proven data structures.

Part D of the basic system includes description methods, which are used in the data and process modelling of the basic system and the application protocols.

The necessary implementation methods are defined in Part E. Thereby both, the necessary implementation architectures and formats, with which data models that are able to convert data models into a computer processable form, are specified.

In Part F the necessary test methods and cases for a sufficient test of the application protocol are documented.

The Glossary in Part G explains essential terms and definitions which are necessary for understanding the basic structure and development of application protocols.

Structure of the application protocol

Similar to the basic system, the application protocol also consists of 7 parts from A to G.

Part A includes an introduction to the technical focus of the application protocol on time management and a delimitation to other planning domains. The further development and therefore the application protocol itself is geared to the approach of the development of application protocols from the ISO standard STEP 10303 [3]. This approach is shown in figure 2.

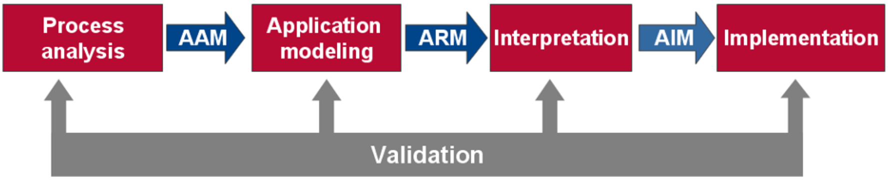

Figure 2. Development of a STEP application protocol

Part B initially defines a basic Application Activity Model (AAM), after the analysis of the user's planning processes. This process model serves on the one hand as a delimitation of the processes in relation to other technical domains and on the other hand as an analysis of the data transferred between the process steps.
Consequently an Application Reference Model (ARM) is created in part C, which contains data objects and their structural relations. This data model is, with respect to certain areas of time management, divided into several sub-models.
Part D specifies the Application Interpreted Model (AIM). AIM is a XML model representing the data format for the data exchange. In this part the mapping of the application data model into the exchange format is defined using the basic data model.

Implementation guidelines for the implementation of the program interfaces are found in Part E. They will enable the implementation for the static and dynamic data exchange. For the dynamic data exchange web services are defined in the context of an SOA approach.
In Part F different validation scenarios are built. Here various parts of the application protocol will be evaluated according to defined criteria and validated.

Finally in part G, an application-specific glossary is created. The defined concepts in part C reflect the understanding of also partially misunderstood technical terminologies used in the application protocol.
In the following a closer look is taken at the sub-sections process model, data model, implementation and validation of the application protocol.

3.2 Process model

The process model or application activity model is based on the methodical representations assigned in the basic system concept. Within the application protocol specific processes are merged into the product emergence process for delimination [4]. In the classic representation the production planning joins the product development and leads to the production. In addition to further analysis of scientific process models for production planning the existing planning processes of the industrial user Daimler Trucks were considered. As a result a generalized planning process was derived, which already begins during the product development and also includes planning processes for optimization during the production. Thereby sub-processes are executed in different systems. The necessary data exchange of time management data between the systems is enabled through the application protocol. The basis for this is a structured data model.

3.3 Data model

The data model consists of three parts, the basic data model, the application data model and the data exchange format covering different aspects of data modeling.

The basic data model provides generic basic structures through objects and their relations. In doing so, these elements were not developed lately but rather proven standards used as a basis. The ISO standard 10303 STEP provides in its application protocol AP 214 objects and structures for a process plan with hierarchical operations [5]. These objects and structures are exactly represented in the OMG PLM Services 2.0 [6] in form of UML class diagrams. The basic data model uses these objects and expands them with objects and relations which are recognized as necessary. This ADiFa extension forms, together with the standard structures, the basic data model, which represents together with the basic process model the core of the basic system. Based on that, the technical realization of the domain time management with the application process model and the application data model follow. The application data model or application reference model reflects the requirements of the users for the time management in eligible data objects. Considered are the individual time-values or -ranges and also information about the datas origin are taken into account. Therefore different sub-models are defined in the application data model. In addition to metadata, such as the user and planning date, time calculation methods and influencing factors are also included. Also important is the relation between the actual time values and the associated time codes as well as special features such as the property of value adding or non value adding. This time management system is defined in UML class models in the application data model (fig 3).

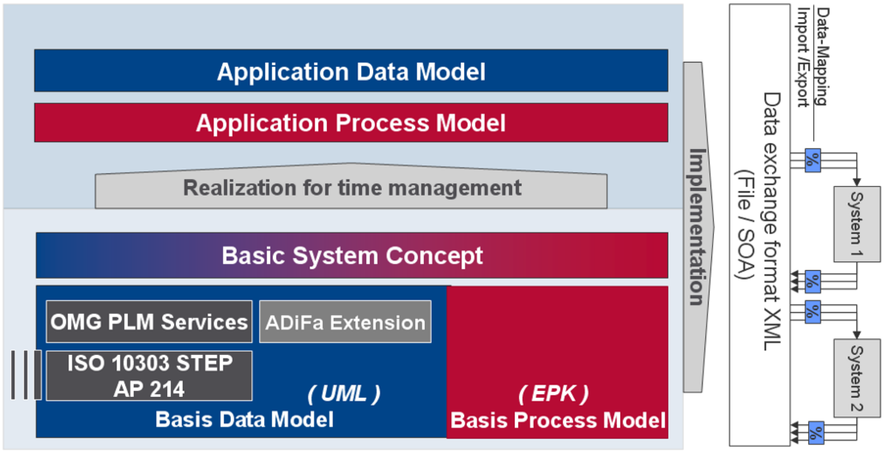

Figure 3. ADiFa concept of process- and data models

The application data model is transferred together with the basic data model into the actual data exchange format, the application interpreted model. Thereby the semantics from the application data model are mapped to the generic objects and structures of the basic data model, defining a third data model as a XML Schema. This XML schema is admitted to a PLM XML extension [7] and can then be used for exchanging data between the time management systems of the Digital Factory.

3.4 Implementation

The implementation concept provides the static and the dynamic data exchange.

The static data exchange occurs in form of XML files, which are compiled and read from interface processors. The dynamic data exchange transmits the data embedded in a SOA concept by using web services. In these web services the requests and the corresponding data from the application interpreted model are defined in order to be exchanged between the programs in the Digital Factory. Each program functions work both as a server to provide the data as well as a client to request data from other systems.

During the ADiFa project an exemplary implementation between the systems "Teamcenter Manufacturing" and "TICON" from the vendors "Siemens" and "MTM Softwarehaus" will be developed. This system integration, with help of the ADiFa application protocol, will enable the exchange of the time management data between the involved systems.

3.5 Validation

Suitable validation scenarios for the process model, data model, methodical approach and for the introduction and expansion of the Digital Factory in a SME were developed on the basis of industrial use cases. The validation of the software-solution, which has to be developed, is carried out by the users, based on these scenarios.

4 Conclusion and Outlook

The joint project ADiFa has the goal to enable the exchange of planning data for time management in the Digital Factory through an application protocol and to simultaneously lay foundations for further application protocols. Therefore a system for unified data description is developed. The core of this system is the presented three-layered data model, which forms an essential basis for the integration of planning tools of the Digital Factory. By including universal standards, as well as PLM Services 2.0 or the STEP AP 214, a solid foundation for the data exchange will be created. The prototypical realisation of an application protocol ensues within the ADiFa framework using the example of the area of time management and of the exchange of time data.

The research project ADiFa (Process Harmonisation based on Application Protocols) is supported by the German Federal Ministry of Education and Research (BMBF) within the Framework Concept "Research for Tomorrow's Production" and managed by the Project Management Agency Forschungszentrum Karlsruhe, Production and Manufacturing Technologies Division (PTKA-PFT). The author is responsible for the contents of this publication.

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Concurrent Development of Products, Processes and Manufacturing Systems in PLM Environments

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Abstract. The paper presents the trends in the development of methods and systems for manufacturing and assembly process planning on the background of Concurrent Engineering strategies. The solutions for the functional integration of design/manufacturing and production preparation phases and the IT infrastructure including PDM systems for the storage of product structure data, design and manufacturing process documentation are presented. The concept and the example of integrated process and manufacturing system planning in PLM (Product Lifecycle Management) environment are presented.

Keywords. Concurrent Engineering, design/manufacturing integration, PLM

1 Introduction

In computer integrated development of products, processes and manufacturing systems, different methods are used to aid the engineers. The most important outcomes of the implementation of modern product development strategies are the shorter product start-up cycles and the faster completion of orders. The magnitude of benefits depends on the degree of information integration between the technical production preparation phase and the production planning activities. To speed-up the design and planning activities, the computer systems for product and manufacturing systems development featuring the growing degree of automation are widely used, while the information integration is achieved by using the integrated IT systems. The Digital Manufacturing portfolio comprises of multiple solution components such as process planning, process simulation and manufacturing process management solution framework for data management, change management, web enabled collaboration etc. So the challenge lies in identifying and integrating the areas to meet the objectives of Digital Manufacturing initiatives with PLM/ IT initiatives.

The papers presents the methodological approach linking CE techniques with capabilities of nowadays manufacturing process management solutions.

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2 Trends in strategies and computer systems for concurrent product development

According to the new development strategies, the product development focuses on:

- as much as possible parallel execution of all development related product life cycle phases, thus creating CE (Concurrent Engineering) environment. CE strategy assumes the development of resources and production facilities at the early product design phases to shorten the production start-up time.
- incorporation of the relations between business and engineering activities CEE (Cross Enterprise Engineering), securing also the access to the resources of cooperating enterprises.

The parallel execution and the integration of products and processes starts on the early product development stages and covers suppliers, clients, as well as internal and external IT solutions. CEE means that product components, parts, assemblies, systems and functional sub-systems are designed and developed across the local business and engineering boundaries. Intranet and internet are here used as the means for the communications and the information exchange.

Concurrent engineering is the computer integrated environment for design and manufacturing – the common platform for computer aided systems used in the product development. The key condition for the effective concurrent engineering and cross enterprise engineering is the computer integrated environment of design and manufacturing – the common platform for computer aided systems for the product development. Effectiveness of the CE and CEE strategies results from the better management of information in production process. The efficiency of activities depends on the provision of right information, to right places, for right peoples in the right time. PDM (Product Data Management) systems play the coordination role in the synchronization of the flow of information. PDM systems manage the data about the product services, product structure, its documentations and processes with the ability of processing data in the electronic form. PDM systems allow for modelling, storage and transformation of all data related to the product. Development of the integrated systems evolves toward the PLM (Product Lifecycle Management) solutions. PLM strategy increases the integration and automation of realized functions [1, 2, 4, 5, 6]. PLM environment includes the following applications for the product development:

- PPM (*Product and Portfolio Management*),
- CAx *(Product Design*),
- MPM *(Manufacturing Process Management*),
- PDM *(Product Data Management*).

3 Integrated process and systems development in PLM environment

Features of modern development strategies indicate the need for product development phase integration.

Integration and parallel execution of activities were received through the separation of the conceptual design stages, allowing for the creation of the variant solutions. Variants are then evaluated in the view of the requirements of the next development phase [3]. The selected variant fulfilling the established criteria is next further developed in the detail design stage (Fig. 1).

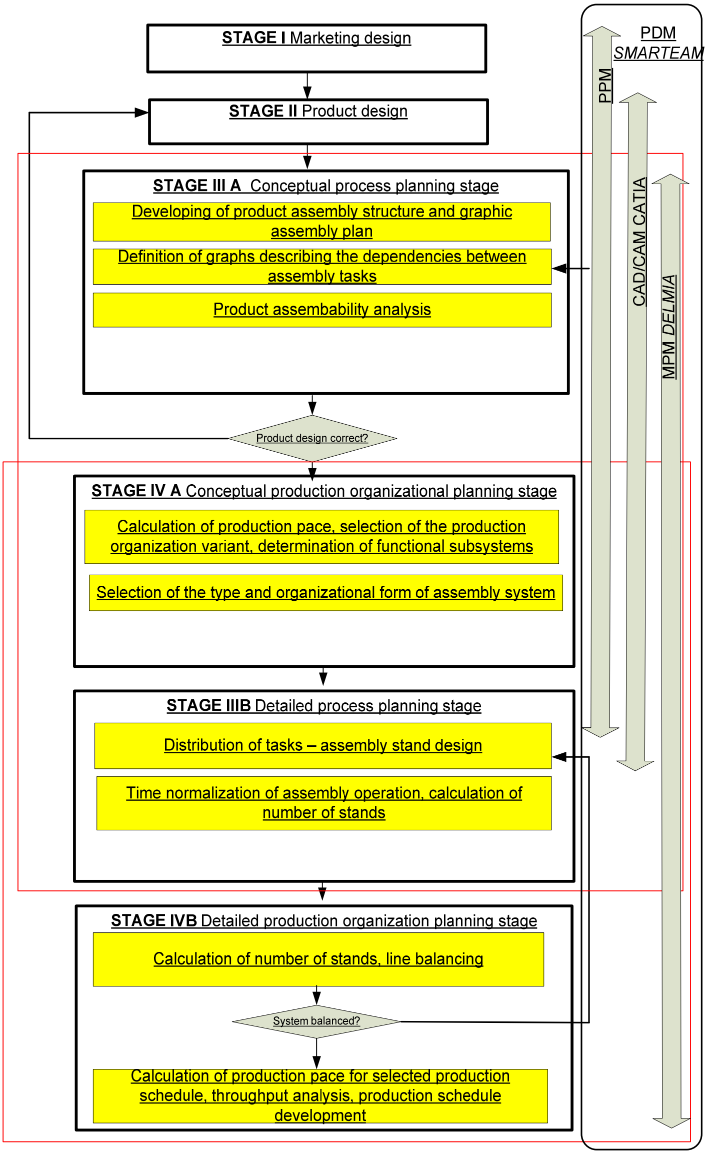

Figure 1. Parallel execution of product development phases

3.1 Conceptual process planning stage

The assembly process is created on the basis of the digital product model prepared with CATIA system. The process planning activities includes:

- the development of the product assembly structure – separation of the assembly units (assemblies, subassemblies and parts),
- development of the assembly process plan including the basic parts for separated assembly units, methods and hierarchical order of assembly of these units to receive the design features of the product,
- mounting of subassemblies, assembles and parts prepared with Part Design module in Assembly Design module based on the developed assembly plan.

The results of the above actions are necessary to make the assembleability analysis of the product and for iterative improvement of the design form in view of the assembly requirements. The product design resulting form the subsequent iterations and its assembly plan form the base for defining the graph of the assembly activities, representing the admissible variants of the execution of product assembly.

3.2 Conceptual production organization planning stage

The conceptual manufacturing organization stage is used to select the appropriate form of the production organization, production pace, and the initial calculation of the number and type of functional subsystems. On this stage, also the type and organizational form of assembly system are selected.

3.3 Detailed process planning stage

The selected type, organizational form of the assembly and the graphical product assembly plan verified with DMU Kinematics module of CATIA are the basis for the assembly process planning. The assembly process planning includes the selection of the operations and activities, selection of the assembly equipment, conceptual design of the assembly stations as well as the decisions on the concept and the selection or design of the transport system components. Based on the above process, the digital model of the assembly system and work places is created. The data required for the detailed production organization calculation and for the calculation of the duration of assembly activities are gathered from the components of the digital model of the system. The duration times of the assembly activities were determined using the MTM methods.

3.4 Detailed production organization planning stage

The selected structure of the assembly process and the determined duration times of assembly activities covered by the operations are the base for the synchronization within the isolated assembly subsystem. For analysed production organization forms, for example production lines, these steps include the calculation of the number of stands and line balancing.

The activities for the selected organization forms (assembly stations) include ergonomic analysis.

The outcome of the detailed production organization stage is the digital model of the manufacturing system linking all the components of the assembly system with assembly process plan stored in library and process schedule. The further test on simulation model are used to analyze and improve the system being developed.

4 Verification

The verification was done with PLM solutions offered by Dassault Systemes. These solutions include the following systems (Fig. 2, 3):

- CAD/CAM CATIA for product, manufacturing process and resource design,
- PDM SMARTEAM and ENOWIA for the development process management,
- MPM DELMIA for process and manufacturing system design.

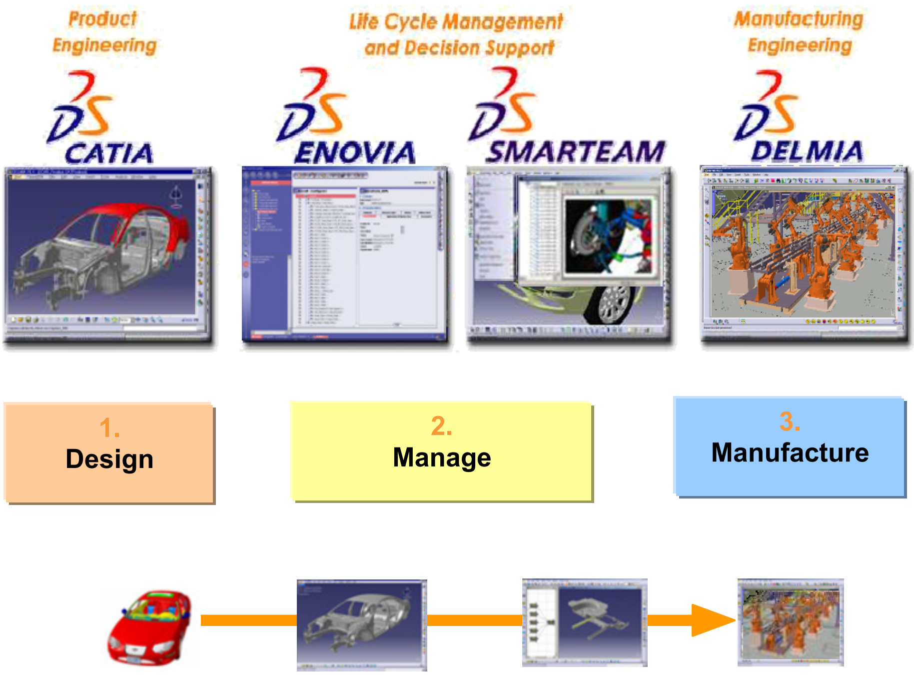

Figure 2. Areas covered by PLM Delmia solution

The projects of gear reducer and car water pump were used to verify the presented concept and CATIA/DELMIA software deployed at Institute of Production Engineering.

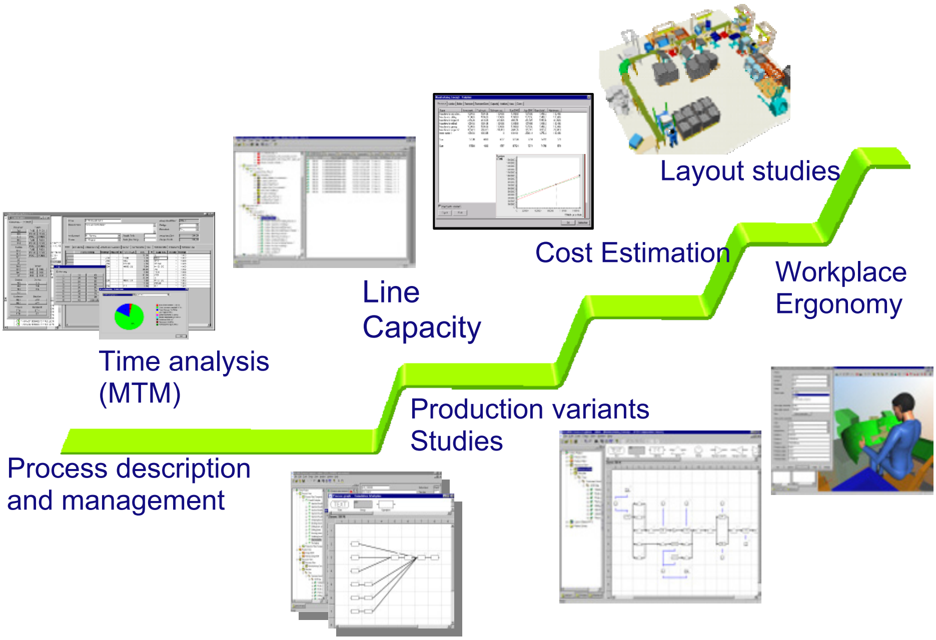

Figure 3. Process Engineer functions

The tests included the following:

- creation of the digital product model,
- creation of the process flow and manufacturing concept,
- creation of the manufacturing concept including the definition of process and assembly system library, and the preparation of the digital models of assembly system,
- creation of the assembly documentation,
- creation of the process simulation and the ergonomic analysis of work stands.

Several computer systems were used during the development, including the software for MTM analysis, line balancing, and assembly process simulation. Fig. 4 shows the graph of manufacturing concept. The nodes of these graphs represents the manufacturing stands, while the relations between nodes represents the flow of the production process (Fig. 4a). Each manufacturing stand has assigned product elements being processed on it. It has also assigned process activities like manufacturing, assembly, testing and non-value adding operations. The manufacturing resources including the transport means and workers are also assigned to nodes of manufacturing concept. The fragmentary layout of resources used in manufacturing concept is presented on Fig. 4b. The initial versions of manufacturing concepts were continuously improved by using results of computer analysis available in PLM system in an iterative manner, as described previously. For example, the ergonomy was examined in details (Fig. 4c).

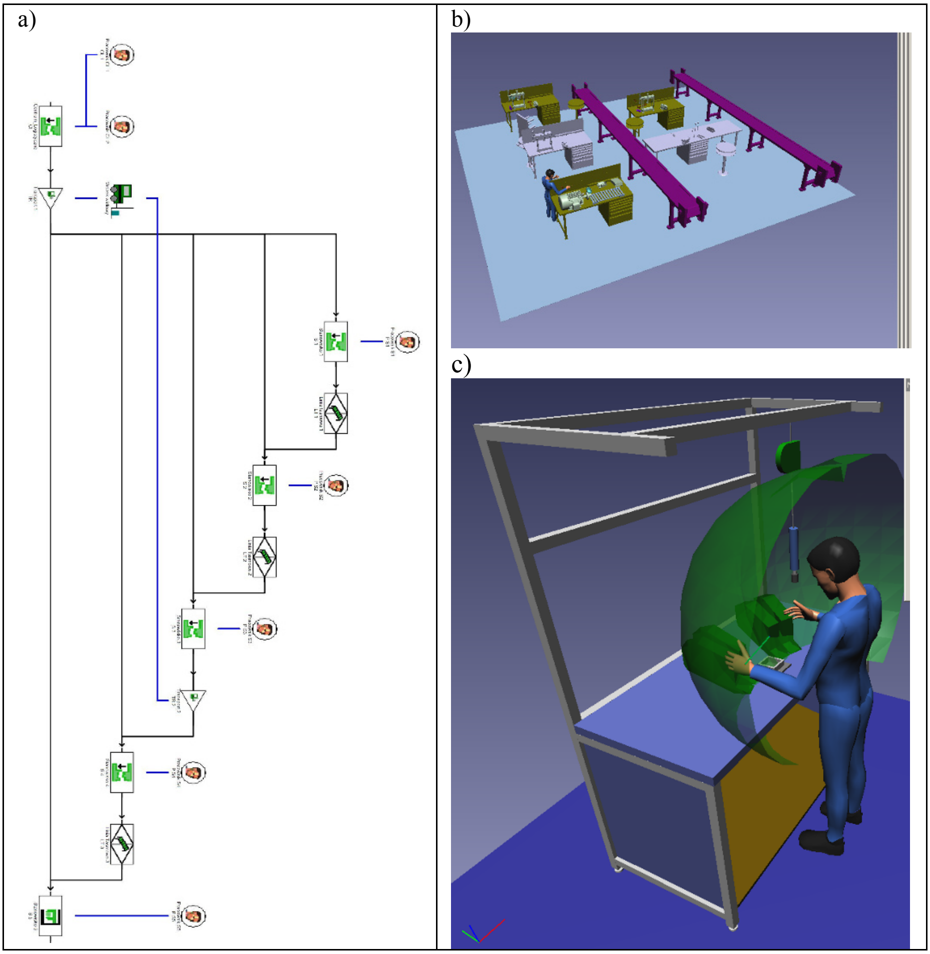

Figure 4. Verification steps: a) Manufacturing concept, b) Line layout, c) Ergonomic analysis

5 Conclusion

The proposed methodology using PLM components like DELMIA CATIA and Process Engineer allows to increase the integration level of the process planning and assembly system design. It covers various design aspects including:

- normalization of the duration times of assembly activities,
- balancing of production line.

On the current level of implementation of integrated process design, MTM, MOST and BLP methods are used together with associated systems. Further actions are needed to include the following design aspects:

- analysis of manufacturing variants,
- throughput analysis,
- cost estimation,
- layout design.

Nevertheless it should be noted the PLM solutions are only the tools speeding up the organizational and process planning stages of production preparation. The key condition to receive the good results are high qualifications of designer, process planners and manufacturing organization engineers developing the system components.

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Part II
Design Knowledge Utilization

Development of Accuracy Evaluation System for Curved Shell Plate by Laser Scanner

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Abstract. Accuracy evaluation system for a curved shell plate was developed. In this system, the point cloud data of a curved shell plate measured by a laser scanner and the design data are registered based on the edge of shell plates. Then the errors which mean the distances from the design surface are evaluated and visualized by color map. In addition to the development of the system, some actual curved shell plates are evaluated and visualized by this system. Some correlations between the distribution of the errors and the making process are illustrated.

Keywords. Curved shell plate, Shipbuilding, CAD, Laser scanner, point cloud, Registration

1 Introduction

The curved shell plates, which are often included in the bow or the stern of a ship are large and thick and have the arbitrary shapes. The only one pair (port and starboard) of the plates which have the same shape exists in a ship. They are deformed plastically by the application of heat and the water-cooling based on the wooden bending templates. There is no clear-cut methodology in this process. The accuracy of the curved shell plates is evaluated at the only several points, where there are bending templates, by the only eyes of craftsmen. In other words, they are considered to have the correct shapes when the markers on the bending templates are looked through as straightly as an arrow by the craftsman. This process carries great risks, which mean the gap between the blocks, the variation in construction schedule and so on because there are no quantitative criteria and the accuracy of

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curved shell plates heavily depends on the implicit knowledge, for example, the skill and the experience of craftsmen.

On the other hand, non-contact 3D scanning by laser scanner has started to spread dramatically in recent years and its performance has been improving drastically. The laser scanner measures the distance by calculating the time in which a laser pulse travels back and forth between the object to be measured and the light-receiving sensor. Then it combines the distance and the direction of radiation and the 3D positional coordinates are obtained. The laser scanner is able to measure a number of points at a time.

As an application of laser scanners to shipbuilding, K.Biskup et al. calculated the displacement of a 40-meter vessel [1]. In the process, the vessel was measured by a laser scanner from multiple positions. The measured multiple point clouds were registered and wrapped with polygonal meshes. Then NURBS [2] surfaces were created over the polygon object.

This paper presents accuracy evaluation system for curved shell plate, which registers point cloud data by laser scanner and design data from CAD, calculates and visualizes the error, and evaluates the accuracy of the whole shell plate, not several points. Then a real curved shell plate are visualized and evaluated by this system in a case study to verify this system.

2 Proposed Accuracy Evaluation System

2.1 Overview

The processing flow of this system is illustrated in Figure 1. First the point cloud data of curved shell plate is obtained by laser scanner. Second, the shell plate part is extracted by elimination of noise or inessential points. Third, the point cloud data and design data are registered based on the center of gravity and the principal axes of inertia and compared. Finally the gap between measured shell plate and design data is recognized by calculating and visualizing the error.

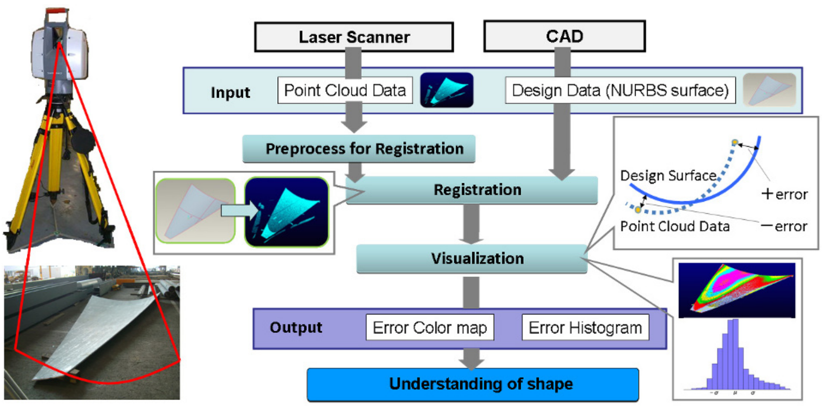

Figure 1. System overview

2.2 Input Data

2.2.1 Point Cloud Data

Coordinate system, color system, data structure and data format of point cloud depends on manufacturer of laser scanner. In this system, Cartesian coordinate system, RGB color system and text data format are used.

2.2.2 Design Data

This system used SAT (Save As Text) format as the design data which is the standard file format of ACIS. In SAT file, surface and curve are expressed as NURBS [2]. The file is parsed and fed into this system. In addition, this design data expresses the mold surface inside the hull in lines plan.

2.3 Preprocess for Registration

Point cloud measured by laser scanner has noise and a lot of inessential points which not only in the curved shell plate, but also in the floor. First, in order to lessen the variability of point cloud measured by laser scanner, smoothing by basic MLS method [3] is executed. Second, the point which is quite-variable or regarded as an outlier is eliminated by plane criteria [4]. Third, this system extracts the point cloud which is not a part of floor but that of shell plate by region growing method [5].

2.4 Registration of Point Cloud Data and Design Data

2.4.1 Outline of Registration

Features which can be the reference points are necessary for registration. The edges are used in this system for being focused on in next process, welding. If edges from the point cloud don’t correspond with the ones from design, the curved shell plate needs to be deformed compulsively to weld the plates.

The edges are detected from both point cloud data and design data. Then the center of gravity and the principal axes of inertia are calculated via the edges. Finally translation and transformation are executed to superimpose two centers and three pairs of axes.

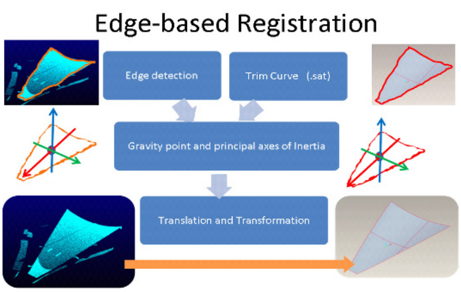

Figure 2. Registration overview

2.4.2 Edge Detection

In this process, the neighborhood of each point in point cloud is searched by k-NN BBF method [6] and the plane is fitted to it by the principal component analysis. Then the neighborhood is projected to the plane. If not all of the 4 quadrants have neighbor as shown in the center of Figure 3, the point is considered as the edge. After this process, point sequence of the edge is obtained. The right images illustrate the result of this process.

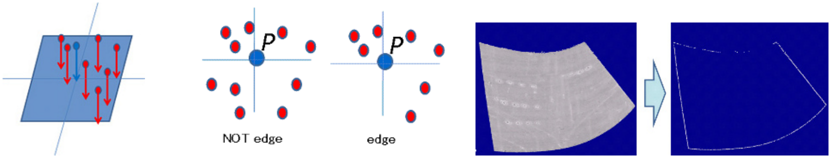

Figure 3. Edge detection

2.4.3 The Gravity Point and the Principal Axes of Inertia

The center of gravity and the principal axes of inertia of detected point sequence and trim curve from design data are calculated by following way. First, as shown in Figure4, weighting coefficient is defined as the distance between two adjacent points and positional coordinate is defined as the center of two adjacent points because the density of point sequence depends on the distance from scanner. If weighting coefficients are equivalent, the center of gravity could be inclined to the scanner side, in which the points are denser than the opposite side.

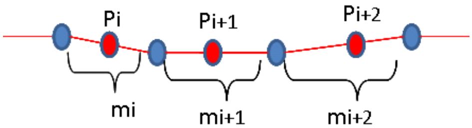

Figure 4. Definition of weighting coefficients and positional coordinates

Second the center of gravity (G) and Inertia tensor (I) are calculated by the following equations. The principal axes of inertia are defined as the Eigen vectors.

$$\mathsf{G} = \frac{1}{n}\sum_{i=0}^{n-1} m_i \mathsf{P}_i \qquad (1)$$

m_i : the distance between adjacent two points.

$\mathbf{P_i}$: the center of adjacent two points.

$$\mathsf{I} = \begin{bmatrix} \sum_{i=0}^{n-1} m_i(|\mathsf{P}_i|^2 - x_i^2) & -\sum_{i=0}^{n-1} m_i x_i y_i & -\sum_{i=0}^{n-1} m_i x_i z_i \\ -\sum_{i=0}^{n-1} m_i x_i y_i & \sum_{i=0}^{n-1} m_i(|\mathsf{P}_i|^2 - y_i^2) & -\sum_{i=0}^{n-1} m_i y_i z_i \\ -\sum_{i=0}^{n-1} m_i x_i z_i & -\sum_{i=0}^{n-1} m_i y_i z_i & \sum_{i=0}^{n-1} m_i(|\mathsf{P}_i|^2 - z_i^2) \end{bmatrix} \qquad (2)$$

2.4.4 Translation and Transformation

The principal axes of Inertia and the center of gravity can be registered definitely in theory .The transformation for superimposing point cloud to design surface is executed for each point, which is represented as following definitions and equation and as shown in Figure 5.

$G_{pointcloud}$, G_{design} : Gravity point of Point Cloud and Design.

$R_{pointcloud}$, $R_{design} = (\mathbf{e}_1, \mathbf{e}_2, \mathbf{e}_3)$ $\mathbf{e}_i$: The eigenvectors for Eigen values of $I_{pointcloud}$ and I_{design} arranged in ascending order.

$\mathbf{p}_i$: point befor transformation $\mathbf{p}_i'$: point after transformation

$$\mathbf{p}_i' = R_{design}{}^{T} R_{pointcloud} (\mathbf{p}_i - \mathbf{G}_{pointcloud}) + \mathbf{G}_{design} \quad (3)$$

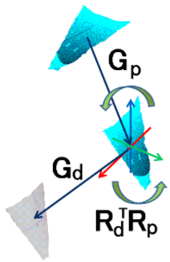

Figure 5. Transportation and transformation

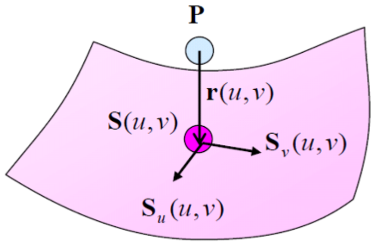

Figure 6. Definition of the error (P: point, S: surface function, r: projection vector)

2.5 Visualization of the Error

As shown in Figure 6, this system defines the error as signed distance from a point to NURBS Surface, which is calculated by Newton method for each point in point cloud.

The calculated errors are visualized to make them easy to understand. There are two visualization modes in this system. The first is gradation mode, which helps users to understand the general shape and the global positional distribution of errors. The left of Figure 7 shows the proportion of coloration for gradation mode (dot-line: red, solid line: green, chain line: blue). Mu means average of errors and sigma means standard deviation (SD) of errors. The second is the histogram mode, which helps users to understand the value distribution of errors in gross quantitatively. The color bar under the histogram is corresponding with gradation color.

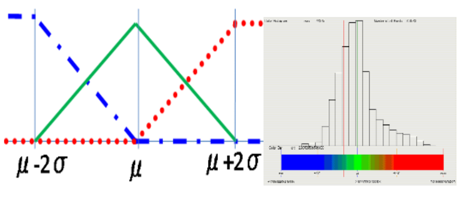

Figure 7. Ratio of coloration(x: value of error, y: luminance) and histogram(y: frequency)

3 Case Study

Currently, the accuracy of curved shell plate has been evaluated only at the position where bending templates are placed and there is no tool to evaluate them at the surface level. Therefore this paper validates this system by estimating platen which has a known shape or a definite plane in section 3.1. Then this system is applied for real curved shell plate in section 3.2.

3.1 Platen

The left of Figure 8 illustrates visualized error of the surface plate by gradation mode. According to this system's evaluation, average of the error is 0.0012mm and SD of the error is 0.26 mm, which means 99.7%(3sigma range) of all the points is included from -0.78mm to +0.79mm.Therefore the accuracy of this system is enough for practical use because 1-2mm interspaces between shell plates and bending templates is tolerable currently in the evaluation by bending templates.

The right of Figure 8 illustrates visualized error of the small plane which is 2mm thick on the surface plate. Average and SD of the error on the small plane are 1.94mm and 0.3mm respectively, which means that the resolution performance of this system is at the lowest 2mm with SD which is 0.4mm.

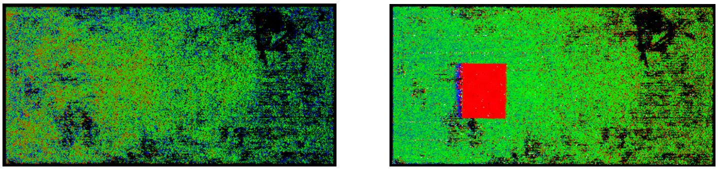

Figure 8. The results of evaluation for the surface plate

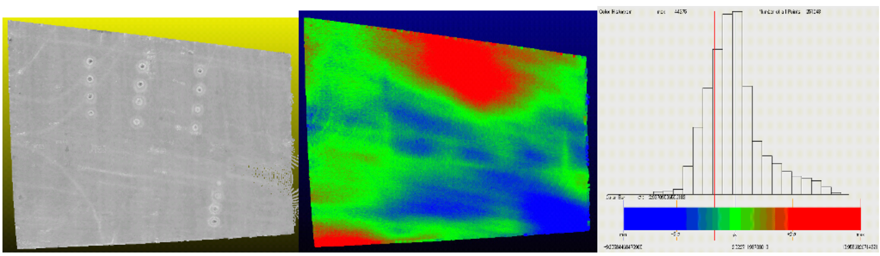

Figure 9. Origin shell plate and the results of evaluation

3.2 Curved Shell Plate

The left image in Figure 9 is the point cloud data measured by laser scanner which is consist of 251,643 points and the results of evaluation by this system are also illustrated in Figure 9.The center image are drawn by gradation mode. The histogram is shown in the right image. According to the histogram, this plate has an error maximum 13.5mm above the design surface and maximum 9.2mm below. SD of the error is 2.9mm. Moreover, in the next chapter, two points are analyzed. One is about the value of error at the templates. The other is about correspondence relation between burning points and the shape of shell plate.

4 Discussion

First, the black vertical lines in the right in Figure 10 represent the position of bending templates, in which there are several vertical lines in the left image. According to the right graph in Figure 11, the gap between the error at bending templates and the error between adjacent templates is a maximum of about 2mm in dot rectangle. The red lines in the left in Figure 11 illustrate the position of templates and blue lines illustrate the position between templates. X-axis of the graph shows the corresponding position of the left picture and Y-axis shows the average of the errors of each part in the bottom left in Figure 11.

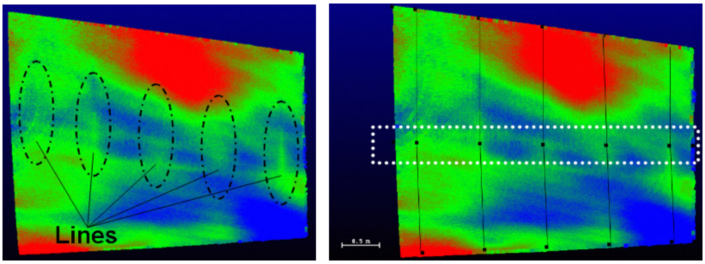

Figure 10. The error at bending templates

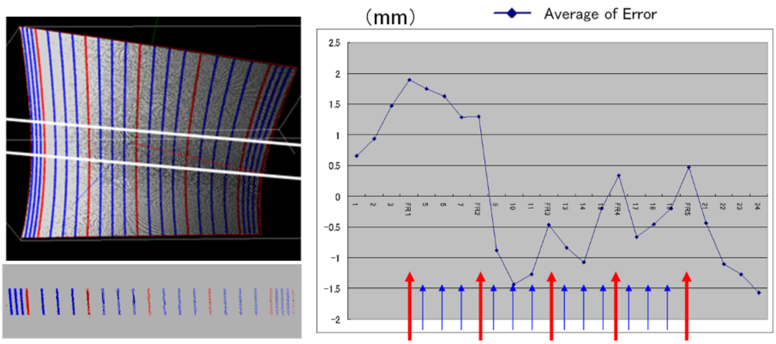

Figure 11. The analysis of the error along with sight line

Second, the left image in Figure 12 shows the heating log to make this plate. The tumor found in the right at the corresponding position with heating point in the ellipse and the lineal dents found in the dot parallelogram are consistent with the fact of swells caused by point heating and lineal dents caused by line heating.

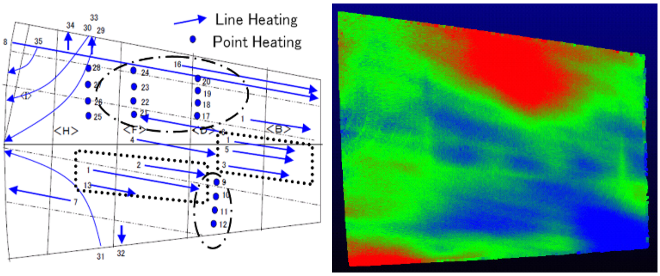

Figure 12. Heating log

5 Conclusion

The errors of real curved shell plate which cannot be evaluated at present are evaluated and visualized on the surface of the curved shell plate and availability of this system is illustrated. The gap between the error at position of templates and the error at the position between templates is illustrated quantitatively. The relation between the heated positions and the error distribution are also shown qualitatively.

6 Acknowledgement

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Managing Demand Uncertainty with Knowledge Utilized Forecasting

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Abstract: This study proposes a production risk management model based on knowledge utilized forecasting. The demand uncertainty of business has been a serious problem for manufactures. As the market globalization has increased the scale and speed of their business, it becomes too big and complex to manage those uncertainty business risks. There are often the cases that misleading demand forecast cause not only business opportunity loss because of stock shortage but also serious overstock at the end of product lifecycle. It is important for manufactures to obtain a reliable production planning that manage their business risk between forecast and sales result. This study proposes a dynamic re-production decision support system by measuring reproduction risk based on knowledge utilized product's lifecycle sales forecast. It gives us proper timing and volume for reproduction even just after products release. As a case study, this model is applied to Japanese book publishing planning and verified how it works. The results showed the twice efficient performance as much as present position under the same risk volume.

Keywords: risk management, forecasting, knowledge utilization, book retail

1 Introduction

As the consumer market globalization has increased the scale and speed of business, business uncertainties have become one of the most serious problems. Manufactures like consumer digital electronics are trying to adopt this new market. It becomes important to stimulate their customers' attention by releasing new models. Therefore the new models are increased, and product lifecycle have been significantly shortened.

New product sales trend has sudden peak and sudden out [1,2]. Fig.1 shows basic concept how demand uncertainty cause two business losses in a same product. Just after its released manufacture finds that its sales is rapidly growing and its stock will be run out. Since manufacture is so sensitive to stock shortage of the market that they make reproduction decision. But when those reproduction items are replenished, product sales sometimes has shown sudden peak out. Thus they find serious surplus stock problems.

Supply chain management studies have allowed us to shorten the supply lead time and to build the leaner business structure. SCM studies contribute to absorb

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those risks in terms of quick reaction to the result. Nevertheless those trial, there remains phase lags that serious problems to manage those risks. Mentzer and Bienstock[3] pointed that forecast of sales influences various decisions at the organizational level. Agrawal and Schorling[4] also pointed out that accurate demand forecasting plays an important role in profitable retail operations. Fisher and Raman[5] reported the quick response to early sales result with forecasting error distribution contribute to demand risk reduction. It is necessary to deal with those risks at on-time-marching to pursue better production utilization. Some intesting forecasating approaces which deal with nonlinear sales product (Trappey et al[6], Chang et al[7], Tanaka[1]) have been reported. This study is an approach to measure business risks by applying those forecastig model.

The main objective of this study is to propose the on-time-marching reproduction risk management model especially for new products to make their demand uncertainty risk under control. In order for it, two system elements are also proposed; the demand propability distribution evaluation method based on knowledge utilized forecasting, and the portfolio production risk evaluation. The verification of this model will be stated.

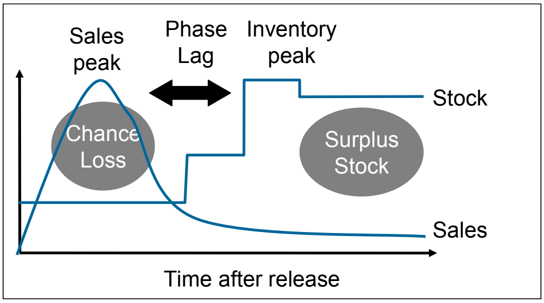

Figure 1. Typical two losses caused by demand uncertainty

2 Proposed Risk Management Model

2.1 Basic Flow

The basic flow of the proposed model in this research is illustrated in Fig.2. This model uses two databases, Static data and dynamic Sales data. Static data has sample product daily sales result data which is used for forecasting coefficient and probability distribution tables based on knowledge utilized reference groups. Dynamic data consists of two ongoing product latest data, the one is target product sales data and the other is its production volume data.

As for the main flow, product i is selected at first step. Then long and short term sales forecast of product i is calculated with NM method[1]. Long term in this model is the days between the present day and the end of product lifecycle. Its forecast means estimated accumulated sales volume of product i throughout lifecycle. Short term is the days of minimum lead time between reproduction decision and market inventory replenishment. Additional items cannot be supplied during the period. As the 3rd step two kinds of risks are evaluated based on probability distribution table. Opportunity loss risk and surplus loss risk are caused by reproduction volume decisions. Then product i local optimized volume option of reproduction is determined. The criteria of optimization can be chosen from following; Minimising toal risk or Maximisimg Return or Maximising Risk-Return ratio. Those four steps are product local risk management parts. The rest steps are regard to product risk portfolio management. If there are other products, evaluate those risks on each product. As the all products' risks are obtained, we evaluate total risk as a portfolio. With evaluation of each products' volume options the prioritization among products are decided according to manufactures' strategy. Finally the production decision of reproducing volume is made.

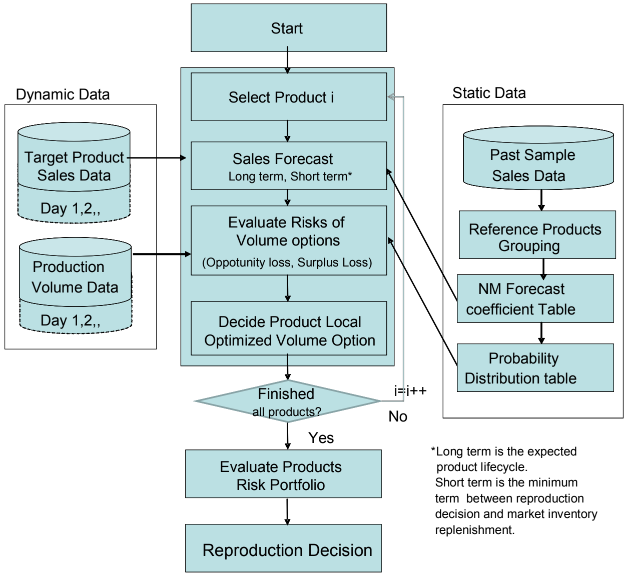

Figure 2. Basic Flow of Proposed Model

2.2 Forecasting Method

In this study NM method is adopted as a forecasting method. NM method is a knowledge utilized accumulated sales forecasting method, which can provides us not only short term forecast but also long term accumulated sales forecast. Using correlation between specific date pair of sales results among the relevant group products, the target forecast is calculated. This method predicts the Mth day accumulated sales forecast based on the Nthday accumulated sales result. (1)(2)

$$X_{Mi}(N) = k(NMgroup, N, M) \cdot R_{Ni} \tag{1}$$

$$k(NMgroup, N, M) = \frac{TotalNum_{NMgroup}(\sum_i R_{Mi} \cdot R_{Ni}) - (\sum_i R_{Mi}) \cdot (\sum_i R_{Ni})}{TotalNum_{NMgroup}(\sum_i (R_{Ni})^2) - (\sum_i R_{Mi})^2} \tag{2}$$

M^{th}, N^{th} are the numbers of days after product i released. R_{Ni} is accumulated sales result of product i at N^{th} day after its release. $X_{Mi}(N)$ is M^{th} day accumulated sales forecast of product i at N^{th} day, *k(NMgroup,N M)* is NM coefficient of M^{th}day forecast from N^{th}day result at reference group *NMgroup*. $TotalNum_{NMgroup}$ is a number of products in NM group. Each N^{th}-M^{th} pair has each NM coefficient. Based on sample sales results, NM coefficient table is prepared for each group. Determining reference product group is the key of its accuracy in this method. In this study we use knowledge utilized method as Tanaka[1] reported. Reference grouping attributes based on experts' knowledge are verified their accuracy with sample data, and determine effective attributes. According to those grouping rule, NM coefficient table of each group are prepared. Probability distribution table for each group is also prepared by adopting NM forecast to sample titles. Then product i local optimized volume option of reproduction is determined. Those four steps are product local risk management parts.

2.3. Risk Measurement Method

There are two type of risks which are arisen by the reproduction decision of volume; Opportunity loss risk and Surplus loss risk. Opportunity loss risk is a intangible risk that is caused by stock shortage. Surplus loss risk is a surplus inventory cost on retirement at the end of product lifecycle because of overstock. Fig.3 indicates the basic concept of those two risks. The gray wave rays indicate possible demand trends in future. If demand moves over the supplied production volume, it arise opportunity loss. If demand moves under the volume, it arise surplus loss risk. Those risks are measured with the colored area in Fig.4. That is calculated with forecast and its probability distribution.

The Opportunity loss risk of product i at N^{th} days after its release is expressed by $RiskOppLoss_i$. It is defined as formula (4)(5).

$$RiskOppLoss_i(\Delta R_{Ni}, R_{Ni}) = NumOppLoss_i(\Delta R_{Ni}, R_{Ni}) \cdot Gross\Pr ofit_i \quad (4)$$

$$NumOppLoss_i(\Delta R_{Ni}, R_{Ni}) = \int_{R_N+\Delta R_N}^{\infty} P_{N+n,NMgroup}\left(\frac{x - Xi_{N+n}}{Xi_{N+n}}\right) \cdot \left|x - Xi_{N+n}\right| dx \quad (5)$$

ΔR_{Ni} [items] represents added volume of production for product i at the N^{th} day. $NumOppLoss_i(R_{Ni}, \Delta R_{Ni})$ is the volume of opportunity loss items caused by inventory shortage. $GrossProfit_i$ [JPY] is gross profit per one item of product i, x[items] is a variable of total reproduction volume option. NMgroup is the reference group used for NM forecast.. To express oppotunity loss, days of short term supply lead time is used as n, where n is days difference between M-N. Then, Xi_{N+n}[items] is another expression for $X_{Mi}(N)$ represents accumulated sales n days ahead forecastat N^{th} day. $P_{N+n,NMgroup}$[%] is a probability function that represents n days ahead forecast probability distribution at N^{th} day. *NumOppLoss* in (5) can be expressed as (6) with using θ which represents the proportion indicator of gap between forecast Xi_{N+n} and reproductin volume option x.

$$NumOppLoss_i(\Delta R_{Ni}, R_{Ni}) = Xi_{N+n} \int_{\theta_0}^{\infty} P_{N+n,NMgroup}(\theta) \cdot |\theta| dx \quad (6)$$

$$\theta = \frac{x - Xi_{N+n}}{Xi_{N+n}} \text{ , } \theta_0 = \frac{R_{Ni} + \Delta R_{Ni} - Xi_{N+n}}{Xi_{N+n}}$$

On the other hand, the surplus loss risk of product i at Nth day after release, $RiskSrpLoss_i$, is also defined as (7). Number of surplus loss, $NumSrpLoss_i$, is expressed as (8).

$$RiskSrpLoss_i(\Delta R_{Ni}, R_{Ni}) = NumSrpLoss_i(\Delta R_{Ni}, R_{Ni}) \cdot CostperItem_i \tag{7}$$

$$NumSrpLoss(\Delta R_{Ni}, R_{Ni}) = Xi_{N+Last} \cdot \int_{-\infty}^{\theta_0} P_{N+Last,NMgroup}(\theta) \cdot |\theta| dx \tag{8}$$

where *Last* in (8) stands the rest days of product lifecycle. $CostperItem_i$ is cost on retirement loss per item of product i. $NumSrpLoss_i$ is the number of surplus items at the end of expected lifecycle of product i.The expected return of product i is defined as $ExpectedReturn_i$, which is also calculated as (9).

$$Expected\,Return_i(\Delta R_{Ni}, R_{Ni}) = MIN(R_{Ni} + \Delta R_{Ni}, Xi_{N+Last}) \cdot Gross\,Profit_i \tag{9}$$

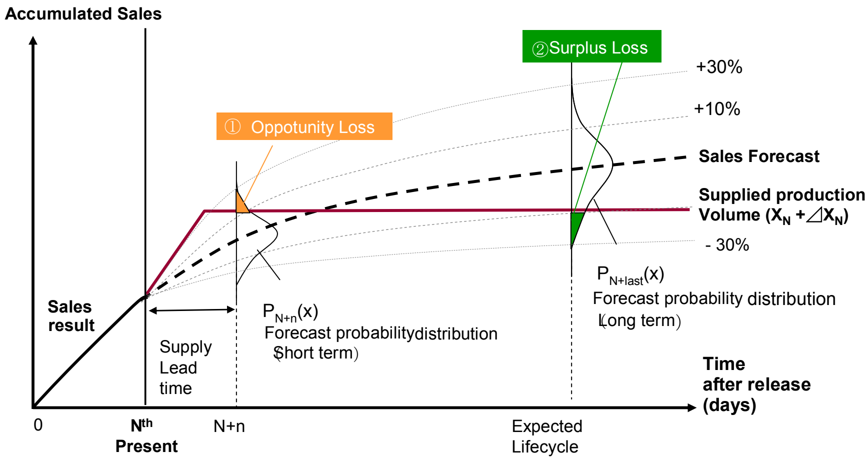

Figure 3 Opportunity loss risk and Surplus loss risk of proposed model

2.4. Risk Return Evaluation and Portfolio Risk Management

With those risk and return measurement methods, the evaluation of risk-return efficiency of each ΔR_{Ni} option can be obtained. Opportunity Loss Risk, Surplus Loss Risk and Expected Return of product i depends on the volume of ΔR_{Ni} (Fig.4). The more ΔR_{Ni} increases, the more *RiskSrpLoss* increases at an accelerating pace. $RiskOppLoss_i$, however, decreases gradually as ΔR_{Ni} increases. Total risk shows gradual increase after a minimum peak. On the oter hand, the $ExpectedReturn_i$ increase gradually with its increments decreasing gradually. The gap between total risk and $ExpectedReturn_i$ should be maximized. There are three ΔR_{Ni} optimum options; minimum risk option, maximum return-risk gap option, and maximum risk-return ratio option. Depends on risk strategy, the product i local optimized volume option ΔR_{Ni} should be chosen.

Manufactures determine reproduction plan ΔR_N under their limited resources. It is important to manage their product portfolio risks. The total risk and return of product portfolio are expressed as follows; (10)(11).

$$RiskPortfolio = \sum_i (RiskSrpLoss_i + RiskOppLoss_i) \tag{10}$$

$$ReturnPortfolio = \sum_i Expected\,Return_i \tag{11}$$

The prioritization over products should be determined by comparing each product's risk-return efficiency. The every product's risk-return axis plot is prepared for comparison over products.

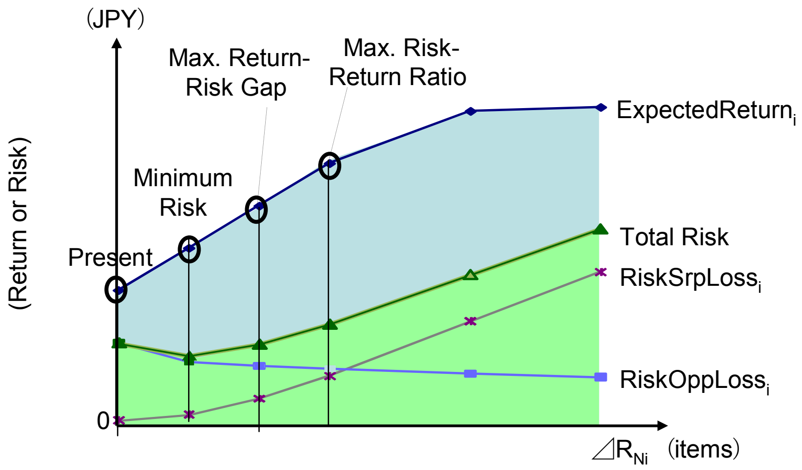

Figure 4. Risk Return Evaluation

3 Case Study

3.1 Conditions of Verification

In this section the performance of the proposed model is verified by applying to the Ree Japanese business junle titles published in Sep.2006 by a middle size publisher, titleA, titleB, titleC. Business book sales trends have a keen peak and sudden peak out. Publishers suffer a lot of cost caused by those features. Static sample data of 1,367 business titles published in 2005 are used for preparing NM coefficient and its probability distribution. Those data are provided by a Japanese leading wholesaler and a publisher. Their minimum lead time for replenishment n is 21 days, and the expected lifecycle is 182 days. The data is changed by fixed proportion because of their confidentiality.The product reference group is made by two grouping attributes. The one is publisher and the other is the topic junle among devided 21 business junles created by book editor.

3.2 Results and Discussion

The product local optimized volume options of titleA at 21st day are indicated in Table1. ExpectedReturn and RiskSrpLoss increase as $\Delta\ R_{21}$ increase. They are 41.8 and 20.1 at maximum ΔR_{21}(real volume decided). On the other hand RiskOppLoss decrease. The value ΔR_{21} of three product local optimized volume options are follows; 1,900 items of minimum risk option, 31,300 items of maximum return-risk gap oprtion, and 6,900 items of maximum risk-return ratio option. Thus this model gives measured risks and return with regard to production volume, and allow us to determine which option to be taken under three possible stragegies. The publisher's real decision without this model was 46,800 and found that over 50% of surplus stock at the end of its lifecycle.

Table1. Product Local Optimized Volume Options (TitleA at 21thday)

(unit:100thousandJPY)	Present	Min Risk	Max Risk-return efficiency	Max Absolute Return	Real Volume Decided	Improve ment
⊿R Option (100items)	0	19	69	313	468	
ExpectedReturn	17.6	23.2	28.8	41.3	41.8	
RiskSrpLoss	0.4	1.2	3.3	13.5	20.1	
RiskOppLoss	10.7	8.2	7.6	6.6	6.1	
Total Risk	11.1	**9.4**	10.9	20.1	26.2	-64%
Return-Risk Gap (Net Return)	6.6	13.9	17.9	**21.2**	15.6	36%
Risk-Return Efficiency Ratio	1.6	2.5	**2.6**	2.1	1.6	66%

The three titles' production decision case of the publisher at 14th Sep 2008 is simulated with proposed portfolio model. Present total risk is 51 milJPY. Total return is 85milJPY. Under the risk-return ratio leveling strategy, the options on the same gradient line are chosen (Fig.5). Therefore portfolio return increases by 95% upto 165milJPY , while portfolio risk increases 27% upto 65milJPY. The portfolio risk-return efficiency increased by 52% from 1.67 to 2.54. Under the strategy of miximum risk-return ratio of each item, portfolio return increase 76% upto 150milJPY, portfolio risk decrease by 2% downto 50milJPY, portfolio risk-return efficiency increased by 80% upto 3.00.

This model proved that it can provide products' risk evaluation and obtain an optimized production volume option. TitleA case gives us the possibilities of 64% risk reduction comapred to real decision by determining proper production volume. The portfolio case indicates that the model provides portfolio return increase with risk-return efficient resource allocation.

4 Conclusion

The proposed model provides a useful approach to manage demand uncertainties by measuring risks and expected return with NM forecasting probability distribution. The model showed better performance in book production case study. Compared with what is actually being done, this model gives better performance as follows; reduction product local risk by 64%, increase products portfolio return by 95%, increase portfolio risk-return ratio efficiency by 80%.

As a further study, on-time demonstration experiment with publishers should be done in order to verify its effectiveness from realistic point of view. Expanding to other industry products should be productive.

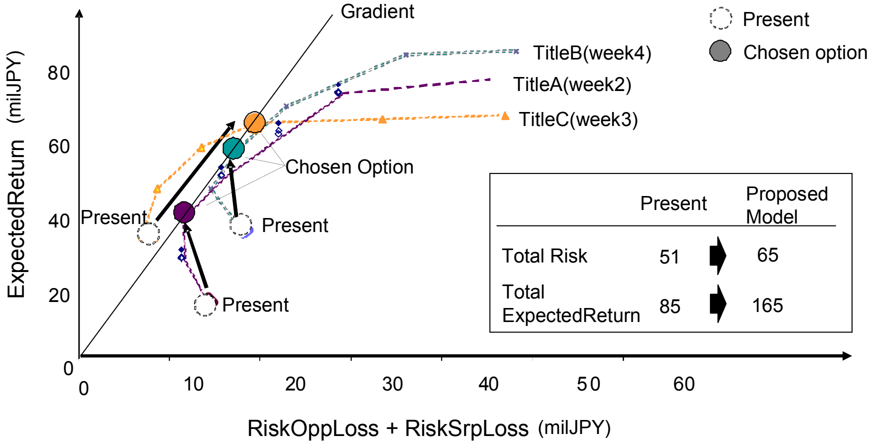

Figure 5. Products Portfolio Management by Risk-Return Ratio Leveling Strategy

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An Application of Simulation Based Process Design

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Abstract. One critical issue in process management is that managers can only rely on their experience when they make decisions in designing their business processes. To provide effective decision-making support, a simulation based approach (PMT:Process Management Tool) has been developed to quantitatively predict the performance of designed processes. In this paper, two types of automotive design processes, one product based and the other function based, were examined by applying the simulation based process design. The PMT analysis revealed the fragility of product based process and the tolerance of function based process to overload. In addition, effective human resource allocations were identified.

Keywords. Process Design, Simulation Based Approach, Effective Assistant for decision-making, Tolerance to the Overload, Way of Human Resource Allocation

1 Introduction

In order to survive the global competition, manufacturers have been employing various methods [1 ~ 4] and technologies [5, 6] for improving their performance of engineering and manufacturing processes. However in the field of process management, there have been few effective solutions for managers to design an entire process or help them make proper decisions about "*How to arrange tasks and assign human resources?*". As a result, considerable numbers of process innovations and improvements have resulted in failure [7].

To develop effective technologies for process design, two critical issues shall be addressed. The first issue is related to the impact of coordination on the process performances. Especially in knowledge application processes such as engineering design, designers need to not only process the actual design work but also actively coordinate with each other through communications, reports, and waiting for decisions and/or replies from others. Few existing methods take coordination into consideration. The second issue has to do with the complex relations between

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clients and corresponding processes and with the impact of these relations on the process performance. For instance, predicting the performance of a design process of 5 car models should be more complex than that of a design process of one model. Although VDT (Virtual Design Team) [8] method explicitly addresses the coordination work, it does not consider the relation complexity between changing clients in the market and the business processes of an enterprise partly due to its focus on project management.

Considering the issues described above, a simulation based approach for enterprise business process design, implemented as PMT (Process Management Tool) [9], was developed. PMT has a graphical modelling editor for designing an enterprise business process, a discrete event driven simulation engine for predicting the process performance, and a graphical reporter to display the simulation results of various performance measures.

In this paper, after a brief introduction of our proposed approach, we describe a case study in which PMT was applied to examinate possible options of designing an automotive press-forming-dies design process.

2 Conceptual Model of PMT

The key concepts of PMT (Figure 1.) include Client, Organization, Process, and Resource. A client is modelled as a source of work for an enterprise. It has its own operations (COP: Client Operation) and sends service requests (SRI: Service Request Item) to the enterprise. A service process of an enterprise is a procedure for processing SRIs. It is composed of a set of required operation (SOP: Service Operation). An organizational position is assigned to SOP and processes SRIs. Positions form an organization through report-to relations. When a position processes a SRI, a coordination work such as communication and exception might be generated. A communication is sent to and processed by a task-related position, while an exception is sent to a supervising position for guidance or decision. This way, a position processes not only the direct work from clients but also the coordination work generated from co-workers. In this information-processing view [8, 10, 11] based conceptual model, a position is considered as an information processor and the requests (SRI) from clients, communications and exceptions from other positions, as well as decisions regarding the exceptions, are considered as the information to be processed by the positions.

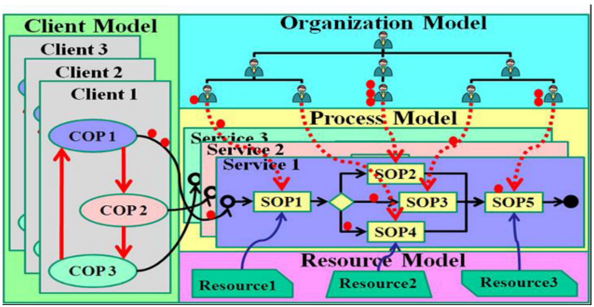
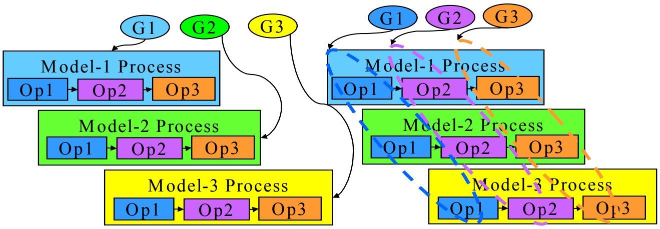


Figure 1. Conceptual Model of PMT

3 The Automotive Press-Forming-Dies Design Case

The following paragraph states the automotive press-forming-dies design case:

The current design process is a product based process (Figure 2. a)). Due to the high demand, the process was overloaded. In addition, a large number of new unskilled designers were allocated to the process and it drastically reduced the design throughput. Finally, its responsible manager started to consider reforming the current design process to the function based process by re-grouping the operations (Figure 2. b)). Most crucial requirement for their design process is to maintain the throughput when the process is overloaded.



a) Product Based Process **b)** Function Based Process

Figure 2. Product and Function Based Process

Based on the case described above, the crucial problems to be addressed prior to re-designing the process were identified (Table 1). The answers to these problems used to solely depend on the Manager's experience.

Table 1. Problems to be predicted

Problems	Predictions	
	Product Based Process	Function Based Process
Tolerance to the overload	Analysis by the simulation based approach	
Where to allocate unskilled designer		

Regarding the design process of the press-forming-dies, the necessary information required for its simulation model was collected as follows (Figure 3).

- Press-forming-dies are designed with respect to 6 model types.
- The Press-forming-dies design requires four major operations, i.e., "Protype Design", "Prototype Try", "Product Design", and "Product Try".
- The operations are becoming more complex from "Product Try" (last operation) to "Prototype Design" (first operation).
- 50 designers, including managers, are assigned into the process.

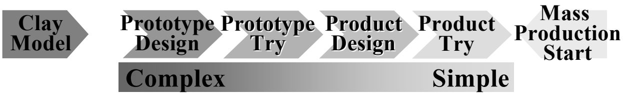


Figure 3. Press Forming Dies Design Process

To examine the process with respect to “allocation of human resources”, the skills and the skill levels of the 50 designers were defined with respect to the four operations in the design process as shown on Table 2. Persons 41 to 50 are the unskilled designer assigned to the process lately.

Table 2. Properties of Human Resources

Staff’s ID	Skills and levels			
	Prototype Design	Prototype Try	Product Design	Product Try
Person1~ 10	High	High	High	High
Person11~ 15	Medium	High	High	High
Person16~ 20	Medium	Medium	High	High
Person21~ 25	Medium	Medium	Medium	High
Person26~ 30	Low	Medium	Medium	Medium
Person30~ 35	Low	Low	Medium	Medium
Person36~ 40	Low	Low	Low	Medium
Person41~ 50	Low	Low	Low	Low

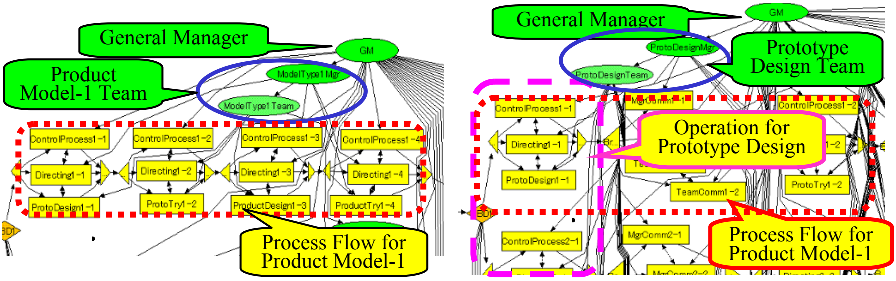
4 Modeling the Design Process

The 6 model types are the sources of requests (works) for the design process. The modeling procedures of product and function based processes are described as follows (Figure. 4).

Firstly, the operation flow for processing the requests from each model type is defined. Each operation flow comprises three types of operations, which are “designing operations”, “directing Operation”, and “control process operation”. The designing operations are “Prototype Design”, “Prototype Try”, “Product Design”, and “Product Try”. They directly contribute to completing the designing work. Directing operation monitors the designing operations and directs the designers. Control operation integrates the all team managers from a management perspective. Both the designing and control operations are information-dependent on the directing operation. For instance, a designing operation may request its necessary information to its relating directing-operation when it is executed, and vice versa. In PMT simulation, when an information request is generated from an operation, it is sent to its dependent operation and processed by its responsible position.

Secondary, the responsible organizational positions are defined with respect to the operations defined above. The four designing operations are assigned to the design teams. The directing operations and the control operations are assigned to the Team Manager and the General Manager, respectively. In PMT simulation, a position processes requests received from its assigned operations and sends them to the next operations after processing. When a position is assigned to a set of operations with respect to a specific model type, it forms a product based process (Figure 4 a)). When a position is assigned with respect to a specific function of operations, it forms a function based process (Figure 4 b)).

Finally, the report-decision relationships between the positions are defined. The network of the relationships forms a service organization. For instance, when a designing operation is executed, it may result in an unexpected consequence (called exception) based on a probability. In PMT simulation, when an exception is generated, the exception report and its decision are sent through the network.



a) Product Based Process b) Function Based Process

Figure 4. Modeling the Processes

5 Simulation and Analysis

In this examination, four scenarios were applied (Table 3.). In Scenario1 and 2, the average skill levels of all design teams were equal. Scenario1 and 2 were for the product based process and the function based process, respectively. Scenario3 was for the product based process. Its average skill levels of all design teams were different from each other. Scenario4 was for the function based process. In this scenario, the average skill levels of the two teams assigned to the first two complex operations were higher than the other two teams. In other words, it considered the complexity and skill level matching. For all scenarios, the simulations were executed by varying the load conditions from 50% to 100% by 10% steps. The following two performance measures are evaluated to assess the simulation results.

Table 3. Simulation Scenario

Scenario	Applied for	Human Resource Allocation
Scenario-1	Product Based	Skill Level of all teams are equal
Scenario-2	Function Based	
Scenario-3	Product Based	Skill Level of all teams are varied
Scenario-4	Function Based	Two teams have higher skill than others

Process Throughput: The process throughput is defined by the number of completed requests from the clients (Model Types) in a specific period of time (3 months in this simulation).

$$TP = Total\_TP / Sim\_T \qquad (1)$$

TP: Process Throughput (Number of requests / Month)
Total_TP: Throughput during a simulation period (#)
Sim_T: Simulation period (Month)

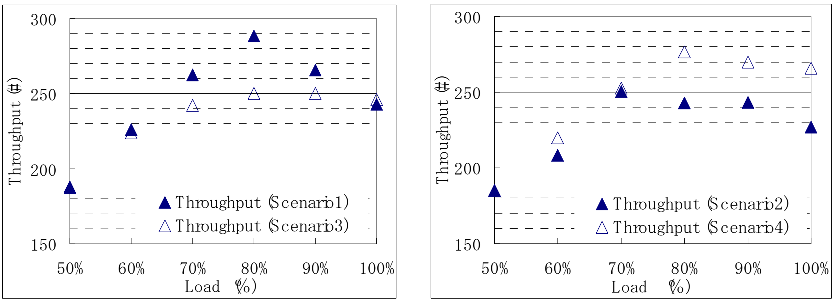
Communication Quality: Communication quality is defined by the ratio of the number of responded communications to the number of the initiated communications within a defined period of time. In this simulation model, a communication-request evaporates after 72 hours. It means that the communication fails if the position cannot respond it within 72 hours. As the number of responded communications decreases, communication quality becomes worse (low).

Comm_Quality = Processed Comm / Requested Comm (2)
Comm_Quality: Communication Quality
Processed_Comm: The number of responded communications by a position (#)
Requested_Comm: The number of received communications by a position (#)

The simulation results have been analyzed to evaluate the organization structure impact on both the Process Throughput and Communication Quality.

Structural impact on both the Process Throughputs: Figure 5a shows the changes of the throughput to the workload with respect to the product based process. As shown in Figure 5a, the peak throughput of Scenario1 is higher than that of Scenario3, indicating that the maximum throughput can be improved by human resource allocation. However, the improvement is only effective around the peak and the throughput after the peak decreases as the workload for the design process increases.

Figure 5b shows the changes of the throughput in response to the workload in case of applying a function based process. As shown in Figure 5, the throughput of Scenario 4 is higher than that of Scenario 2. From this result, it is recognized that the maximum throughput can be improved by the human resource allocation. In addition, the improvement is still effective after the peak and the throughput after the peak remains almost the same as its maximum.



a) Product Based Process b) Function Based Process

Figure 5. Work Processing Performance

From the above observations, the followings can be concluded regarding the throughput performance of the two types of processes.

- Function based process is more tolerant to the overload than the product based process.

- Although human resource allocation to the product based process can improve maximum throughput, it cannot improve its tolerance to overload.
- The human resource allocation to the function based process can improve the maximum throughput and the tolerance to the overload.

Structural impact on both Communication Qualities: Figure 6 shows the the changes of the communication quality with respect to workload. To the product based process, the better human resource allocation regarding the processing capability, Scenario 1, was applied. To the function based process, the worse allocation, Scenario 2, was applied.

In the product based process, the communication qualities of operations Prototype-Design and Product-Try become worse at the same pace after a certain workload level. It is considered that the communication qualities of all operations would decrease in a similar way when the workload reaches to the maximum capability of all operations in a process.

In the function based process, the communication quality of Prototype-Design becomes worse after a certain workload level. However, the communication quality of Product-Try stays almost constant with all load levels. It is considered that the last operation Product-Try is less sensitive to the overload situations because the first operation Prototype-Design would not send to the operation the amount of work more than it can complete.

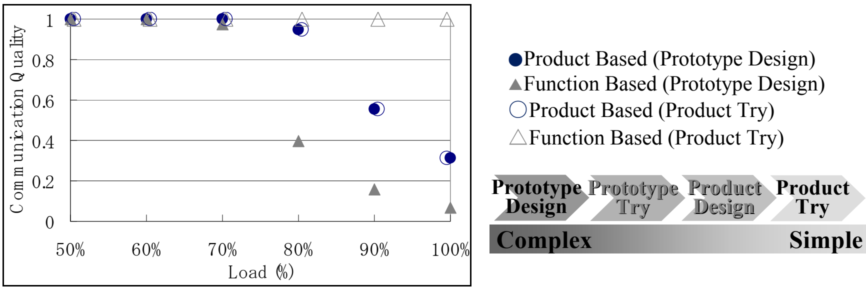


Figure 6. Communication Processing Performance

From the analysis results described above, the followings can be concluded regarding the effect of human resource allocation on the two types of processes.

- When the product based process is overloaded or highly loaded, the unskilled designers are unable to receive enough information to complete their work because they need more information than the skilled designers.
- In the function based process, the unskilled designers should be allocated at the last or later operations in order to get enough information for them.

Through the analyses described above, the problems listed on Table 1 were predicted as follows.

Table 4. Problems and Predictions

Problems	Predictions	
	Product Based Process	Function Based Process
Tolerance to the overload	Weak Cannot be improved	Improved by human resource allocation
Where to allocate the unskilled designer	Cannot be solved	Allocating to the last operation

6 Conclusion

As an application example of our proposed simulation based approach for process design, a press-forming-dies design process was examined using PMT. This examination verified the conceptual model of PMT for modeling and simulating the actual design process. In addition, it was also verified that the simulation results could deliver effective solutions for designing business processes. The findings through this examination were discussed with the managers of the enterprises that had similar design processes. Through the discussion, it was found that our approach and the PMT system would be effective for supporting actual business process design.

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The Use of Expert Systems Associated to Agents for Routing Suggestions for Service Orders

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Abstract. In dynamic environments, a great obstacle for the integration between process planning and production scheduling is the lack of flexibility for the analysis of alternative resources during the allocation of the jobs on the shop floor. In this phase the process plan is treated as fixed, that is, scheduling does not consider all the possible manufacturing combinations. In order to solve this problem, it was proposed and developed a multiagent system that enables the use of process plans with on-line alternatives. After implementing the system, a large number of tests were carried out, resulting in a database with more than twelve thousand simulations. By analyzing the results, it was observed that despite shorter makespan and flow times were attained, the standard deviation was high when comparing with other approaches found in the literature. As the problem is significantly complex, involving many parts, resources and alternative plans, an Expert Agent based on the JESS language (Java Expert System Shell) was implemented which, through the application of rules, filters the information in the database of simulations and provides the system with an adequate suggestion of the route to be executed.

Keywords. Multiagent systems, Expert systems, Routing

1 Introduction

Acording to [1] adapting the use of knowledge based systems in any field, rests on the fact that the knowledge relevant to such field can be systematized into structures, such as: rules, logics, scripts, semantics and others, being handled by an inference mechanism in order to solve a problem.

The association of agents and expert systems can be found in a wide variety of fields, such as: tutoring systems [2]; knowledge representation, [3]; industrial simulation [4]; supply chain [5].

This association, according to [6] makes use of the main advantage derived from linking objects to rules, which rests on the fact that object-orientation, despite offering a concise structural representation of static relations, does not provide the

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means to directly describe in a declarative way how the stored knowledge must be used, which can be done through production rules. Ultimately, while object-orientation provides a rich, simple, and natural mean for expressing the objects of the field, its relations and behavior; production rules provide simple and natural means to express the system´s reasoning [6].

2 Functioning and Implementation

The developed system is composed by a simulation model [7] developed in the Java language, according to the FIPA standard [8], using the JADE platform for agent development [9], the Eclipse development environment [10], and the MySQL database [11].

To integrate the developed prototype into the JADE platform, JESS - Java Expert System Shell [12] was chosen. JESS is a enviroment for expert system development and an inference engine, written in the end of the 90s in JAVA language by Ernest J. Friedman-Hill at Sandia National Laboratories [13]. With the advances in the use of JAVA language and in agent-based systems, JESS also began being used as a decision component of an agent, which is implemented in a declarative way [14].

Firstly the simulation model, which in not within the scope of this document and can be found in [15], generates data related to the makespan, flow time, and queue time, based on the simulation results for sets of pre-determined production orders [16]. These data are stored in a database developed in MySQL.

The Expert Agent uses the acquired knowledge along these simulations to indicate to the production orders which is the best resource to be hired in the first round of negotiations between parts and resources during the following simulation. A detailed description of the negotiation protocol applied between the agents is given in [7].

The code developed in JESS is an interface between the Expert Agent, which runs in the Java memory domain, and the expert system and its rules, which in turn runs in JESS's memory domain.

In order for a routing suggestion to be generated, initially the user should select the parts to be analyzed, and their respective times to setup (machine and fixturing). Then this information is sent to the Expert Agent responsible for the interface with the expert system.

Based on the chosen parameters, the database is searched for simulations that have similar number of parts, setups and amounts. In this work the MySQL database located in a local server, but it could be stored anywhere, in a distributed way.

In this context, JESS acts as decision-making assistant, allowing the agent, in the case of the developed prototype, to choose based on previous similar experience by consulting a base of existing simulations, even if the field of action is unknown to the agent. The association between the prototype developed in JADE framework and JESS was developed so that the structure for entering and retrieving information from the code takes place through JAVA static functions. However, the rules to be implemented and the logic utilized by the expert system were developed in JESS code, thus benefiting from the advantages provided by both languages.

2.1 Server Agent and Expert Agent

Within the developed simulation model [15], the Server agent has two responsabilities which enable the proposed system to not only be used to create new consulting bases through new simulations, but as a knowledge source for comparison of pre-existing cases, through the use of an expert system, cases such as: (a) detecting the availability, or non-availability, of an Expert Agent on the simulation platform and (b) make the correct decision on either of the previouly mentioned case -Expert Agent availability on non-availability- before instantiating production orders.

At first, once instantiated, the Server agent goes into WaitingOrders state, initializing WaitForOrders behavior. This behavior is cyclic, meaning, the Server agents remains enabled to receive fresh orders for the manufacturing of new parts during its entire lifecycle. The WaitForOrders behavior is interrupted when: (a) the retrieval of unit processing plan is requested; or (b) it receives a new order request, being that the request will remain stored until a new simulation begins. For the integration with the Expert Agent to occur it is necessary that the above mentioned condition (b) has already taken place, that is, that the Server agent has received a request with orders to run a new simulation. At this moment the Server agent goes from WaitingOrder state to StartingSimulation state, and also switches to StartSimulation behavior.

In this state, the Server agent will run the ask_for_Expert method, responsible to check for the availability or non-availability of an Expert Agent on the agent platform. When an Expert Agent is available, the waiting_for_Expert method responsible for sending a Best_Simulation message to the Expert Agent is run, requesting the best routing suggestion for the present order.

The Expert Agent´s main function is to suggest a routing option between the production orders and the resources available on the shop floor, by a single cyclic behavior called Communication. This routing suggestion will be used in the first round of negotiation of the proposed model. For this purpose, the Expert Agent will have three responsibilities to fulfill upon receiving Best_Simulation message, containing the data for the simulation, as well as the criterion to be used for case comparison: (a) create a fact base to retrieve similar cases from a databank; (b) generate from the fact base a simulation ranking based on the presented results and on the chosen solution criterion; and (c) feed the Server agent with the best routing suggestion within the selected criterion. The interface functioning between Server agent, Expert Agent and JESS is represented in Figure 1.

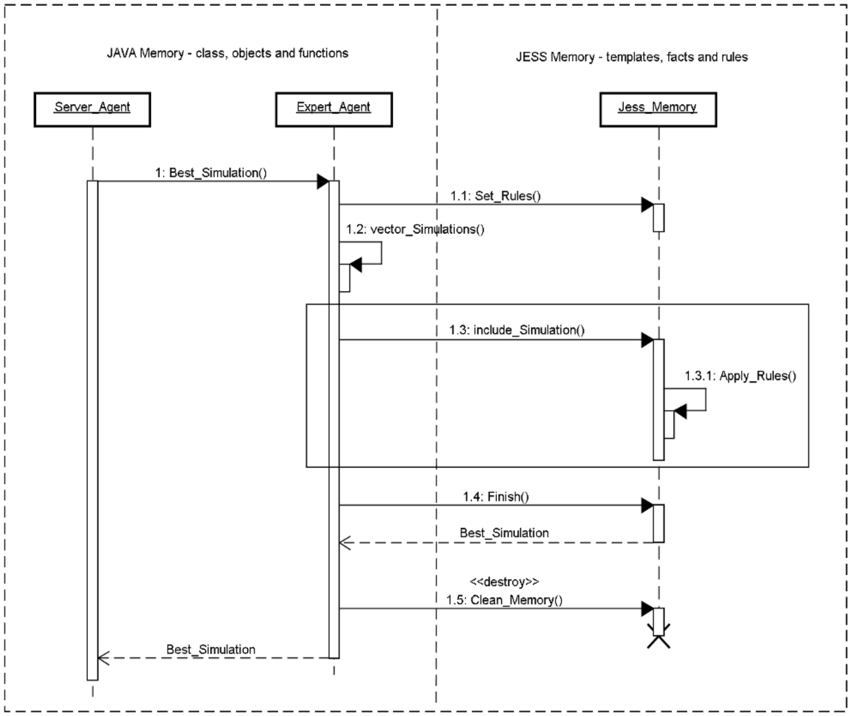


Figure 1. Expert Agent and its interface with JESS

Initially the Communication behavior of Expert Agent is blocked and remains in this state until the agent receives a Best_Simulation message from the Server agent. Upon receiving this message the Expert Agent invokes the setRules method, responsible for loading the selected rule –based on the criterion received in the Best_Simulation message to the JESS memory. Up to this point, three rules have been developed in the proposed prototype, all based on a response variable which can be used to establish comparisons between cases, the rules are: shorter makespan, shorter flow time, and shorter queue time. It is important to note that in order for a rule to be developed, it is necessary to instantiate JAVA classes as facts in the knowledge base of the Expert Agent, as well as instantiating the JAVA classes from the facts in the knowledge base of this agent. The double instantiation allows for a two-way communication between the JAVA memory and the JESS memory. Then, the Expert Agent invokes the includeSimulation method responsible to initiate a databank search for all similar simulations to the simulation to be controlled. This is done in a programming loop responsible for the selection of simulations with characteristics similar to the ones pre-established in the order. These simulations are then added to the JESS memory one at a time, after being instantiated as facts. This is necessary, because as a class is instantiated as a fact in Expert Agent´s memory, object and fact remain two separate entities, with the option of being associated to each other. Similarly, as a fact is instantiated in the JESS memory from a JAVA object, a pointer is created from which a fact can be recovered. During the loop, the fact base being created is scanned, applying a rule or a set of rules previously enabled by the Applyrules method in order to select the best simulation according to the selected comparison criterion, made available by the JESS memory to the Expert Agent through the BestSimulation object. Finally the Expert Agent invokes the BestSimulation method whose response is a reference to the BestSimulation class, which was previously instantiated by the Server agent, sending a message with the best simulation to the Server agent and clearing the JESS memory, preparing it for the next search.

3 Application Example

Following is an example of the difference in how production orders can be generated with or without a routing suggestion. Initially the Server agent receives a manufacturing order for three different parts, namely 3, 8 and 12, whose process plans are shown in Figure 2.

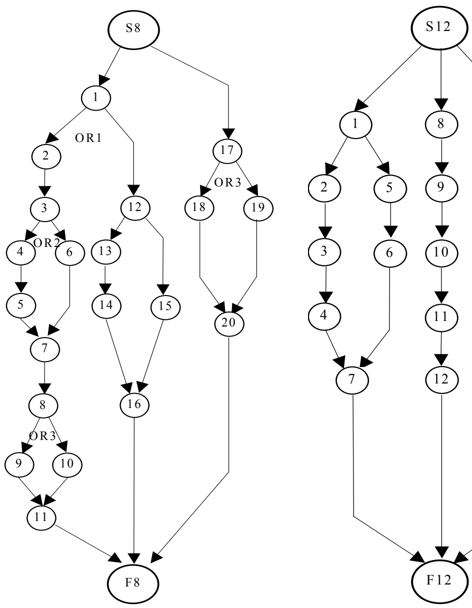
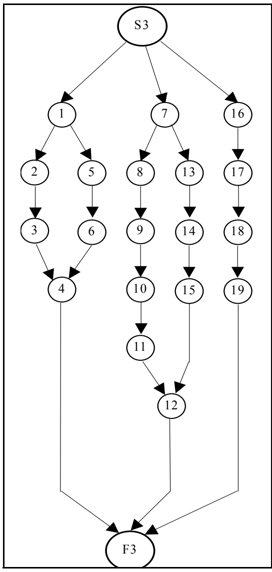


Figure 2. Routing suggestions from Makespan variable

The complexity of the problem by presenting the process plan for part number 3, as well as the alternative resources, for each operation, as illustrated in the Table 1.

Table 1. Routing suggestions from Makespan variable



Op	Resources				
1	R4	R7	R11		
2	R2	R8	R11	R12	R15
3	R1	R6	R7	R10	R14
4	R2	R3	R6	R7	
5	R 2	R3	R4	R5	R7
6	R 1	R7	R10	R12	R13
7	R 1	R5	R6	R13	
8	R 1	R12			
9	R3	R4	R5	R13	R10
10	R3	R4	R7	R12	R13
11	R2	R4	R9		
12	R1	R4	R9	R12	R14
13	R9	R14	R15		
14	R2	R4	R6	R7	
15	R1	R8	R12	R13	R14
16	R10	R15			
17	R10	R12	R13		
18	R6	R7	R9	R10	R13
19	R3	R8	R10	R14	R15

The characteristics of this order are the batch size which equals to 1, and the times for preparation, fixture, and setup which equal to 0.1. Upon receiving this order the Server agent goes into StartingSimulation state, switches its behavior to StartSimulation and invokes the previously described ask_for_Expert method. If the ask_for_Expert response is null, that is, it doesn´t find an Expert Agent registry, the Serve agent will proceed to function via createJobOrdersAgents method.

Three orders are generated, one for each part in the order received, being that in those orders the routing of the parts within the resources available in the shop floor will not be defined. That means that in the first round of negotiations between orders and resources, all alternatives in the process plans are considered. Therefore, part 3 will negotiate operations 1, 7, 16; part 8 will negotiate operations 1 and 17; and lastly part 12 will negotiate operations 1, 8 and 13, among all the available resources for the given simulation and with the capabilities to run such simulations.

However, if the ask_for_Expert method finds the registry of an Expert Agent, the message Best_Simulation is returned to the Sever agent with a routing suggestion based on the requested comparison criterion. In the case of the Figure 3, this criterion was the lowest value for the makespan response variable for the manufacture order of part 3, 8 and 12.

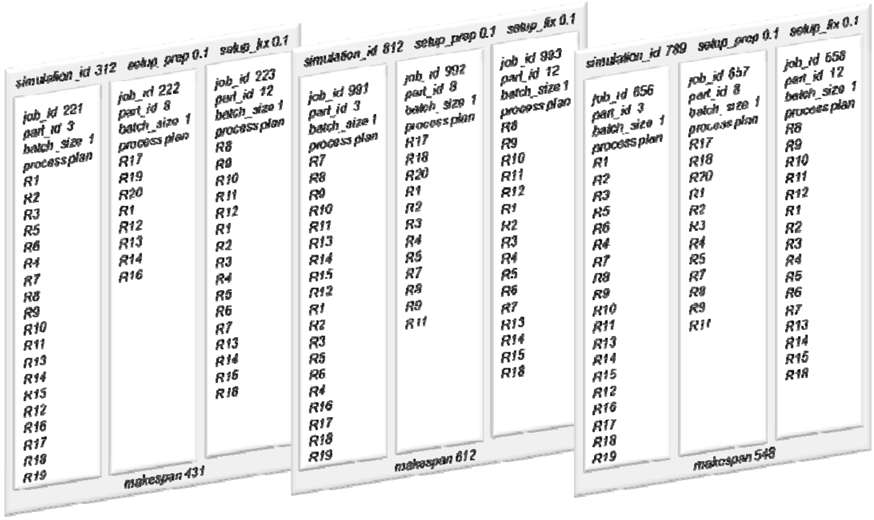


Figure 3. Routing suggestions from Makespan variable

By this criterion, we have three simulations, in which the characteristics setup_prep, setup_fix, part_id and batch_size meet order specifications. These simulations are 312, 812 and 789, and makespan values of 431, 612 and 548, respectively. Then the three simulations are ranked in order of best solution based on the selected criterion, presenting, in ascending order, that is, from best to worst, simulations 312, 789 and 812, as shown in Figure 3.

Finally, oriented by this ranking, the first round of negotiations between orders and resources will follow the routing suggestion in simulation 312, in which part 3 will negotiate operation 1; part 8 will negotiate operation 17; and lastly part 12 will negotiate operation 8.

4 Conclusion

This work proposed the integration of an expert system developed in JESS with a simulation model developed in JAVA, in order to reduce the standard deviation generated during the routing of parts in a job shop manufacturing environment.

The model allows the use of a large number of rules, and the increase of its complexity in order to optimize the routing of orders, and the effectiveness of the order sequence is evaluated through the makespan, flow time, and queue time.

The optimization degree allowed by the expert system depends mainly on: (a) the amount of available data; (b) the quality of the rules; and (c) how they can reflect the empiric knowledge of the process planners.

Finally, it is important to note that the term used is routing suggestion, because there´s no constraint in the generation of service orders in case the first round on negotiations cannot be implemented due to unforeseeable reasons, such as the non-availability of a certain resource. In this case the orders will be generated as usual, using all the alternatives in the process plans of the first round of negotiations between operations and the resources available in the shop floor.

For future works, in order to improve even more they obtained results, it is intended to add other artificial intelligence tools to the system, such as reinforcement learning and neural networks.

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Augmented Reality for Machinery Systems Design and Development

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Abstract. The paper presents the application of augmented reality to support product design and development. The paper concentrates on a new engineering tool. By this reason design and its issues are presented in a very limited way. The goal of the research was to improve design process and reduce product development time. The presented system bases on CAD software which is integrated with an expert system and augmented reality techniques as a human-computer communication interface. The authors present possibilities of using augmented reality technology in CAD design with the hope that maybe someday it would become integral part of a standard design process of more reliable and durable machinery systems.

Keywords. augmented reality, human-cumputer interface, CAD, reliability, computer-aided decision making

1 Introduction

A technical evolution causes that people design more and more complex technical objects with the use of methods and tools from various disciplines. A computer technology allows to improve efficiency of design and development process. Some problems (e.g. concerning on reliability of machinery systems) without computer-aided systems could be non-solved [12]. CAD systems are very useful tools to make allowance for reliability of products. The designer which makes some modifications (e.g. in power transmission system) is able to evaluate an influence of these modifications on reliability of the designed machinery system [12]. In addition to CAD more and more virtual and mixed reality (see [2] [3] [10] [14] [16]) techniques are used to improve and optimize the design and development process. Digital (virtual) prototypes are built at the beginning of a product development process. These virtual prototypes should be changed and modified easly to optimize the development process.

As always, to make a proper decision by the designer during design process (e.g. conceptual design) and evaluate reliability of a future product, it is important

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to adequate present (visualize) the product [3] [6] [16]. Thanks to modern visualization systems it is possible to maximize legibility of product models (e.g. possibility of visualization in 1:1 or higher scale). For that purpose the designer can use innovative tools of visualization: 3D monitors, virtual caves, head-mounted glasses etc. Over the last few years an innovative technology called augmented reality (AR) may be used for aiding designers in efficient way [2] [3] [6]. Augmented reality creates and environment where virtual (most often 3D) are inserted in a predominantly real world enironment (fig. 1).

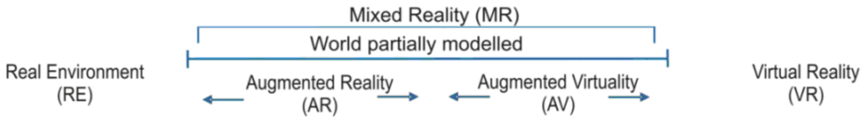

Figure 1 Reality-virtuality continuum [6]

AR technology can enhance a user's perception of the real world with information that is not actually part of the scene but is relevant to the user's present activity [1]. It provides a natural and intuitive means for user to work efficiently in the real worlds environment. Augmented reality systems allow to aid the user in his/her operation thanks to combing in one environment information about virtual and real world. Using AR techniques, the designer wearing HMD devices can move about in a phisical 3D space to view interactive 3D models that are being displayed from different perspectives.

Adapting AR to practical uses is connected with various problems (see reports included in [11]), especially concerning hardware technologies. There are still some problems to solve, but for industrial partners to be interested in investing into this technology its possible benefit and its integration into the whole company has to be visible. There are several reports of trying to apply AR in industry. In [13] the authors present research, development and deployment of AR systems in the automotive, aviation and astronautics industries. In [9] the author summarizes research realized by industrial AR (IAR) consortium which supports the augmented reality for development, production, and servicing in industry (especially in automobile industry).

In this paper the authors describe results of research on augmented reality technology to aid machinery systems design and development. The paper concentrates on a new engineering tool. The design process and its issues are presented in a limited way. The paper presents the results which are a continuation of the research initiated by the authors in 2005 [8].

2 Research background

Our research concentrate on improving CAD and development of machinery systems with the use of modern techniques of visualization. The new AR systems (as presented in this paper) may be considered in the support of concurrent engineering and remote and group collaboration methodologies. The goal of research was to elaborate a method and system for supporting CAD. The method should allow to improve efficiency (e.g. shortening of development time) of a design process and in effect design more reliable and durable machinery systems.

At the beginning the authors decided to elaborate some mechanisms of searching, collecting, processing of data (especially 3D models) necessary for the designer during designing of a new product. A method for knowledge/data representation which are necessary for the designer was one of the main challenge of the authors. These data should be concerned on existing constructional solutions. These data could be used by the user to design new products or improve existing constructional solutions in order to increase reliability. To solve the problem a simple expert system and a database were elaborated. Design knowledge is acquired from: domain experts, a professional/scientific literature or results of research (exploitation, laboratory etc.) collected in databases [7]. The expert system delivers to the designer knowledge about successive steps of the design process of a machinery system and practical solutions of realized constructional problems. Data adequate to solved problem (concerning on algorithm of design process) are displayed in a real environment (with the help of AR system) around the user while he/she is going to make some decisions.

An elaboration of a system for presenting knowledge and data to the user was the next research problem. The designer should be able to use data and knowledge from the system during a design process [15]. For that purpose AR as a tool to control a dialogue between the designer and the CAD system and the system aiding decision making could be used. The system should allow visualization of data about: existing constructional solutions, symptoms of failures and inefficiencies (e.g. exceeded limit of vibrations, noise, temperature, pressure etc.) in a previous version of a product, algorithms of design processes of selected group of machinery systems (e.g. mobile robots) or machinery parts and elements, critical points of the design process etc. Knowledge for the designer should be presented in form of: drawings, pictures, 3D models, schemes, tables, text or audio specification. In case of 3D models (not only, but especially) should be able to display them in any scale (especially 1:1 scale) with possibility of view from any perspective in a very intuitive way.

Using AR techniques in CAD causes some advantages. First of all is that the user has possibility to preview data (especially 3D models) in real environment, directly around users at any place, from any perspective (each of designers have own perspective), in any scale. AR also gives possibility of total interacting with displayed data by manipulation of position and orientation in a space around the user. It was proved in [14] that perception of 3D designs in better when changing views by observer movement than by model rotation (e.g. with the use of the standard monitor). AR mode for changing views of data - especially 3D models - allows the user to understand the prospective system in a more comprehensive way, thus making design process more efficient than the one supported by conventional present-day CAD systems [4] [5]. The designer has possibility for fast and efficient verification of designed products in order to increase reliability. Advantages of AR techniques cause rationalization of the design process: shortening development time, reducing development costs, improving utilization of existing constructional solutions and utilization of existing exploitation data [4] [5].

3 Overview of the proposed prototype system

The authors carried out an implementation of the prototype system for a design process of selected group of machinery systems – mobile robots. Although, it is also possible to build the system for any machinery systems.

3.1 Hardware and software components of the system

The basic component of the implemented system is a computer with MS-Windows® XP system installed. The computer runs Dassault Systemes CATIA V5R19 (modeling software) and a special elaborated AR application. The HMD with a small USB camera attached is connected to a video card of the computer. The video camera captures video of the real world and sends it to the computer. HMD allows to see data from the computer (e.g. 3D models, text etc.) in real environment surrounding the user. The user wears the HMD with the video camera attached, so that when she/he looks at the tracking card with a special marker through the HMD a virtual object is seen on it (fig. 2).

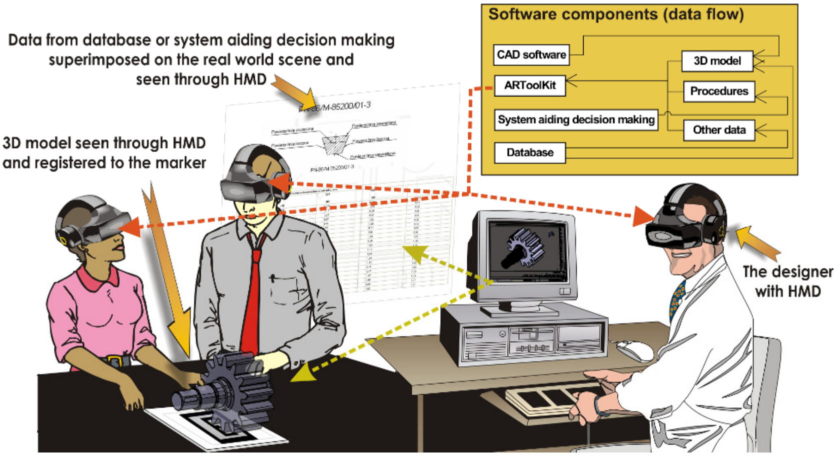

Figure 2. System for aiding the designer of machinery systems (components)

Very important and difficult part of AR system proposed by the authors is software. The presented system consists of: ARToolKit tracking libraries, VRML (Virtual Reality Modeling Language) parser, expert system (system aiding decision making) with database with 3D models (in CATPart or VRML formats), Dassault Systemes CATIA V5R19 (modeling software), a main application to integrate all software components and to realize system functions. The system base on the public-domain augmented reality tracking library called ARToolKit (from HIT Lab [17]) with LibVRML97 parser for reading and viewing VRML files. ARToolKit is a software library that uses computer vision techniques to precisely overlay VRML models (3D models, text, pictures etc.) onto the real world. For that purpose software uses markers. Each marker shows a different digitally-encoded pattern on it, so that unique identification of each marker is possible. In presented conception the markers are printed on the cards. We can compute the user's head location as soon as the given marker is tracked by the optical tracking system. Finally the main application allows to display data superimposed on the real world (exactly on the card with the marker position and orientation).

Thanks to an elaborated graphical user interface (GUI) users have possibility to e.g. (fig. 3): update knowledge in a knowledgebase (by a Knowledge Engineer), view instructions about stages of a design process of a mobile robot (the system aids the designer in a design process), preview data from a database (tables, drawings, pictures, text, voice or video information), use (by export to CAD system) existing 3D models to improve them, view results of designer's work (e.g. 3D models, results of simulations: kinematics, structural strength, thermal strength), in AR mode etc. All displayed information (especially 3D models) could be viewed in the real environment in full 3D mode and 1:1 scale.

3.2 Aiding decision-making

The main goal of the implemented system was to aid the designer of machinery systems for designing more reliable mobile robots. Knowledge (necessary during design process) to the knowledgebase is acquired e.g. from experts and inscribed in knowledgebase thanks to an electronic form. Knowledge (represented in procedural form) and data is used in the design process to eliminate causes of failures and inefficiencies in future products. Data is collected in the database. The designer can take advantage of data (3D models, drawing documentation, diagrams, BOM's, catalogue data etc.) or knowledge as often as needed (fig. 3c,d). In the database the data is collected in form of text, graphics, drawings, sounds, 3D models. The presented prototype system guides the designer during successive stages of the design process of a mobile robot.

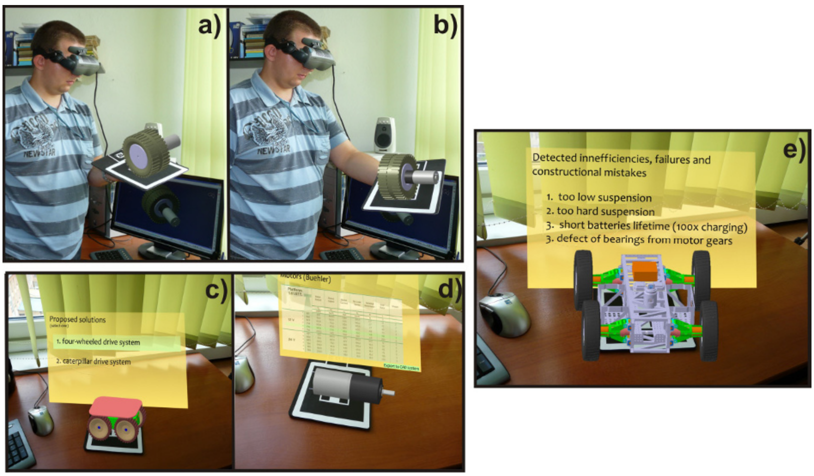

Figure 3. Main functions of the prototype system: a) b) viewing results of designer's work, c) d) previewing data from a database, e) viewing instructions or procedures concerning design process (AR system aiding decision making)

The system aids the designer in decision making with the use of a modern AR communication human-computer interface (fig. 3e).

The expert system aids the designer only in qualitative way, nevertheless future research are going to aid the designer also in quantitative analysis. Prompts inferred by the expert system after user acceptance are automatically applied in designed product

3.3 Aiding the designer - functioning of the system

In the presented conception of the system the user with HMD on the head sits in front of a computer. The user looks in the direction of the card with marker(s) through HMD and virtual objects are seen onto this card. As virtual objects the text information, 3D models, pictures, catalogue tables, drawings from the database or instructions from the knowledgebase could be displayed (fig. 3). Information displayed with the use of AR system are very helpful for the designer. In the same time the user can design the mobile robot in CATIA CAD system.

The user can view models of existing robots or components of robots in AR mode (in 1:1 scale, from any perspective). It is possible to export/import these parts between modeling software CATIA V5R19 and AR system. The designer in the CATIA's workplane can see the part and simultaneously this part could be seen in AR mode (fig. 4). When the design process is accomplished the user can preview results of his/her work in AR environement.

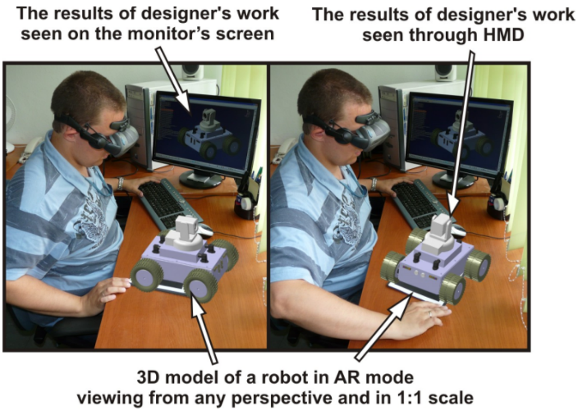

Figure 4. Previewing results of designer's work and manually manipulating the model for an inspection

The designer can manually manipulate the model for an inspection. It is also possible to export the models with results of analysis e.g. strength analysis and the others. Other designers if sit around a table with a marker and examine projects of a robot can also see a three-dimensional virtual image of the 3D model. The image is exactly aligned over the real world so the designers are free to move around the table and examine it (collaborative work) from any viewpoint. Each person has their own viewpoint to the model. They are also free to interact with the model in real time. All the helpful information from AR system and models of machinery systems are viewed by the user in the real environment from any perspective in a very efficient and intuitive way.

3.4 Verification

The verification of the system was realized only in an easy way because of early stage of the system development. Within a framework of a verification of research, some experiments depend on realization of a complete design process of a mobile robot were carried out. Experiments were realized with the use of presented in this article system and without. Some experienced and non-experienced designers were selected to take part in the experiment. Efficiency of the system was confirmed, thanks to shortening development time of an elaborated product (mobile robot). In the case of experienced designers the development time was shortened about 10%, while in case of non-experienced designers the time was shortened about 20%. As well, utility of the subsystem for aiding decision making during a design more reliable mobile robots was confirmed. The system allows for the designer to choose a better solution of the problem e.g. application of caterpillar drive instead of wheel drive, which was worse in previous version of a similar mobile robot to inspect ruins. Non-experienced designers have more efficient access to data and knowledge, so they are able to finish the design process faster than designers which don't use the presented system.

The system evaluation was carried out only on the base of special forms filled by designers after an experiment. Detailed verifications will be realized during further development of the system, and the authors are going to present the results in successive publications.

4 Conclusions

A development of AR technology in design (but not only, also in maintenance and diagnostics) has been initiated by the author and research team from Department of Fundamentals of Machinery Design few years ago [8]. The results of research confirm advantages from application of AR techniques in a design domain. AR mode for visualizing data and completely understanding the model content is more efficient, intuitive and clear than the traditional one (e.g. with the use of a monitor). By this reason the AR technology, as a kind of new user interface, introduces completely new perspective for the computer aided design systems.

Results of research confirm other potential advantages derived from the presented system using AR techniques, especially:

- extended efficiency of direct access to data and knowledge which is necessary during a design process,
- possibility of aiding decision making and delivering detailed design algorithms to improve reliability of designer machinery systems,
- an improved mechanism of making full use of existing knowledge and data (possibility of importing/exporting data between a knowledgebase/database and CAD system),

- possibility of presenting data necessary during a design process (e.g. tables, results of research, schemes, 3D models) and results of this process (e.g. final 3D models) in efficient way, with possibility of interaction with these data and viewing from any perspective and also in any scale (also 1:1 scale).

The presented system basing on the method of computer-aided design of reliable machinery systems and using AR techniques is in an early stage of development. However, advantages of systems based on AR confirm possibility of future introduce of augmented reality technology in design engineering enterprises.

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Development of a Virtual Environment to Implement a Computer-Based Tool for Interactive Simulation of Lathe Operation

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[b] The co-authors of the paper are employees of the Central Institute for Labour Protection - National Research Institute in Warsaw, the Safety Technology Department. They gained vast experience in the virtual reality-assisted research.

Abstract. In the paper presented is an action plan to create a computer-based tool for interactive simulation of lathe operation. The assumptions concerning a virtual environment are presented; the environment being functionally associated with the tool and the way to create computer-generated objects is described; the objects are forming complete metal shop working environment. The environment created that way in Quest software made it possible to undertake a number of actions (that are underway now) related with the environment development, in order to enable an interaction between its individual elements and to interface a number of pieces of peripheral equipment (i.e. data gloves, Head Mounted Display (HMD) and tracking system) to the tool under construction. This way a tool will have been built that makes use of virtual reality technology in order to conduct real time research oriented at accident situations encountered while operating lathes. The tool will enable educational and training processes aimed at future lathe operators to be enriched and will provide the opportunity to operate interactively a virtual lathe. It will also make it possible for the trainee to participate personally and in non-traumatic way in pre-arranged accident situations and will give an opportunity to present such situations in the most realistic manner.

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Keywords: Mechanical hazards, virtual reality (VR), lathe.

1 Introduction

Working at lathe involves many mechanical hazards mainly because of the possible direct contact of the operator's hand with moving lathe chuck and a work piece. The hazards may provoke very severe injuries to the operator's body resulting from being struck, trapped, dragged in, cut and severed. The issue ranks high and is evidenced by 375 accidents that happened at work while operating lathes. From the statistical reports issued by GUS (Central Statistical Office of Poland) it appears that one of their main reasons is lack of experience of lathe operators with less than 1 year practice in operating lathes (26 % of the total number of the accidents). Therefore any preventive actions are of high importance including the ones that enhance the knowledge and skills of the operators as early as in vocational education or training

The virtual reality technology [VR] is more and more widely exploited [1, 2] for the purpose of machine and equipment operators (e.g. of locomotive, forklift, construction equipment and vehicles operators) and welders training. It is obvious that using VR technology will not be a substitute for hands-on-the-machine training; however it will allow the operators to gain the knowledge and skills faster. This will be achieved owing to visual observations of dangerous events occurring at the machine they operate, by thorough understanding of the reasons and circumstances behind the accidents, by improving their skills to run the particular machine and by inducing proper safety-based behaviour while operating the lathe in the virtual environment.

The subject of the paper is to present actions undertaken in order to develop a virtual environment for the purpose of implementing a computer tool (now under construction), for simulation a lathe operation. This tool is going to be made use of in order to investigate the situations that stand behind accidents occurring when operating lathes and to conduct trainings that form good habits among operators thereof.

The tool will have been developed using innovative solution based on VR technology. It will allow the person immersed in the virtual environment to have an impression of participating in the simulated machining process and in accident situations in the virtual environment.

2 Plan of action to create the tool for interactive simulation of lathe operation

Before the tool for interactive simulation of lathe operation was developed the plan of action to create the tool had been made (Fig.1.). The action plan has been developed on the basis of the analysis of typical accident situations encountered in metal industry, after the reasons thereof were identified. In the plan also taken into account were the results of an analysis that covered market-available tools needed to develop a virtual work environment, within which the interactive simulation of lathe operation will took place.

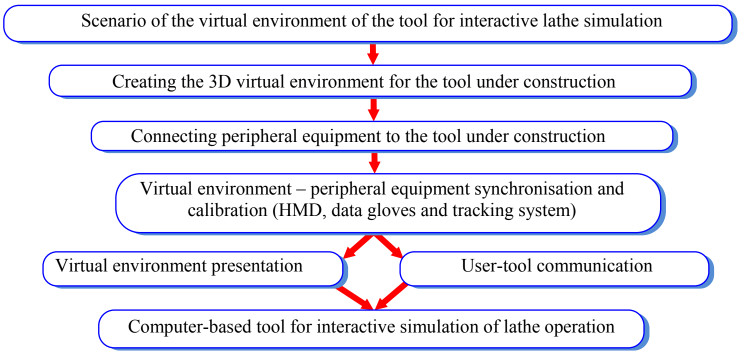

Figure 1. Plan of action to create the tool for interactive simulation of lathe operation [1]

Within the plan assumptions were formulated concerning the ways of making the tool and its associated virtual environment and equipment. A method of peripheral equipment functioning (data gloves, HMD, tracking system) has been established; the equipment being interfaced with the tool in order to effect an interactive communication between the user (operator) and the virtual work environment
(Fig 2). Thus the operation of the virtual lathe and virtual machining process will be made possible.

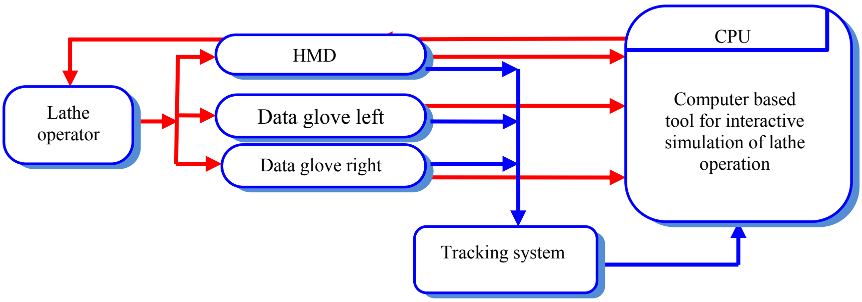

Figure 2. Functional diagram for peripherial equipment in the system of operator – tool for interactive simulation of lathe operation

3 The virtual environment to implement a computer-based tool for interactive simulation of lathe operation

Basing on the plan of action developed to create the tool and on the formulated assumptions concerning the machine-shop virtual environment, work began to create the tool for interactive simulation of the lathe operation. The tool was made using Quest 3D VR Edition program from Act-3D (Photo 1). The program is a software with a 3D graphical engine and graphical environment enabling real time movement within the virtual environment.

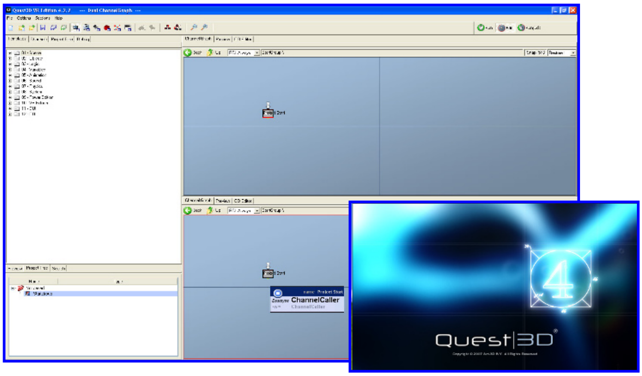

Photo 1. Editor window of Quest 3D program with the start screen

To develop the tool for interactive simulation of lathe operation, first a graphical structure of the tool was created in the form of the so-called *tree-structure* (Photo 2. item 1). The structure is built by linking together individual modules (Photo 2. item 2) called "channels". These modules are nothing more than ready-made function library routines which make it possible to create interactive 3D applications and connect peripheral equipment (i.e. data gloves, HMD, mouse, joystick etc.) with the applications.

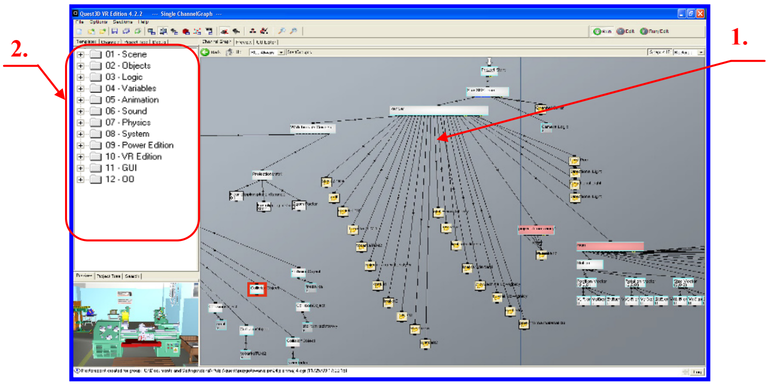

Photo 2. View of the graphic tree-structure (1) in Quest 3D edit window, and module windows (2)

In order to build the tool for interactive simulation of lathe operation, a number of modules were made use of, among which the most important were the *"Scene"* module to start the virtual environment creation (including among other things *"Rendering"* to render all the environment in the real time, *"Lights"* to lighten the environment, *"Cameras"* to watch the events in the virtual environment), and *"Objects"* to create basic 3D models and to connect and arrange in the environment being created the 3D models imported from other applications. In addition, the following modules were used to create the tool: *"Collision"* that enables to enter collisions between objects belonging to the virtual environment, and *"Animation"* to generate movement of the operator's model and other elements of the working environment including machine parts. To create the interactive tool itself, the modules listed below were made use of: the *"System"* module to run dynamic simulations, e.g. chuck wrench being thrown out from the chuck; *"Physics"* – an engine of physical phenomena, e.g. gravitation, *"VR Edition"* to connect the peripheral equipment with the tool being created and *"GUI"* (Graphical User Interface) to create an interface to manage the interactive tool.

3.1 Virtual working environment of the machine- shop

In order to build the virtual environment, first a 3D scene "*Start 3D scene*" (Photo 3. item 1) was created to which "*Render*" (Photo 3. item 2), *"Light"* (Photo 3. item 3) and *"Camera Logic"* (Photo 3. item 4) modules were linked to render lighting and obtain an initial preview of the scene under creation. In this way, the basis for virtual environment development was created for the purposes of the tool for interactive simulation of lathe operation.

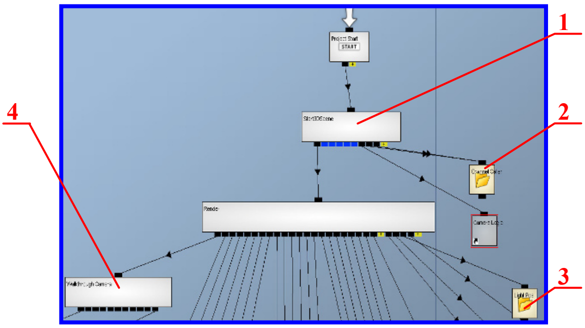

Photo 3. Modules of the graphic structure of the tool for interactive simulation of lathe operation: 1. Start 3D scene, 2. Render, 3. Light, 4. Camera Logic module

To the ready 3D scene that prepared in this manner there were imported foreground and background objects formed by means of 3Ds Max software from AutoDesk [5], this creating the virtual working environment of the machine-shop (Photo 4.).

The foreground computer objects are the ones that belong to the working environment and are located in the user's working area, like the TUK-40 lathe and the work station equipment i.e. containers with semi-finished products and discards, a partition, the chuck wrench, a wooden platform etc. The objects (Photo. 4) were made so as to resemble as close as possible their real working environment counterparts, including colouring and size.

The background objects are the working environment components situated at some distance from where the user (operator) of the tool for interactive simulation of lathe operation is located. They have been done with less detail, but their colouring, proportions, shapes and contours have been preserved.

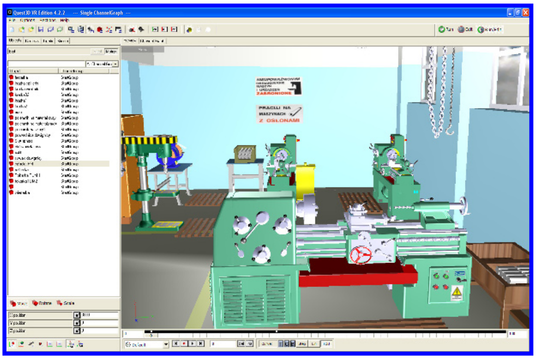

Photo 4. A part of the computer-generated machine-shop working environment imported into Quest software

The components of the computer-generated lathe model (Photo 5.) and the equipment in the vicinity of the machine were transferred to the Quest program with a separate operation. This is because the components have to be given „active" status (for the sake of interactivity) that enables the tool user (operator) to act on them (i.e. to press pushbuttons, set levers, pick the chuck wrench or work piece and put it somewhere else, open the chuck guard and lower it back, etc.) and because movements within the virtual environment are to be provided (i.e. switching chuck/lead screw rotation on and off etc.)

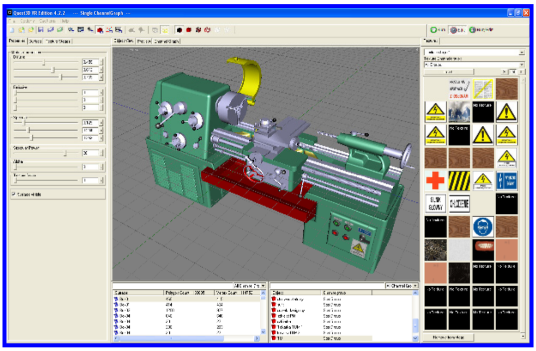

Photo 5. Quest 3D editing window with the imported lathe model

After having completed the setup and edition of the virtual environment objects, the next steps were performed concerning the software to operate the "*Walkthrogh Camera*" (Photo 6. item 1) in the virtual environment. Then, various parameters were set as follows: the speed of the camera being moved in the virtual environment, height of framing when observing the events staged in the said environment, and collisions with the virtual environment objects (Photo 6. item 2), and camera reset (Photo 6. item 3), etc. Photo 6 shows the tree-structure that enables the camera to be moved within the virtual environment.

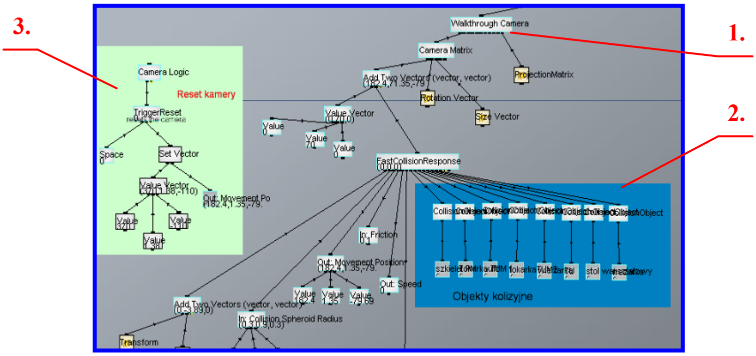

Photo 6. Tree-structure module of Walkthrogh Camera (1) including collisions with the virtual environment objects (2, and camera reset (3)

The virtual environment of a machine-shop and made with Quest software made it possible to do activities aimed at creation of computer-based tool for interactive simulation of lathe operation. At present are underway the activities concerning:

- machine-shop virtual environment software (for example two additional cameras giving VE images for HMD, interaction between environment objects),
- interfacing the peripherial equipment [data gloves (Photo 7.1.), HMD (Photo 7.2.) and tracking system (Photo 7.3.)] to the tool.

Synchronisation of the equipment with the virtual environment and its calibration will be the next step.

Photo 7. Peripheral equipment: 1. 5DT data glove, 2. eMagin Z800 HMD, 3. POLHEMUS tracking system

At the same time developments are underway to program the collisions that occur in the virtual environment between the peripheral equipment used by the tool user (operator) and TUK-40 lathe controls and work pieces. As the last step to create the tool for interactive simulation of lathe operation, an interface to manage the tool will be made.

4 Summary – discussion

The tool being developed will make it possible to undertake research projects and to train lathe operators.

The first action line where the tool under creation may be made use of is the research oriented at accidents occurring while operating lathes. It shall be feasible to conduct real-time research when operating the virtual lathe. The research shall cover the causes and circumstances of accident situations and impact of employee conduct on the occurrence of accidents (e.g. accidents resulting from inappropriate movements of the upper limbs, improperly mounted work piece or tool, etc.) During the research, it will also be possible to determine how malfunctioning, incorrect or damaged safeguards contribute to the occurrence of accidents. The collected data will allow undertaking proper preventive actions in order to improve the safety of lathe operators.

Within the second action line, the tool may complement trainings of young lathe operators who begin their work at the machines and may help to improve the skills of experienced turners. Interactive participation in the process of virtual lathe operation will have a positive effect on improving their lathe-turning skills faster. Moreover, in-person observation of the accident situations encountered while operating lathe in the virtual environment and of the reasons thereof will make their hazards consciousness deeper and will help them to gain more knowledge regarding accident causes.

Furthermore, the tool under creation will allow running simulations of dangerous dynamic phenomena related to accidents that may happen when operating lathes. It is not feasible to run this type of simulations at the real workstations or during training.

In the near future, it is planned to start activities aimed at connecting the ready-made tool with a real-world lathe in order to create a lathe operation simulator. Such connection will allow the person immersed in the virtual environment to feel the lathe controls by hand, making the whole cutting process simulation more realistic. Therefore, during development of the tool presented in the paper, great emphasis has been put on the accuracy of lathe controls mapping and the behaviours thereof, in order to make the lathe controls (to be operated by the users of the tool i.e. turners) as realistic as possible.

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Interoperability of Complex Business Networks by Language Independent Information Models

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Abstract. With the demand of globalization, the opportunities for collaboration became more evident with the effect of enlarging business networks. In such conditions, a key for enterprise success is a reliable communication with all the partners. Therefore, organizations have been searching for flexible integrated environments to better manage their services and product life cycle, where their software applications could be easily integrated independently of the platform in use. However, with so many different information models and implementation standards being used, interoperability problems arise. Moreover, organizations are themselves at different technological maturity levels, and the solution that might be good for one, can be too advanced for another, or vice-versa. The work presented in this paper responds to the above needs proposing a framework for model language independent P2P mappings on a need-to-serve basis for interoperability of complex business networks.

Keywords: interoperability, model morphisms, collaboration networks, MDI, sustainability

1 Introduction

Nowadays, more and more enterprises realize that one important step to success in their business is to create new and innovative products. Many times the solution to do that is to abandon the idea of an enterprise as an "isolated island", and get collaboration with others: worldwide non-hierarchical networks are characterized by collaboration and non-centralized decision making [1]. This increases the autonomy of hub organizations, enabling different rules and procedures within the business network, but decreases the effectiveness in terms of integration and interoperability [2]. Interoperability is a property directly related with the heterogeneity of model languages, communication capabilities, databases and semantics. Differences in these hide a great barrier to achieve the time-to-market symbiosis that can unleash a solution more valuable than the sum of its creators [3] [4] [5] [6]. Interoperability is more than just a communication support: it is a software approach to maximize the benefits of diversity, rather than to integrate the different system into one. Such diversity leads to more fruitful results than by just

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integrating different systems into one. Since many organizations developed and purchased software solutions based on their own needs, the required cooperation with others is not a trivial activity and business partnerships are less effective, evidencing low level of interoperability.

In many scenarios common to SME-based industries, most goods are still handed-off through faxes, phone calls, paper documents, and a wide range of proprietary systems [1], [7]. This way, despite of the available edge-breaking research and development, and the different types of advanced interoperability practices described in [2], many organizations are not yet ready for these technologies, as adopting a complete standard for data exchange, or a full ontology to enhance semantic interoperability.

To solve this problem, instead of adopting a paradigm that obligates every organization to migrate their systems, or develop complex mappings in a single step to comply with these advanced practices, one can act at the communication module, where the data is exchanged. Hence, it is possible to establish gradual P2P relationships on a need-to-serve basis for interoperability of complex business networks, by language independent information models. This paper addresses research on this subject, proposing a conceptual model common to the entire business network, in a framework that enables the abstraction of individual models at their meta-level and increase language independency and interoperability, keeping all the enterprise software's integrity intact. The strategy presented allows an incremental mapping construction, to achieve growing integration.

The authors propose Model Driven Architecture (MDA) based technologies for the development of transformations and execution of automatic and executable Model Morphisms, also providing traceability and repeatability on them. The proposed framework enables to respond automatically to the network dynamics and its sustainability, i.e. changes that occur over the time and impact negatively the interoperable state can be tuned and balanced. In Section 2 the paper introduces ongoing solutions to attain model interoperability, and to deliver executable basis of model transformations; Section 3 defines the concept of model morphisms and introduces formalization for transformations; Section 4 proposes a framework based on a conceptual meta-model, and defines mappings for an EXPRESS meta-model; In Section 5 the case study scenario is presented illustrating where the research has been developed; Finally, in Section 6, the authors conclude and outlook on future work.

2 Model Driven Interoperability

Model Driven Interoperability (MDI) is a framework to solve interoperability problems between enterprises' applications and software systems, through the extensive use of models in vertical and horizontal integration of the multiple abstraction levels defined in the MDI's Reference Model [8] [9]. As detailed on Figure 1, it introduces different conceptualization levels to reduce the gap between enterprises models and code level during the model transformation of MDD and MDA sub-domains. Model Driven Development (MDD) is an emerging practice for developing model driven applications. Its defining characteristic is that `software development focus on models rather than computer program functionalities [10]. This way it is possible to express information models using concepts that are less bound to the underlying implementation technology and closer to the problem domain relative to most popular programming languages. One key premise behind MDD is that code is automatically generated from the corresponding models. This makes information models easier to specify, understand, and maintain, thus widening the creation of new systems to domain experts.

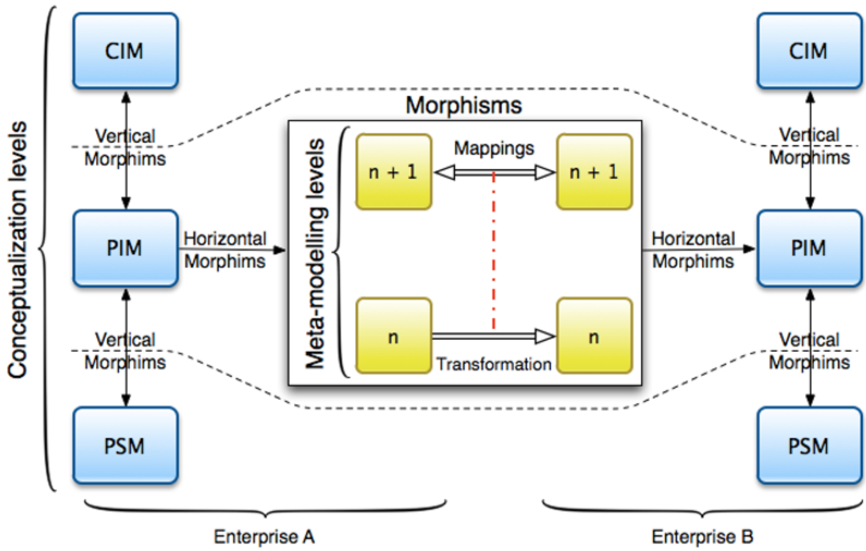

Figure 1. Level of Model Driven Framework

2.1 Model Driven Architecture

Model Driven Architecture (MDA) [11] is the basis for MDI and MDD. It has as its foundation the design and implementation of different kinds of systems by means of performing successively model transformations as automatically as possible. This architecture defines a hierarchy of models at three different levels of abstraction (see Fig. 1): the Computation Independent Model (CIM), which describes the business context and requirements for the software systems; the Platform Independent Model (PIM), which describes software specifications independent of execution platforms; and the Platform Specific Model (PSM), which describes the realization of software systems [12] [8].

When performing a model transformation (e.g. converting instances of a model to instances of another model) an explicit or an implicit mapping of the "meta-model" has to be performed [13]. Thus, the idea that when performing a transformation at a certain level "n", this transformation has (implicitly or explicitly) to be designed by taking into account mappings at level "n+1".

Any model considered in MDA must be an instance of a well-defined meta-model, and can be classified according to the meta-modeling level they belong to: **Level 0** - model level that is not possible to instantiate, it is called in various way such as instance level or ground level (e.g., instances); **Level 1** - model level that has to be instantiated to obtain ground instances (e.g., UML model); **Level 2** - known as the meta-model and describes the language itself (e.g., UML language); **Level 3** - meta-meta-model, where models are the base for generating different languages (e.g., MOF).

Once the "n+1" level mapping is complete, executable languages (e.g. ATL, QTV, Xtend) can be used to implement the transformation [14] [15] [16]. As described in the center part of Fig. 1, a transformation at the "n" level, can be executed automatically. For instance, when applying ATL to an UML profile, the transformation from the original information model to the destination one is executed, semantics are preserved, traceability and reverse operations enabled [12].

2.2 Executable Transformation Languages

There are several transformation languages with support for automatic model transformation execution. Some of these are based on the Object Constraint Language (OCL) [17], like Atlas Transformation Language (ATL) [14] and MOF Query/View/Transformation (QVT) [15].

QVT is a hybrid declarative and imperative transformation language. It supports bidirectional transformations, and allows model to model only transformations, conforming to any MOF 2.0 meta-model. This means that model to text, or vice-versa, is simply not supported. ATL is inspired in QVT. This way it is also a hybrid of declarative and imperative transformation language. The difference is that it can only be used to do unidirectional syntactic and semantic translation. An ATL transformation is composed by a set of rules that define how the source model elements are linked and navigated enabling and instantiating the elements of the target model. Non-OCL based, Xtend/Xpand [16] is a JAVA looked-alike transformation language, which is now a component of the open development platform Eclipse.

From the three languages, ATL has the largest user base and it is very well documented, as well as it has a good JAVA integration, but nevertheless it is neither a standard nor a simple language to use [18].

2.3 UML Profiling

An UML [19] profile is an UML package stereotyped "profile", which extends the UML language to accommodate new constraints, syntactic elements, or even to restrict it. It can be used as an extension of a meta-model, another profile, or even to define a new language without the need of creating it from scratch [20]. Typically an UML Profile is made up of three basic mechanisms [12]:

- **Stereotypes**: are specializations of the meta-class "Class". They define how it can be extended and may extend one or more meta-classes;

- **Tagged Values**: properties of a stereotype and are standard meta-attributes;
- **Constraints**: are conditions or restrictions expressed in natural language text or even in a machine readable language such as OCL [17].

To define a profile one has first to declare the set of elements and their relationships, as well as a description of their semantics, i.e., a meta-model. As envisaged by MDA (see above), only then can be defined the mapping of these new concepts onto UML (either meta-model, profile or language itself), by applying the profile's set of basic mechanisms to the meta-model, linking it to destination model basic constructs. Once the Profile is well defined, an executable transformation language can be applied to it (e.g. ATL) and achieve morphism automation from a model conforming to the defined profiled meta-model. The final result is an UML model, which also conforms to the profile created.

3 Model Morphisms

"Model Morphism", originally from mathematics, is the abstraction of a structure-processing process between two structures, but applied to data models [13]. Thus, this new usage of "morphism" specifies the relationship (i.e. mapping, merging, transformation, composition or abstraction) between two or more model specifications that may be described in different languages. Since models can be attained from several different modeling languages with different syntaxes, expressive power, formal semantics, meta-models, etc, achieving a lossless expressiveness "link" between two models unleashes a new potential interoperability on a heterogeneous community. Model Morphisms can be classified in: non-altering and altering morphisms [21]. From now on, let M be the set of all inner-relationships of a model's elements in some language.

Model non-altering morphisms are based on the concept of traditional *model-mappings*, where no changes are applied to the source models and relationships are identified among two or more existing models. These relationships can be assigned as 1-to-1, 1-to-n (where an element represents a sub-graph of relationships of the other model(s)) or even m-to-n. Formalization: "A non-altering morphism is a relation $\phi, \forall_{A,B \in M}$, where $\phi \subseteq \text{Sub}(A) \times \text{Sub}(B)$, where $\text{Sub}(X)$ is a sub-graph of relationships of X".

Model altering morphisms can be viewed as functions applied to specific models (operand) that relate a set of rules (operator) to modify the operand into a new model (output). They can be divided in two categories, i.e.: *Model transformation* (see Fig. 2), where the source model (A) is modified by a function Ŧ in order to obtain a new output model (B) expressed, or not, in the same language. Formalization: "$\forall_{A,B \in M}$ and a function Ŧ: $M_1 \rightarrow M_2$, a model altering morphism is Ŧ, having Ŧ(A) = B"; *Model merging*, which occurs when multiple models (e.g. A and B) act as input for the model transformation, preserving all original semantics from the input models. Formalization: "$\forall_{A,B,C \in M}$ and a function Ŧ: $M_1 \rightarrow M_2$, a model altering morphism is Ŧ, having Ŧ(A,B) = C".

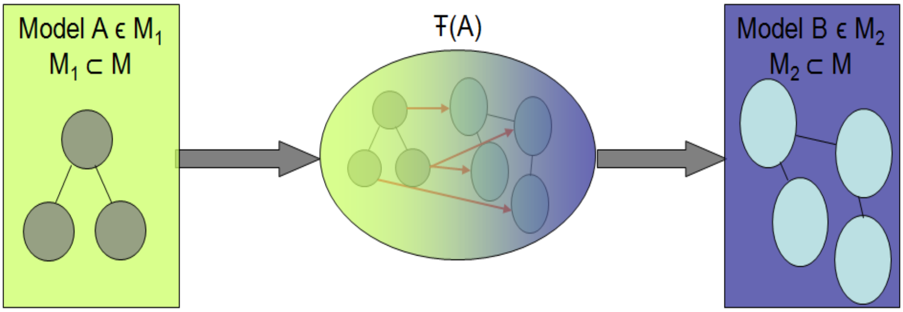

Figure 2. Model Transformation [21]

4 Framework for Model and Language Independency in Multi-sized Business Networks

To enhance interoperability in complex business networks, as well as business and information model integration adapted to the companies' needs, organizations require mechanisms capable of abstracting the model from the technology in which it is described. If that would be the case, more organizations could enlarge their business networks without having to make huge investments on specialized personal and tools to handle technologies they are not aware.

This way, the authors propose a framework that enables organizations to achieve model language independency. Without this obstacle, it will become possible to establish gradual P2P mappings on a need-to-serve basis, independently of the language their information models are described on, and the number of business relationships within the collaboration networks they are part of. The proposal is based on a four level structured relationships between meta-meta-models, meta-models, information models and data (see Fig. 3). The left-hand side of the figure represents the organization's internal models, whereas the right-hand side represents the common UML base which will serve as a standard during the mapping establishment within the collaboration network.

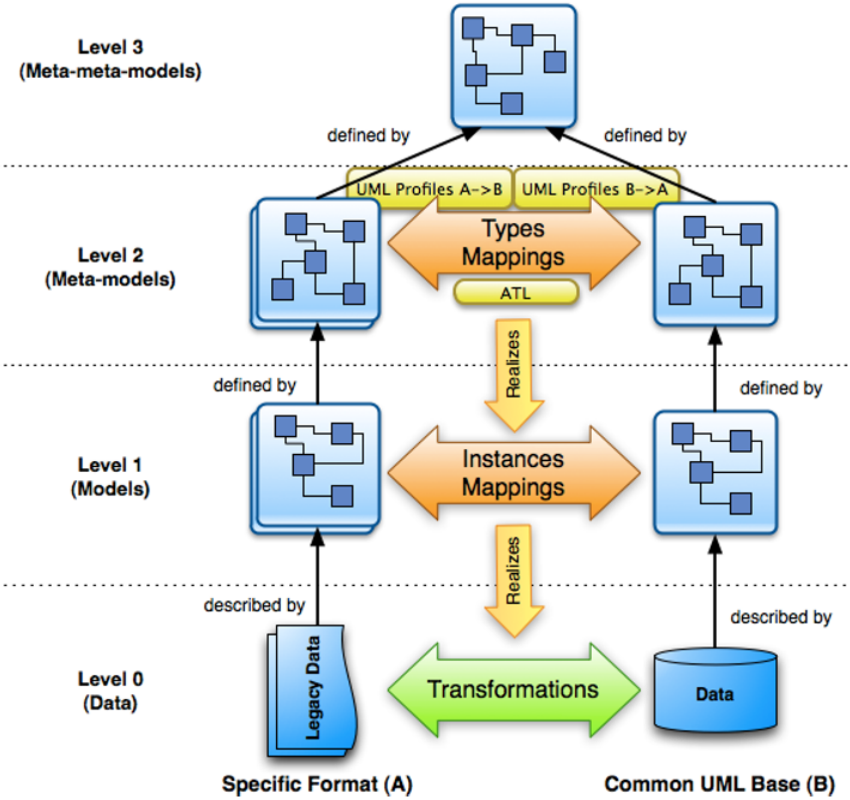

Figure 3. Framework for language independency based in MDA

Using an UML profile at the meta-model level (Level 2 of the MDA), it's possible to map any organization's information model (Level 1), which can be described in any specific format, to a common UML base (e.g. to an UML meta-model – our conceptual meta-model) on the right-hand side. Since ATL can be applied to UML profiles [12] [22], automatic model transformations at the model level are attained (Level 1). This way, one can represent multiple models on the common UML base, and if there is an UML profile defined for each origin model language, multiple models from multiple languages can be represented by equal number of instances of the conceptual meta-model.

Consequently, using the proposed framework, the language mapping procedure is a manual process, but the language transformations are always automatic and repeatable. Considering that the number of languages used for information modeling is not so high, it is an acceptable cost.

The process of mapping between different information model structures at the conceptual meta-model instances (i.e. Level 1) is not part of this solution at this point yet. However, with such a framework, the complete automatic data exchange and translation can be accomplished between different model instances at the Level 0, thus completing the base for sustainable systems interoperability. All mappings of Level 1 can be stored on a local knowledge base, enabling to gradually add more mappings with other enterprises, and edit or even delete past mappings. A scenario explaining the complete picture is included in Section 5.

4.1 Conceptual Meta-model

The conceptual meta-model proposed is described as an UML meta-model in Fig. 4. It was intended to be simple and generic to support multiple language mappings, with as little loss of expressiveness as possible.

Many of the information modeling of languages, e.g. EXPRESS [23], UML [19], OWL [24] and XSD [25], have been analyzed in detail. They were the focus of the authors' attention to create this meta-model, and as far the mappings defined for those languages demonstrate, the conceptual meta-model is comprehensive enough to support them. Indeed, it is possible to represent all major concepts like entities, attributes, basic types, aggregations, etc. Nevertheless, some explicit non-supported elements also exist, such as expressions and functions from the EXPRESS language, but they are not fundamental for the following process which is focused on the information model mapping at the Level 1 of the framework.

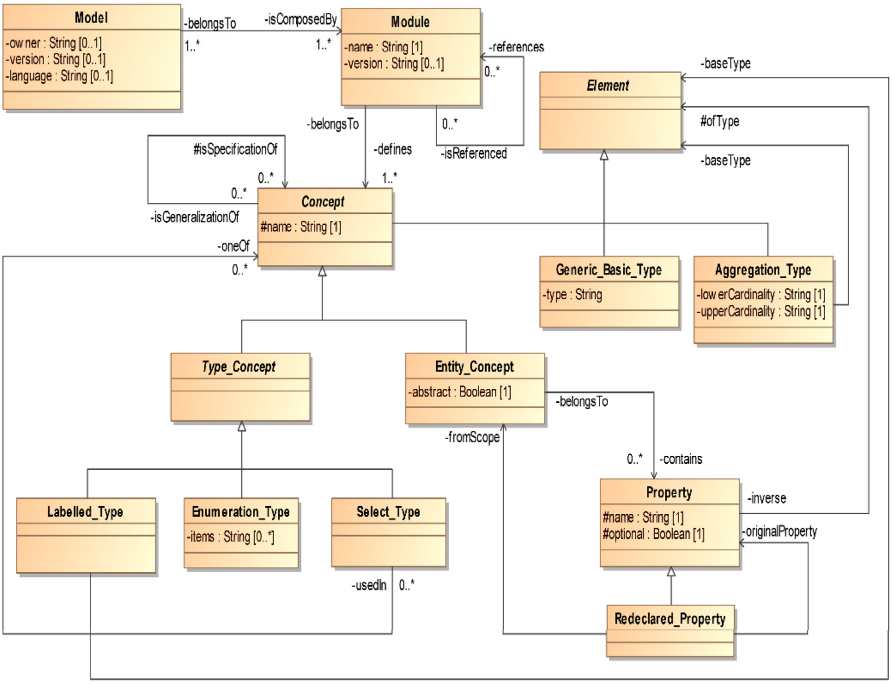

Figure 4. Conceptual UML Meta-Model proposal

4.2 EXPRESS Profile

EXPRESS (ISO 10303-11) [26] is a modeling language combining ideas from the entity-attribute-relationship family of modeling languages with object modeling concepts. It can represent complex inheritance relationships and functions, and includes a rich set of constructs for specifying constraints on populations of instances [27]. EXPRESS also provides general and powerful mechanisms for representation of inheritance among the entities constituting the conceptual model.

For more than 20 years, the International Organization for Standardization (ISO) has been pushing forward the development of standards and models [28], and efforts like STEP (STandard for the Exchange of Product Data), have tried to deal with integration and interoperability issues. Nowadays, STEP encloses a number of information standards which provide neutral mechanisms that are capable of describing products throughout their life cycle (PLC). However, the extent of standards required to support all the detailed characteristics of systems in the PLC, leads to highly complex models, i.e. Application Protocols (APs) described using the EXPRESS language.

However, despite of the potentiality of STEP, its success is limited to the large industries. Smaller sectors dominated by small and medium-sized organizations have been evidencing reluctance in moving towards such kind of standards. They claim the technology is too complex, hard to understand and expensive, since only a small set of tools work with STEP [21], [27], [3].

This way, the authors consider that EXPRESS is a relevant case study for the framework, since organizations that implement STEP standards might also need to keep on doing business with smaller organizations that don't, and vice-versa. A complete mapping between EXPRESS and the conceptual meta-model was made based on the OMG EXPRESS meta-model standard [23], and defined in a UML profile as part of the framework presented above. Due to space constrains only a part of the EXPRESS "EntityType" mapping is presented.

Table 1. EXPRESS's "EntityType" partial mapping to the conceptual meta-model (extract)

EXPRESS Concepts	**EXPRESS Meta-model [23]**	**Conceptual Meta-model**
For each ***SchemaElement as EntityType***	**EntityType**	**Entity_Concept**
	(InvertibleAttribute) EntityType.attributes	NOT MAPPED
	EntityType.isAbstract	Entity_Concept.abstract
	(EntityType) EntityType.subtype-of	(Entity_Concept) Entity_Concept.isSpecificationOf
SchemaElement.id == ((SingleEntityType) EntityType.declares).id	((ScopedId) ((SingleEntityType) EntityType.declares).id). localname	Entity_Concept.name
	(Attribute) EntityType.local-attributes	(Property) Entity_Concept.contains
Property as Redeclared_Property	(Redeclaration) EntityType.redeclarations	(Redeclared_Property) Entity_Concept.contains

In the first column, EXPRESS concepts are selected from [23] and specialized through the various types they support (e.g. “SchemaElement” as “EntityType”, where “EntityType” is sub-type of “SchemaElement”). In the second column, the various attributes are selected in order to map to the corresponding element(s) on the conceptual meta-model (the third column). The notation used, allow the authors to identify both the origin and destination of a class relationship, e.g. “(Attribute) EntityType.local-attributes”, means that the “local-attributes” belongs to the “EntityType” class and links with the “Attribute” class.

5 Achieving Interoperability in Dynamic Collaborative Business Networks

Our proposal to achieve interoperability of complex business networks by language independent information models, presented in section 4, relies on a scalable framework which enables to define information morphisms and accomplish automatic peer-to-peer communication with business partners at execution time. To obtain a fully automatic communication between two enterprises, both models and semantics must be mapped at some point. Fig. 5 illustrates a typical application scenario that can be applied to most business collaboration networks, e.g. supply chains, where retailers and e-marketplaces need to be interoperable with manufacturers to publish their catalogues and sell their products, e.g., manufacturers need to be interoperable with their suppliers to obtain a wider configurability on their products, and with designers for more innovative structures, and similarly down the chain. Let’s say that in this scenario two enterprises (A and B) represent a manufacturer and a retailer, and the first is publishing its product catalogue:

(1) The first step towards reaching an interoperable state involves model translation to a common language of understanding and vice-versa, thus achieving the envisaged language independency. In our solution, this step consists in doing a transformation of the enterprise A model(s) language to an UML instance of the conceptual meta-model of section 4.1 (M2N morphism: Model to Neutral Language), as well as the opposite procedure (N2M morphism: Neutral Language to Model). By applying the profile presented in Section 4.2, this would refer to the M2N translation of an information model (A), represented using the EXPRESS language, to UML using a comprehensible neutral structure that reorganizes A just with high level concepts such as “Module”, “Entity”, “Property”, etc. Once the profile that enables this transformation is defined it can be used to generate an executable transformation language rules, e.g. ATL;

(2) The second step is the repetition of the fist but focusing on Enterprise B;

(3) The third step starts once both enterprises have their models represented at the conceptual language (CM_A and CM_B), where the model mapping and semantic matches begins. All relations between the two models must be established by a business expert, and registered in the form of rules in a local knowledge base (KB) that contains all the mappings with the organization’s business partners. This also enables gradual mapping on a need-to-serve basis since the KB can store the work

progress. Through this step it is possible to obtain second level of morphisms (M2M morphism: Model 2 Model) and the basis for the automatic final solution.

(4) Once the above steps are complete, all the generated executable transformation code stored in the local KB will be used to transform data in the bidirectional communication between each pair of enterprises. Having this, if more enterprises are required to enter/leave the network, it is possible to add, remove and edit all the mappings and the transformation code.

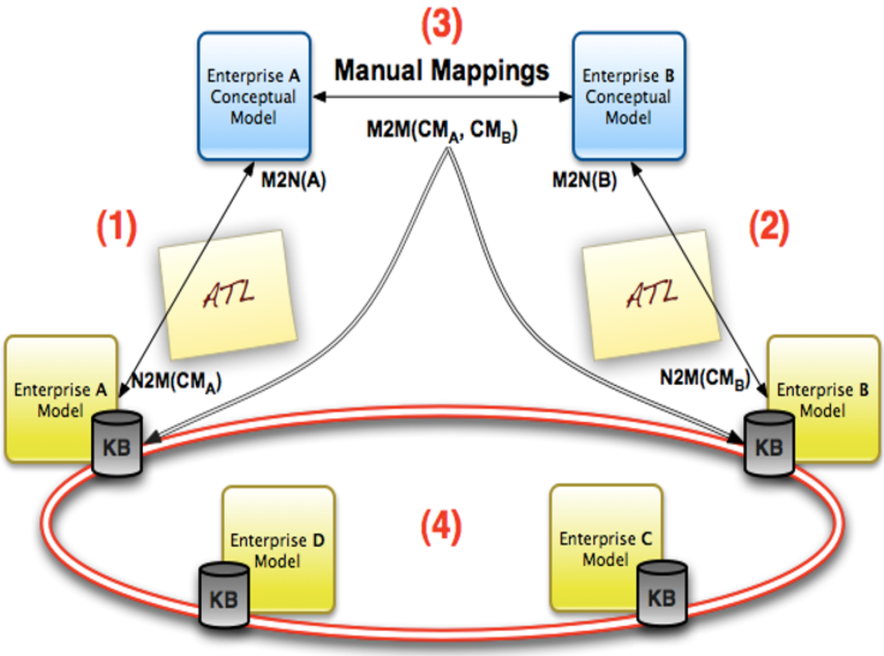

Figure 5. Application scenario

6 Conclusions and Future Work

Apart from being a technical issue, interoperability challenges also appear in the enterprises at organizational and semantic level, underlying the need for patterns and solutions that support the seamless cooperation among ICT systems, information and knowledge, organizational structures and people [29], [30], [31]. An enterprise's competitiveness is largely determined by its ability to seamlessly collaborate and interoperate with others and the lack interoperability has been identified in several business networks has a major cost, blocking the achievement of the time-to-market demanded by today's competitive environment. Schrage [32], emphasizes that the issue in collaboration *"isn't communication or teamwork,* *it's the creation of value"*. By this it is possible to conclude that he was looking at collaboration from a perspective of people and not systems. Therefore, if instead of just the software systems perspective, one could generalize to the everyday's experience, it is possible to conclude the even though people have different cultural backgrounds, if they speak the same language, they can communicate. The authors use this premise and apply it to the systems inter-enterprise level. Without the obstacle of language, in this case the information model language, organizations could have an interoperability basis. This way, a meta-model that can provide a common basis for understanding and conceptualize with minimal loss, information modeling languages, e.g. EXPRESS, is proposed. MDA technology can be then used to enable automation of model morphisms, and therefore, translation at the information model and data levels (level 1 and 0 of MDA). The first translation is used exclusively to obtain language independency and provide a common ground so that business experts can talk using a neutral representation of their information models and define the necessary mappings to enable systems interoperability. The second realizes the real link between two enterprises willing to communicate without changing their models and software platforms.

The proposed framework enables gradual and sustained system interoperability, since it envisages that each organization within the business network uses a knowledge base as a repository for all the morphisms that it has defined with its business partners. Therefore, the enterprise is always in control of the amount of information it can map and exchange with its partner. If at any time the collaboration requirements change, both organizations can increase their interoperability level by complementing the mapping between their information systems. The KB stores executable mappings (e.g. ATL) which can be accessed any time information need to be exchanged or the mapping complemented. Although ATL has the largest user base and documentation of the executable transformation languages, it hides a difficult take off curve and confusing mixed old and recent documentation. Once difficulties surpassed, ATL is a very powerful model to model tool, only not delivering many to many model transformations.

Future work resides on the improvement of the knowledge base that provides the support for evolvable systems and changing requirements. This frequently implies ontology-based process-specific modularity at fine granularity with local intelligence and a distributed control solution. Hence, the internal environment of the organization and its information system can create the adequate response to the external environment. Therefore, there is also a need for a heuristic framework capable of capturing environment knowledge and relate human choices and preferences, using monitoring and decision support to enable semi-automatic readjustments to the mappings and "true" sustainable interoperability across the information models life cycle in complex business networks.

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Part III
Human Centric Product Design and Development

A Kansei Clustering Method for Emotional Design Using Design Structure Matrix

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Abstract. In order to satisfy a more discerning eye of consumers, product design and development nowadays has shifted its emphasis from product functional requirements to user experiences gained from the interaction with the products. Consumer's emotional requirements, or the so-called kansei needs, have become one of the most important concerns in designing a product. Conventionally, kansei engineering has been widely used to co-relate these requirements with product parameters. However, a typical kansei engineering approach relies heavily on the intuition of the person who clusters kansei adjectives. As a result, the selection of kansei adjectives may not consistent with consumer's opinions. Accordingly, a kansei clustering method using design structure matrix (DSM) is proposed in this work. The method takes customer's voices, e.g., kansei needs, into consideration in emotional design. The details of the proposed approach are presented. The performance of the proposed method is illustrated using a case study on wireless battery drills. The results show that the proposed method is promising in handling kansei clustering problems.

Keywords. Emotional product design, kansei engineering, kansei clustering, design/dependency structure matrix.

1 Introduction

In recent years, product design and development has shifted its emphasis to the experiences gained from the interaction with the products [8]. The studies of the users' experiences (or user-centered design) may tackle different problems in various perspectives. In this regard, the so-called kansei engineering approach proposed by Nagamachi [6,7] is considered as one of the most reliable and useful methodologies to handle consumers' emotional requirements [1].

A conventional approach to studying kansei involves the following nine (9) consecutive steps [4]: (1) collecting as many kansei adjectives as possible from various sources (about 300-500 kansei adjectives for a product); (2) pre-

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processing/clustering kansei adjectives collected in such a way that a small number of kansei adjectives can be used to represent the whole unit (about 25-30 clustered kansei adjectives); (3) collecting product samples; (4) listing product attributes and attribute variables; (5) surveying and evaluating representative products using clustered kansei adjectives; (6) representing the survey results in a proper format; (7) identifying the correlation among kansei adjectives using factor analysis, followed by a cluster analysis to further cluster kansei adjectives; (8) identifying the correlation between clustered kansei adjectives and product attributes using such methods as quantification theory type I or cross tabs analysis; and (9) presenting the results using such tools as bar and radar charts to interpret, explain, and check the results. Although relatively less studied, the beginning steps, i.e., up to Step 2, deserve more in-depth investigation, because the results obtained from early steps may significantly affect later steps.

A typical kansei engineering approach collects as many kansei adjectives as possible from the customers. However, it depends on the user(s) of the method to decide how kansei adjectives should be pre-clustered (Step 2). The question is how to justify that a set of much fewer kansei adjectives selected be used to represent the whole meaning of kansei adjectives collected from the customers. For example, a case study from Grimsæth's work shows that two words, 'freedom' and 'comfort', were reduced to one, 'freedom', by the researcher's subjective judgments [4]. Nonetheless, to other researchers, 'freedom' might lead to 'comfort', but 'comfort' is not necessarily referring to 'freedom' only. The elimination of 'comfort' is debatable. Therefore, this work proposes a kansei clustering method to deal with such problems as abovementioned. Many data clustering methods/algorithms are available for grouping objects with similar properties together [2,11]. However, most existing data clustering methods/ algorithms are not able to fully handle kansei clustering problems owing to the characteristics of kansei data. A new clustering method is thus needed.

The Design/Dependency Structure Matrix (DSM) proposed by Steward in 1980s has the distinct advantages in showing the information cycles or connections among all units in a system in a visual and traceable manner [9]. Loops or iterated connections among nodes can be easily identified in a DSM. Using various partitioning methods [3,5,9,10], which rearrange a DSM into a lower triangular form, loops located along the diagonal line can be minimized. Nonetheless, the lower triangular form is not preferred in dealing with kansei clustering problems. Hence, a new DSM partitioning method, i.e. DSM for Kansei Partitioning, is proposed in this work.

The proposed kansei clustering method uses a completed set of kansei adjectives during product evaluations. In order to facilitate the evaluations, the set is divided into several kansei sub-sets. Then, a combined DSM is accordingly built. Subsequently, the DSM is partitioned, which results in clusters of kansei adjectives, based on the customers' viewpoint. Thereby, a small number of kansei adjectives could be further used in kansei engineering implementations. The next section, Section 2, describes the proposed method. Section 3 illustrates the proposed method with a case study and Section 4 discusses the experimental results. The work is briefly concluded in Section 5.

2 Method

The proposed method intends to improve the Step 2 of a conventional kansei engineering implementation [4] in such a way that the kansei adjectives are clustered based on customer's voices/opinions. Therefore, the resulted design may better reflect customers' emotional requirements. The method comprises eight steps as follows.

(i) *Collecting kansei adjectives.* Kansei adjectives are collected from all available sources where words (mainly adjectives) are used to describe the product under study. As many kansei adjectives should be collected as possible in this step. Usually, the number may reach 300 to 500 adjectives for a product.

(ii) *Building sub-sets of kansei adjectives.* The collected kansei adjectives are divided into a number of sub-sets. Each sub-set may contain 10-25 words depending on the design of survey questionnaires and the total number of kansei adjectives. Any two adjacent sub-sets share half (50%) of the same words.

(iii) *Collecting product samples for evaluation.* The purpose is to examine as many similar products as possible in the market. Virtual models, e.g. future or ideal products depicted by photorealistic renderings, can be used too.

(iv) *Evaluating survey questionnaires.* The representative products are evaluated with respect to every kansei sub-set by corresponding customer groups. The evaluation involves four sub-steps as follows.

1) Prepare evaluation forms. Place every representative product together with each kansei sub-set. Therefore, if there are *m* kansei sub-sets and *n* representative products to be evaluated, *mn* different evaluation forms would be required.

2) Manage the participants. If there are *m* kansei sub-sets, participants are randomly divided into *m* groups. Usually, each group comprises five to ten people.

3) Evaluate the forms by participants. Each group evaluates one kansei sub-set for every representative product.

4) Collect evaluation results and calculate the mean values using Equation (1).

$$AS_{in} = \frac{\sum_{j=1}^{k} S_{inj}}{k} \tag{1}$$

where i is the i-th representative product; n is the n-th sub-set of kansei adjectives; k is the number of evaluators in a group; j is the j-th evaluator in a group; AS_{in} is the average score of the n-th sub-set of kansei adjectives of the i-th representative product; S_{inj} is the score of the n-th sub-set of kansei adjectives of the i-th representative product by the j-th evaluator in a group.

(v) *Handling correlations among kansei sub-sets.* In this step, the Pearson product-moment correlation is utilized to measure the distance (similarities) between kansei adjectives in each sub-set. Compared with other types of correlation measurement, the Pearson method provides the most convenient and straightforward way to exhibit the similarity relations between any two kansei adjectives in a standardized interval (-1 to 1). The correlation coefficients of the same pair of kansei adjectives might be different in distinct sub-sets, because they are derived from values evaluated by different groups of participants. Note that the coefficients are not necessarily the same because they are merely used as a reference to judge whether there is a correlation or not. In addition, the differences eliminate possible bias of evaluations by a single group of customers.

(vi) *Building DSM of sub-sets.* Criteria have to be set for judging whether a pair of kansei adjectives is considered positively, negatively, or not correlated. Positive, negative, and no correlations are marked with '1', '-1', and '0' respectively for each kansei sub-set. The numeric DSM for each sub-set can be combined. Recall that any two adjacent sub-sets share half of the same kansei adjectives. These adjectives are used to link the numeric DSMs.

(vii) *Processing the combined DSM.* The combined DSM is partitioned in this step to cluster kansei adjectives. Obviously, those positively correlated kansei adjectives should be put in one block (or cluster) and those negatively correlated should be separated into different partitions. In order to do so, all positive values are kept in the DSM diagram; negative values in the upper triangular area are removed.

(viii) *Analyzing and manipulating the results.* After partitioning the combined DSM, possible kansei clusters are formed. Advanced DSM techniques, e.g., tearing and binding, can then be employed to analyze and manipulate the resulted kansei clusters. The purpose of this step is to refine the kansei clusters obtained in the previous step. The refinement provides a more flexible way to handle kansei adjectives and clusters.

In essence, Steps (vi) to (viii) convert Pearson correlations of kansei adjectives into a binary DSM, i.e., either positively or negatively correlated between two adjectives, based on a selected threshold value. The binary DSM is comprehensive and can be easily partitioned subsequently. However, selecting a suitable threshold value might be difficult in some situations. Therefore, instead of processing binary DSM, an alternative way is to partition numeric DSM directly. In this regard, a so-called DSM for Kansei Partitioning (DSMKP) algorithm (Algorithm 1) is proposed. In the algorithm, n is the total number of kansei adjectives and v_{ij} is the value of element (row i, column j) in the numeric DSM. Basically, the proposed algorithm arranges kansei adjectives from column 1 to n in such a way that the corresponding values follow a descending sequence in the top-down direction. In addition, it has to consider the combination effect of kansei groups. In other words, values of former kansei adjectives are summed up and compared. As a result, heavy weights, i.e., large correlation values, would mostly be distributed along the diagonal line. The DSMKP could also be used as a basis to deal with combined DSM, i.e. binary DSM.

Algorithm 1. DSM for kansei partitioning (DSMKP)

```
Pseudo-code of DSMKP
For column j = 1 to n
    For row i = j +1 to n
        v_m = max(v_j);
        IF max(v_j) > v_ij ; and, sum(v_mk) > sum(v_ik), where k = j -1 to 1
            Exchange v_ij with v_mj, where j = 1 to n; except (v_ii, v_im, v_mi, v_mm);
            Exchange v_ij with v_im, where i = 1 to n; except (v_ii, v_im, v_mi, v_mm);
        End IF
    End For
End For
```

3 Results

A case study on wireless battery drills, which involves a number of participants (customers), was conducted to illustrate the proposed method. Several kansei sub-sets were established. One kansei sub-set, which involves sixteen (16) kansei adjectives (Table 1), was randomly selected to demonstrate the proposed clustering method. The adjectives are denoted from A to P.

Table 1. A kansei sub-set to be partitioned

A Kansei Sub-set							
A	control	E	portable	I	plastic	M	cartoony
B	functional	F	smooth	J	classic	N	futuristic
C	comfort	G	clean	K	professional	O	speed
D	ergonomic	H	personal	L	masculine	P	torque

Product samples were collected and the representative drills were evaluated by a group of participants using the kansei sub-sets. The scores given by the participants were averaged. Based on the results, correlations were calculated to measure the distance (similarities) between kansei adjectives in the kansei sub-set. Table 2 shows the correlation coefficients of kansei adjectives.

Table 2. The kansei correlation matrix

Correlation between Kansei Adjectives																
	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
A	1.00	0.91	0.59	0.76	-0.47	0.19	-0.73	-0.12	-0.04	0.51	0.55	0.26	0.12	0.4	0.85	0.11
B	0.91	1.00	0.44	0.69	-0.53	0.07	-0.75	-0.15	-0.27	0.59	0.46	0.11	0.12	0.29	0.77	-0.02
C	0.59	0.44	1.00	0.56	-0.49	0.03	-0.48	-0.23	-0.05	0.3	0.73	0.35	0.35	0.77	0.46	0.24
D	0.76	0.69	0.56	1.00	-0.72	-0.13	-0.53	-0.16	-0.48	0.34	0.4	0.58	0.07	0.5	0.74	0.42
E	-0.47	-0.53	-0.49	-0.72	1.00	0.62	0.49	0.59	0.55	-0.6	-0.47	-0.69	0.25	-0.48	-0.5	-0.45
F	0.19	0.07	0.03	-0.13	0.62	1.00	0.16	0.48	0.41	-0.58	-0.03	-0.48	0.62	0.11	0.04	-0.35
G	-0.73	-0.75	-0.48	-0.53	0.49	0.16	1.00	0.09	0.16	-0.65	-0.25	-0.38	0.2	-0.25	-0.66	-0.02
H	-0.12	-0.15	-0.23	-0.16	0.59	0.48	0.09	1.00	0.25	-0.43	-0.53	-0.28	0.47	-0.19	-0.22	-0.37
I	-0.04	-0.27	-0.05	-0.48	0.55	0.41	0.16	0.25	1.00	-0.02	-0.03	-0.33	0.11	0.04	-0.26	-0.45
J	0.51	0.59	0.3	0.34	-0.6	-0.58	-0.65	-0.43	-0.02	1.00	0.44	0.18	-0.42	0.15	0.35	-0.04
K	0.55	0.46	0.73	0.4	-0.47	-0.03	-0.25	-0.53	-0.03	0.44	1.00	0.14	0.13	0.58	0.35	0.36
L	0.26	0.11	0.35	0.58	-0.69	-0.48	-0.38	-0.28	-0.33	0.18	0.14	1.00	-0.31	0.3	0.47	0.73
M	0.12	0.12	0.35	0.07	0.25	0.62	0.2	0.47	0.11	-0.42	0.13	-0.31	1.00	0.39	0.01	-0.21
N	0.4	0.29	0.77	0.5	-0.48	0.11	-0.25	-0.19	0.04	0.15	0.58	0.3	0.39	1.00	0.2	0.1
O	0.85	0.77	0.46	0.74	-0.5	0.04	-0.66	-0.22	-0.26	0.35	0.35	0.47	0.01	0.2	1.00	0.41
P	0.11	-0.02	0.24	0.42	-0.45	-0.35	-0.02	-0.37	-0.45	-0.04	0.36	0.73	-0.21	0.1	0.41	1.00

The DSMKP algorithm is used to partition/cluster the kansei correlations matrix. The results are shown in Figure 1(a), where a darker color grid denotes a larger value. In the partitioned DSM, the sequence of sixteen kansei adjectives is arranged in such a way that dark areas are distributed along the diagonal line, while light areas are not. Therefore, dark chunks can easily be differentiated from light surroundings. Figure 1(b) suggests that there might be four major kansei clusters, i.e., cluster 1 – control, functional, speed, and ergonomics, cluster 2 – professional, comfort, and futuristic, cluster 3 – masculine and torque, and cluster 4 – smooth, plastic, personal, portable, and clean.

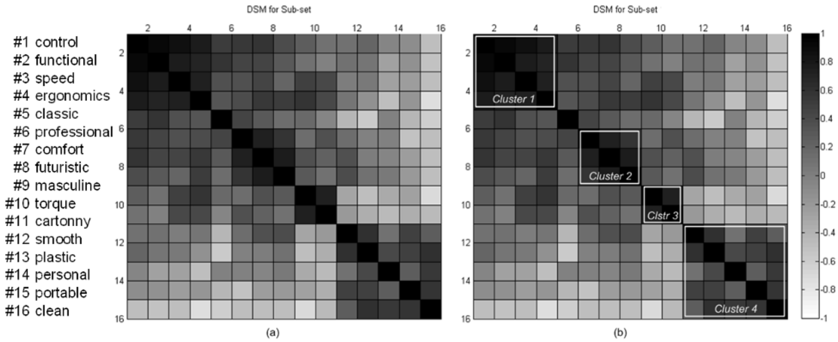

Figure 1. DSM for the kansei sub-set: (a) The partitioned DSM, (b) Four kansei clusters

Similarly, another three kansei sub-sets are partitioned using DSMKP algorithm. The results are shown in Figure 2. It shows that there are four, five, and three major kansei clusters under sub-sets 2, 3, and 4, respectively.

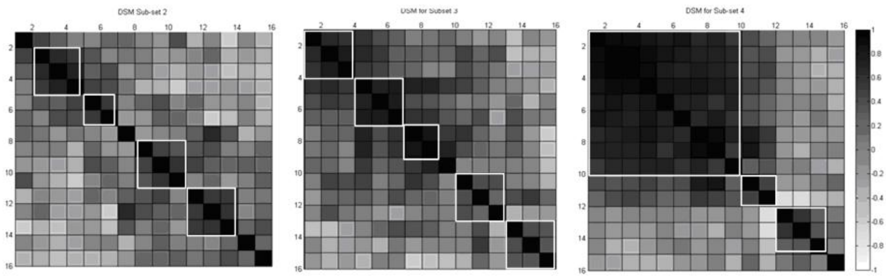

Figure 2. Three partitioned kansei sub-sets

Kansei sub-sets 1 to 4 can be combined into a single DSM, which contains thirty-two kansei adjectives. The combined DSM and its partitioned result are shown in Figure 3. Eight major kansei clusters are identified based on the partitioned DSM: 1 – control and speed, 2 – functional and elegant, 3 – comfort and futuristic, 4 – boring and safe, 5 – professional, ergonomics, masculine, and torque, 6 – reliable, aggressive, and sturdy , 7 – modern, personal, expensive, smooth, power, clean, and stable, and 8 – rugged and cartoony. Others are stand-alone kansei adjectives.

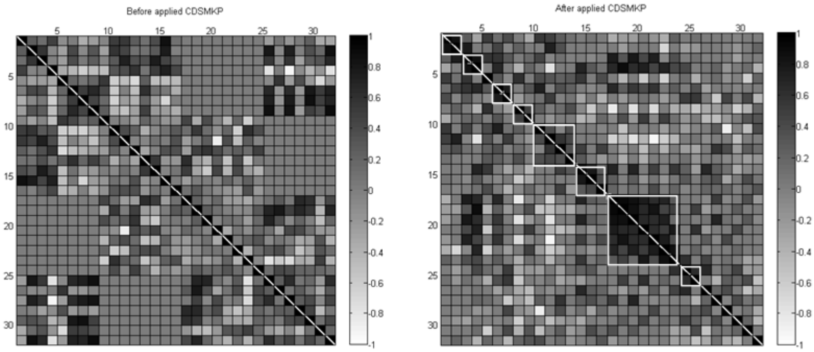

Figure 3. The combined DSM before and after CDSMKP partitioning

4 Discussion

There are two key tasks to be executed using the proposed method if all kansei adjectives could be positioned on a map with the distances determined by their meanings. One task is to identify the locations of kansei clusters. The conventional method estimates the locations of clusters according to the intuition of the person who clusters kansei adjectives. In contrast, the proposed method identifies the locations of clusters based on customers' evaluations. More specifically, the proposed method uses correlation coefficients between kansei adjectives as the distances for each sub-set and, hence, locations of clusters are calculated. The other key task is to determine the radii of clusters so that the number of kansei adjectives in each cluster can be controlled. This task is taken care of in Step (viii) of the proposed method, i.e., analyze the partitioned DSM.

DSM provides the basic information of correlations between any two kansei adjectives. These correlations need to be analyzed from various viewpoints in order to properly cluster the adjectives. Figure 3 shows a partitioned numeric DSM using the proposed DSMKP algorithm. It appears that the result obtained using DSMKP is better than that obtained by the binary DSM-based clustering method. This can be observed from two aspects. First, in DSMKP, threshold value(s) needs not to be defined before partitioning. Therefore, it has less bias caused by the method user's own judgment. For example, if a threshold value is set at 0.5, correlations that a bit less than 0.5, e.g., 0.49, are eliminated for consideration towards combination effects of kansei groups. Second, binary DSM-based clustering method can only partition kansei adjectives above threshold values. If the threshold value(s) is set high, many kansei adjectives would not be partitioned. In contrast, DSMKP partitions all kansei adjectives no matter how low the corresponding correlation values are.

In summary, the DSM helps to realize a kansei map, which displays and positions all kansei adjectives based on their similarities of meanings. The map is depicted according to customer's voices/opinions. Without the DSM-based map of kansei relations, it has to fully rely on the intuition of the person who clusters kansei adjectives. In that case, the clustering result might not be consistent with customer's opinions.

5 Conclusions

A kansei clustering method is proposed in this work. The method takes customer's voices, e.g., kansei needs, into consideration in emotional design. It incorporates DSM in realizing the map of kansei adjectives, which positions all kansei adjectives based on their similarity of meanings. The details of the proposed approach are presented. The performance of the proposed method is illustrated using a case study on wireless battery drills. The results show that, compared with a conventional kansei engineering approach, the proposed method is promising in handling kansei adjectives clustering problems. Future work would be focusing on improving the effectiveness and accuracy of identifying the radii of kansei clusters. In this regard, it is envisaged that a fully customer-oriented DSM-based kansei clustering method can be realized.

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User's Subjective Interpretation of Bodily Movements as Gestural Commands to Robot Companions

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Abstract. Statistics show that domestic service robots for household chores, entertainment, or other social purposes will become a common scene in our future life. However, many of the human-robot-interactions still behave and feel like robots belong in laboratory or factory, and are not well-suited toward the wide variety of home users. Researchers have consequently called for better interaction design of robot companions to engage users in a more socially meaningful style. In order to cope with the challenge of HRI, understanding how people interpret their own gestures will aid design of effective HRI. This study explored how users subjectively assessed their bodily movments in terms of gestural command in HRI. Literature survey, analysis of current related intelligent products, and in-depth interview with experts were adopted to identify the feasible gesture samples and commands used in nowaday robot-related products. An experiment was conducted to ask participants to view and experience each gesture sample, then make their subjective assessments of each sample in reference to a set of commands by a three-point scale. The results obtained are discussed in terms of implied guidelines for designing a natural and intuitive gestural interaction for companion robots and other intellectual appliances targeting non-expert users.

Keywords. Robot Companion, Human-Robot Interaction, Gestures

1 Introduction

Statistics indicate that domestic robots for household chores, entertainment, or other social purposes will become a common scene in our future life. For instance, 3.4 million personal service robots were in use worldwide in domestic settings in 2007, and the number is expected to increase to 4.6 million robots by 2012, according to the Statistical Department of the International Federation of Robotics [7]. The Ministry of Information and Communication in South Korea expects to have a robot in every family by 2013. And the Japanese Robot Association predicts

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that the personal robot industry will be worth more than $50 billion a year worldwide by 2025 [6].

Traditionally, robots are widely used in manufacturing, assembly, packing, and transportation. Nowadays many domestic robots are used for basic household chores, such as Roomba. Others are intended to act as educational or entertainment partners (e.g., AIBO), or serve as companions (e.g., PARO). This new type of robots is generally called robot companion or social robots [1,5]. In these kinds of applications, robots will interact closely with a wide variety of home users in their everyday environment; hence it is essential to create interaction models for natural and intuitive communication between users and robots. Because the field of domestic robotics is derived from industrial robotics, traditional human-robot interaction (HRI) is supplemented with social human-robot interaction. However, many of the robots in the home still look and behave as if they are for laboratory or factory, and the human-robot interaction are not well-suited for the non-expert home users. Researchers have consequently called for better interaction design of robot companions or social robots to engage users in a more socially meaningful style [8, 12, 14].

The advent of social and companion robots poses many challenges regarding the nature of interactivity and social interaction between robot and humans. In this study, we will focus on the use of body movement to express users' intention to robot companion; more specifically the actor's subjective interpretation of his/her own action while interacting with a robot companion. This paper is organized as follows: section 2 provides a brief overview on gestural interface in HRI; section 3 describes our methods; section 4 presents the results of our experiment along with a discussion of some interesting findings; and finally, section 5 summarizes the main outcomes of our research.

2 Background

Researchers argue that the cognitive models and methodology for human behavior are insufficient for today's interaction design because of the narrow understanding of human behavior as an automatic and inevitable consequence of the human cognitive process, and the neglect of actual world where people stay in and interact with. Many operations or gestures to controll intelligent artifacts assigned by designers are often "generated from or subservient to abstract reasoning" [4]. In addition, the increasing attention on interaction per se rather than interface in recent design researches gives rise to design approaches that place emphasis on the action or movement of embodied agents directly, but not on the media to make interaction understandable [13]. While many embodied interaction concepts have been developed, the role of bodily movements in human-artifact-interaction is not fully understood yet [18].

This paradigm shift also occurred in the field of robotics [2]. Recently, the use of gestures or bodily movement has been identified as crucial to the design of social robots [5]. Li et al. [8] argue more studies on robot gestures are necessary because few guidelines exist for the design of robotic gestures, and previous HRI researches have investigated robotic gestures creation but have not convincingly evaluated people's understanding of those gestures. Nakata, Mori, and Sato [10] claim proper use of robot's body movement can convey certain emotional impression to users, and a framework for body expression is proposed to facilitate evaluation and forecast of users' impression onto robot's movement. However, approaches to study gesture in HRI have mainly focused on the development of understandable robots movement [8, 10] and better gesture recognition technology [15-17]. Few are concerning what these gestures make sense to users: Do gestures convey the same message to the recipients as well as to the actors themselves, the human users in HRI? What are the user's subjective interpretations or feeling about his/her own movement in the gestural interaction? Are they aware of any randomness or inconsistency between their bodily feelings of the actions and the intended commands assigned by HRI designer? Hence instead of focusing on the design of comprehensible gestures of robots, this study aims to investigate the actor's subjective interpretations of his/her gestural actions as commands to communicate with a robot companion.

3 Methods

The study reported in this paper is part of a larger study to explore a more intuitive and pleasant use of bodily movement in HRI. The focus of this paper is to understand how people perceive their own bodily movement in terms of gestural commands for HRI. An experiment was conducted to collect participants' subjective assessments on what various gestures meant to themselves while they were using these gestures to interact with a social robot. An association rating sheet was developed to help participants to rate how their gestures are correlate to some general commands in HRI by a three-point scale.

In order to determine a corpus of gesture examples and commands for the experiment, the palette of human gestures and movements proposed by Saffer [13] was used as the potential gesture examples from the outset. There were 103 gestures in total, consisting six types of bodily movements, head movement, torso movement, leg movement, arm movement, hands movement, and face movement. Through an in-depth discussion with HCI experts, 41 apparently infeasible movements for HRI were eliminated; the total number of user gestures was reduced from 103 to 62. The 62 gesture samples included "head tilt forth", "head tilt back", "head tilt right" , "head turn left", "head nod", "head shake no", "finger point", "hand wave", "hand clap/applause", "fist", "thumbs up/down", "okay gesture", and etc.. All of these 62 gesture examples were performed by our research assistants and video-recorded, as shown in Figure 1.

In the mean time, brochures and user manuals of current robot companions and related intelligent products were collected and analyzed, and a set of commonly used commands were carefully selected as the reference of subjective messages in the experiment. There were 22 commands included "turn on", "turn off", "go/turn left", "go/turn right", "go forth", "go back", "stop", "yes/confirm", "no/deny", "cancel", "repeat", "increase volume", "decrease volume", "walk around", "approach", "recharge", "follow me", "move up", "encourage (enjoy)", "forbid (dislike)", and "greetings". Each of the commands was paired with the gesture examples above for participants to assess their association.

(A)

(B)

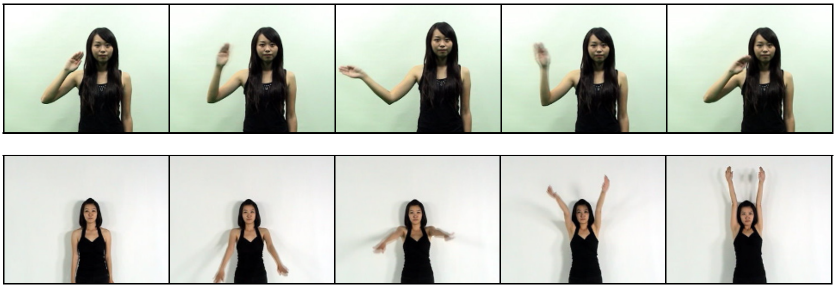

Figure 1. Snapshots of two gestures videos used in this study (A) wave, (B) arms up.

In the experiment, participants were asked to view the video clips of gesture examples displayed on a projected screen one by one. For each gesture example, participants needed to first imitate and experience the bodily movement shown on the screen, and imagine themselves communicating with a robot companion. A stuffed animal was placed in front of participants in the experiment setting for this purpose. Then participants were asked to mark the association rating sheet to record their subjective assessments on how they feel the gesture was correlate to each of the 22 commands listed in the sheet by a three-point scale (1= strongly agree, 0= undecided, -1= strongly disagree). Participants were given time to repeat the gesture as many times as they needed before rating it.

Forty participants (19 female, 21 male) ranging in age from 21 to 40 were recruited from Taichung city area. The study was conducted at the Campus of National Taichung Institute of Technology located in the center of Taichung city. The participants were drawn from a specific area and all results have to be interpreted with this particular aspect in mind. The participant characteristics are listed in Table 1. The results of this study are presented and discussed in the following sections.

Table 1. Participant characteristics (N: 40)

Gender	Male	52.5%
	Female	47.5%
Age (years)	21-25	77.5%
	26-30	12.5%
	31-35	10.0%
	36-40	2.5%
Education Level	High School	7.5%
	College	17.5%
	Graduate School	75.0%
Computer Experience	1-3 years	7.5%
	4-9 years	25.0%
	10 years or more	67.5%

4 Results and Discussion

To get an overview of how participants perceive their own bodily movement in terms of HRI commands in the experiment, 40 association rating sheets was first collected and all the ratings for a particular gesture-command pair were added together. The sum of all participants' ratings of the association strength between each gesture and command could range from -40 to 40. The larger the number meant more participants considering the gesture-command pair correlate, and vice versa.

There were 30 gesture samples (e.g., "push", "pull", "finger crossed", "pinch", "cup palm") that their sums of ratings in reference to the 22 HRI commands were all below 0, which meant most of participants considered they were not related to any of the 22 commands. Furthermore, there were 3 HRI commands (i.e., "power on", "power off", and "move down") that their sums of ratings in reference to the 62 gestures were all below 0, which meant most of participants considered they were not related to any of the 62 movements.

Then, we removed those gestures and commands that most participants subjectively judged as unrelated, the sum ratings on the association of remaining gestures and commands were listed in Table 2. In order to visualize the association strength of each gesture-command pair, the numbers were replaced by symbols, " - ", "○", "◉", "⦿", and "●".

While this research is a first step in investigating users' subjective experience on their own gestures as controlling command in HRI and should be seen as exploratory, four tentative design guidelines are inferred. First, 32 out of 62 gesture samples in this study are found associated with some HRI commands, which means some gestures can elicit users' subjective responses corresponding to certain commands in HRI. Such users' bodily experience and subjective feelings of their movement should be taken into account in creating more intuitive and self-evident gestural interactions. Second, there is a gap existing between users' subjective experiences of their own movements and others' (not the actors themselves) interpretations. Some gestures make sense through looking and thinking, but not through acting. For instance, "hand wave" (an open hand is moved left/right) is suggested to be used for activating, scrolling left/right in HCI literature [13], which makes sense to authors in this study. However, the results shown in Table 2 indicate that participants feel this movement is more about sending greetings to a robot or denying/cancelling an option. Third, users tend to employ interpersonal gestures to express social behavior and emotion (e.g., "hand wave" as greetings, "hand clap" and "thumbs up" for enjoyment and encouragement) while they are communicating with robot companions, as if they were alive. Hence, if gestures commonly used in daily interpersonal communication are applied in the interaction design for robot companion, designers should follow the convention and do not randomly assign new meaning to them to avoid conflict. Finally, some of gesture samples are ambiguous to the participants. For instance, the gesture "head tilt forth" can be interpreted as "go forth" or "yes/confirm", and the gesture "come here" as "go forth", "approach to me", or "follow me". When ambiguity happens, gestures alone are not sufficient to convey meanings, even to the actor his/herself.

In order to keep the interaction fluent and reduce the mental load on the user, additional data is required for users to make sense of their own gestural commands.

Table 2. The sum of 40 participants' ratings on the association of gestures and commands

Gesture		Go / Turn Left	Go / Turn Right	Go Forth	Go Back	Stop	Yes/Confirm	No/Deny	Cancel	Repeat Once	Increase volume	Decrease volume	Walk Around	Approach	Go Recharge	Follow Me	Move UP	Encourage (Enjoy)	Forbid (Dislike)	Greetings
Head	Tilt Right	-	◉	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Head	Tilt Back	-	-	-	○	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Head	Tilt Forth	-	-	○	-	-	○	-	-	-	-	-	-	-	-	-	-	-	-	-
Head	Turn Left	◉	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Head	Nod Yes	-	-	-	-	-	●	-	-	-	-	-	-	-	-	-	-	-	-	-
Head	Shake No	-	-	-	-	-	-	◉	-	-	-	-	-	-	-	-	-	-	○	-
Hand	Point	-	-	-	-	-	-	-	-	-	-	-	-	-	◉	-	-	-	-	-
Hand	Wave	-	-	-	-	-	-	○	○	-	-	-	-	-	-	-	-	-	-	◉
Hand	Clap/Applause	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	●	-	-
Hand	"Okay"	-	-	-	-	-	●	-	-	-	-	-	-	-	-	-	-	-	-	-
Hand	Thumbs Up	-	-	-	-	-	○	-	-	-	-	-	-	-	-	-	-	●	-	-
Hand	Fist	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	○	-	-
Hand	"Shh"	-	-	-	-	-	-	-	-	-	-	◉	-	-	-	-	-	-	-	-
Hand	"Come Here"	-	-	◉	-	-	-	-	-	-	-	-	-	◉	-	○	-	-	-	-
Hand	"Shoo"	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	◉	-
Hand	"Stop"	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	◉	-
Hand	Slap	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	◉	-
Hand	Blown Kiss	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	○	-	-
Hand	"Tip of the Hat"	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	◉
Hand	Finger Wag	-	-	-	-	-	-	◉	-	-	-	-	-	-	-	-	-	-	◉	-
Hand	Move Hand Up/Down. "This Tall"	-	-	-	-	-	-	-	-	-	○	-	-	-	-	-	◉	-	-	-
Hand	Nose Tap	-	-	-	-	○	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Hand	Extend Index Finger. #1	-	-	-	-	-	-	-	-	◉	-	-	-	-	-	-	-	-	-	-
Hand	Cup One Hand Around Eyes	-	-	-	-	-	-	-	-	-	-	-	◉	-	-	-	-	-	-	-
Hand	"Check Please"	-	-	-	-	-	◉	-	-	-	-	-	-	-	-	-	-	-	-	-
Hand	Hands Cover Ear. "Hear No Evil"	-	-	-	-	-	-	-	-	-	-	◉	-	-	-	-	-	-	○	-
Hand	Rapidly Wave A Hand. "Hot"	-	-	-	-	-	-	-	-	-	-	-	-	◉	-	-	-	-	-	-
Hand	Cup Ear with A Hand. "Say What?"	-	-	-	-	-	-	-	-	-	◉	-	-	-	-	-	-	-	-	-
Hand	Crook Finger	-	-	-	-	-	-	-	-	-	-	-	-	◉	-	-	-	-	-	-

Arm	Arm(s) Up	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	⭘	-	-	-
	Arm Out to the Side	-	-	-	-	○	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Forearm Up	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	⭘	-	-	-

- : sum< 0 ○ : 0 ≦ sum ≦ 5 ⭘ : 6 ≦ sum ≦ 19 ◉ : 20≦ sum ≦ 27 ● : 27 < sum

5 Conclusion

In this study, a collection of human daily gestures were carefully selected, then participants were asked to perform each of them, experience it , and subjectively rate its association of different commands in HRI. Base on results of the experiment conducted, some gestures do elicit participants’ subjective responses corresponding to certain commands in HRI, which makes the gestural interaction self-apparent and intuitive. However, there are some iconic gestures that make sense to designers or audience, but participants (actors) just don’t feel the same way. Hence, we argue that what users consider natural and intuitive gestures during their interacting with robot companion can be different from what others expect. Furthermore, when we discuss about using gestural commands in HRI, how user’s gesture is detected by intelligent devices, or what message a gesture leaves the majority of the audience with might be important, but in order to design an intuitive and communicative interaction between a user and his/her own personal robot companion, what user’s action mean to his/herself is important too. It is recommended that future HRI research take into account users’ bodily experience in creating socially meaningful interaction.

In addition, the same gesture can sometimes elicit more than one subjective interpretation. We suspect the ambiguity is due to lack of situational context in the experiment. Research has suggested that both in interpersonal communication and HRI the perceived meaning of a gesture depends on its social context [3, 9]. The issue of gesture’s situational context will be considered in our forthcoming study.

The focus of this research is to investigate user’s interpretation of his/her bodily movement in term of commands for HRI, and to understand how these gestures are relevant to some commonly used commands. Hopefully, findings in this research can serve as reference for the design of gestural interaction for companion robots and other intellectual appliances targeting non-expert users in domestic settings.

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A Study on Color Emotion for Plastic Eyewear

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Abstract. This study explored consumers' Kansei evaluation of the color of plastic eyewear. The procedure included: (1) collecting over 400 plastic eyewear samples on Taiwan's market; (2) collecting emotional adjectives for describing the color of eyewear frames, (3) selecting one representative eyewear frame and 10 variation colors by four design experts, (4) selecting 8 representative emotional adjectives with Kawakita Jiro method, (5) conducting experiment with Semantic Differential method to record the subjective evaluation of the eyewear samples, (6) analyzing data collected with multi-variable analysis and principal component analysis. The results indicated that: the Red frame had the highest scores on "avant-garde", "strong" as well as "unique"; the Pink frame exhibited "soft" feel; the Yellow frame showed "young" most; the Green frame demonstrated "vulgar" impression; the Indigo frame displayed the most "popular" and "rational"; the Black frame presented "traditional", "stable", "noble" and "formal"; while the Purple frame represented the most "sensational". On the whole, the color of plastic eyewear had significant emotional appeal for peoples. Different color collocation of eyewear will change the overall emotional reflection. The results of the study may serve as a reference of color plan for eyewear designer as well as end users.

Keywords. Kansei Engineering, Kawakita Jiro Method, Color Emotion, Cognitive Psychology, Plastic Eyewear

1 Introduction

1.1 General Background

Psychologists noted the meanings of color conveyed to people may vary, e.g. red can be a symbol of passion, but also signifying danger. Which lead to the psychological theory of color [2]. Kobayashi (1986) mentioned in his book that color and shape are two sides of a form. However, many studies have shown that humans visual perception of color are more sensitive than that of shape. Therefore, colors, in the normal state, have stronger emotional impact on people than shapes, because colors act not only on one's psychology, but also on his/her health

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management. Color and shape are two important visual elements in design. A good design not only must function well, but also should appeal to the users. To achieve these objectives, the color element cannot be overlooked [5].

Professional designers usually equip with acute sense of color about their designs. But many studies proved that color preference is rather a subjective feeling. Therefore, we cannot make sure that the emotion users reflected from an object is the same as that of designers. Hence, it became a research issue to be explored in depth. The composition of a pair of eyewear is also consisted of two basic elements, shape and color. Shi (1995) employed the theory of artificial neural net to explore the relationship between the shape of eyewear and the Kansei images to provide a reference for the eyewear designers [10]. In this study, the relationship between the color of eyewear design and users' emotional reaction was explored via Kansei Engineering approach to guarantee more appropriate eyewear color design for targeted users.

As users' emotional feelings about any object are so subjective, there is no single standard to judge the appropriateness of any design. To assure product competitiveness, one must faithfully reflect and satisfy marcket demands. In other words, one has to meet the emotional needs of the target consumers. Humans perceive external information stimulated by the product form with sensory organs, and generate activities of cognitive evaluation of thoughts and emotion internally. Which means consumers come into contact with product via its external image, such as shape, size, color etc., and then, result in a comprehensive feel [1].

1.2 Purpose of the Research

The aim of this study was to explore users' emotional reaction about the color of plastic eyewear. It was hoped to come up some applicable rules for eyewear designers in the end. The objectives can be summarized as follows:

(1) Exploring commonly used colors for plastic-framed eyewear and the situation of usage.

(2) Understanding the adjectives used in describing color image by current Taiwanese eyewear consumer groups.

(3) Investigating users' color cognition of the plastic eyewear.

(4) Analyzing the relationship between the color of plastic eyewear and users psychological cognitive factors.

(6) Summarizing the results to provide as reference for future research and design purposes.

2 Theoretical Background

2.1 Cognitive Psychology

Cognitive psychology can be defined as a scientific analysis of humans mental processes and structure for understanding humans behavior [6]. In this definition, there are three key components: scientific analysis, mental process and structure and understanding humans behavior.

Scientific Analysis - cognitive psychology must use scientific method. The objective, validated methods can be repeated to guarantee the same procedure can reach the same results. Therefore, cognitive psychologists have to invent appropriate tools for observing and analyzing humans mental activities.

Mental Processes and Structure - mental processes and structure are the two major studied areas of the cognitive psychology. Mental processes focusses on exploring how we use or handle information or knowledge while engaging in some work, while mental structure on exploring how we store information and knowledge and what information or knowledge we store in the memory.

Understanding Humans Behavior - the ultimate aim of any psychological science is to understand humans behavior. The aim of cognitive psychology is to better understand and predict humans behavior through precise analysis of mental processes and structure [11]. For example, analysis of the mental processes in answering to a math problem can understand why and predict who are able to answer while others not [9].

2.2 Color Perception

In the late nineteenth century, color perception and color aesthetics have begun to be taken seriously. French scholar Chevreul (1786-1889) first proposed the concepts of hue harmony, similar harmony and contrast harmony. Almost at the same time, the oppinion about the classification for hue, brightness and saturation of color was also raised. Bullough (1880-1934) argued that it could be divided into the following four groups based on people’s reaction to colors [13]:

(1) Objective Type: attribute based evaluation of color. Rational and critical attitude, not emotional one was adopted toward color perception. Analyzing color with an attempt to find traces of other colors and to determine either pure or impure for a color. It gives experimenters the impression that this type of people does not seem to have close relations with color. They rarely reveal any visible or sustained preferences on any certain color. But they often hold certain criteria for judging the characteristics of color. This type of people tends to hate certain colors more often than other types of people.

(2) Associative Type: associating objects to colors before the evaluation of color. This type of people is particularly sensitive to irritating or soothing, warm or cold colors. They have stable preference for red color. Some subjects are even trembling when they view certain cold blue. Overall, this type of people can better appreciate color than others, but seldom enjoy the aesthetics of color due to the shift of attention away from color itself to the associative effect the color generated.

(3) Physiological Type: feelings generated affected by color. This type has smaller population realtively. Most of the subjects made judgments either objectively or physiologically. They have different preference over colors because each has different associations to specific taste. For example, for those who often think of the nature like green most. For those who often think of clothing like the colors of their favorate clothings.

(4) Character Type: emotional reaction toward colors. This type of people tends to enjoy color more than the Objective Type. During the experiment, a few subjects can be found as transitional type between the Physiological Type and the Character Type.

2.3 Color Image

Color image is a comprehensive psychological quality of color characteristics based on color attributes. There are three major dimensions in measuring color images: evaluation, potency, and activity [7].

For example, Beauty-Ugly, Elegance-Vulgar, etc. are evaluative, Strong-Weak, Light-Heavy, Masculine-Female, etc. are potent while Dynamic-Static, Bright-Dark, Compelling-Tedious, etc. are activated values of color images. In short, color can triger people's psychological feeling and emotional reaction [12].

In daily life, we often use various adjectives to represent images of objects. These adjectives can usually convey the inherent qualities of objects or reflect viewers' psychological feelings correctly, such as: "Fashionable" clothes, "Elegant" restaurant, "Romantic" candlelight dinners. Color believed to have stronger power than form in effectively conveying the images of objects [4].

2.4 The Structure of Eyewear

Eyewear is defined in Encyclopedia Britannica as: "lenses set in frames for wearing in front of the eyes to aid vision or to correct such defects of vision as myopia, hyperopia, and astigmatism." [3]. The differences of the basic structure among various eyewears are not large.

The structure is broadly divided into: A-main body, B-rim, C-bridge, D-nose pad, E-flange, F-joint, G-arm, H-feet, I-rim eyebrow, J-shield button, K-temple and L-lens. (Figure 1.)

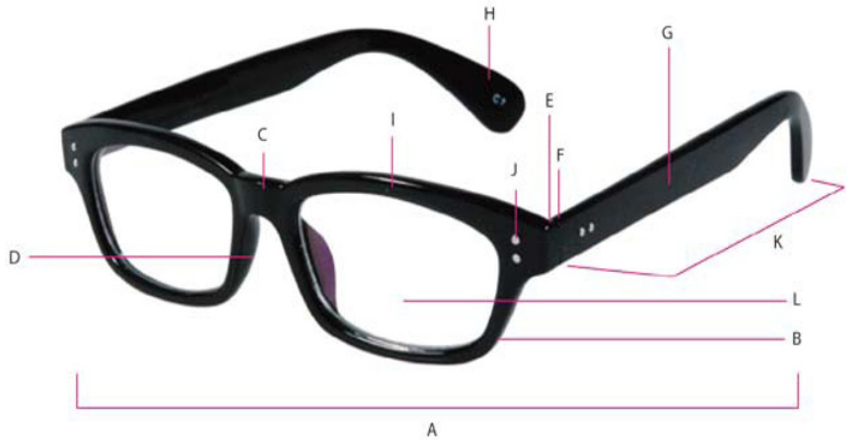

Figure 1. The structure of eyewear

3 Method

3.1 Sample Collecting and Screening

First, the plastic eyewears available on the market were extensively collected from both websites and catalogs. A total of 400 original images from different brands displayed in the same direction were collected. Followed by a screening process by experts to select the representative ones. Figures 2 and 3 show a portion of the 400 samples and the representative frame respectively.

Figure 2. A portion of 400 samples

Figure 3. Representative frame selected by experts

3.2 Emotional Vocabulary Collecting and Selecting

A group of four design experts was invited to generate emotional vocabularies suitable for describing eyewears via brainstorming sessions. After the brainstorming sessions, duplicates or similar ones were deleted. Finally the most representative ones were selected based on majority counts from the four experts to pair up opposite adjectives.

The final 8 adjective pairs are: Avant-garde - Traditional, Soft - Strong, Rational - Emotional, Common - Unique, Poise - Lively, Young - Old, Elegant - Vulgar, Casual - Formal.

3.3 Color Samples Selecting

According to the most popular colors used for current eyewear frames and the hues people can easily tell, 10 representative colors based on Munsell Renotation System were chosen for experiment. Figure 4 shows the ten colors: 1-R (red), 2-PK (pink), 3-Y (yellow), 4-O (orange), 5-G (green), 6-W (white), 7-B (blue), 8-I (indigo), 9-K (black) and 10-P (purple).

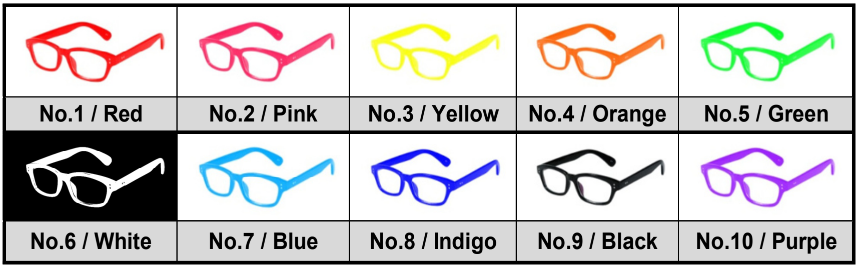

Figure 4. The 10 representative colors of plastic eyewear

3.4 Conducting Experiments

A questionnaire with 7-level Lickert scale was designed to record subjects emotional reaction toward the ten samples against the 8 Kansei adjectives.

4 Results and Analysis

4.1 Descriptive Statistics

Total of 30 subjects tested, ages from 18 to 35 years old (inclusive), with experience of wearing plastic eyewear and normal color vision ability. Table 1 shows the descriptive statistics of the 10 samples against the 8 adjective pairs.

Table 1. Descriptive statistics of the 10 eyewear samples against the 8 adjective pairs

Sample		Avant-garde - Traditional	Soft - Strong	Rational - Emotional	Common - Unique	Poise - Lively	Young - Old	Elegant - Vulgar	Casual - Formal
R	Mean	**1.6667**	**5.5333**	5.0667	**5.8667**	**6.1667**	**3.7667**	4.7333	**2.1000**
	N	30	30	30	30	30	30	30	30
	SD	.80230	1.07425	1.68018	1.38298	.59209	1.95965	1.28475	.80301
PK	Mean	1.8667	**3.2000**	5.3333	5.7333	6.1000	3.3000	3.9667	2.3667
	N	30	30	30	30	30	30	30	30
	SD	1.00801	1.68973	.99424	1.22990	1.02889	2.13590	1.65015	.99943
Y	Mean	3.1000	3.4667	4.9333	4.6333	5.1000	**2.3333**	4.6333	2.3000
	N	30	30	30	30	30	30	30	30
	SD	.75886	1.22428	.94443	1.03335	1.32222	.66089	1.54213	.59596
O	Mean	2.9333	3.5000	4.4000	5.5667	4.6000	3.6000	4.7000	3.5000
	N	30	30	30	30	30	30	30	30
	SD	1.61743	.93772	1.40443	1.04000	1.63158	1.88643	.98786	1.30648
G	Mean	2.4000	5.3333	3.9333	5.4333	5.2333	3.0333	**5.5667**	2.1667
	N	30	30	30	30	30	30	30	30
	SD	1.32873	.99424	1.70057	1.52414	1.19434	1.09807	1.13512	.91287
W	Mean	1.7333	3.5333	3.8667	3.7333	4.3333	2.5333	2.6333	3.2667
	N	30	30	30	30	30	30	30	30
	SD	.52083	1.40770	1.25212	1.99885	1.53877	.89955	1.03335	1.55216
B	Mean	2.2667	3.5333	4.1000	4.1667	5.5333	2.7333	4.9667	2.7333
	N	30	30	30	30	30	30	30	30
	SD	.78492	1.38298	1.32222	1.36668	1.00801	1.22990	1.09807	1.08066
I	Mean	2.3000	4.4667	**2.7667**	**3.3333**	4.2667	3.4667	5.0667	4.3667
	N	30	30	30	30	30	30	30	30
	SD	1.08755	1.79527	1.22287	1.29544	1.72073	1.10589	1.33735	1.35146
K	Mean	**4.3667**	5.5000	3.1333	3.8667	**1.4333**	3.3000	**2.5333**	**4.9000**
	N	30	30	30	30	30	30	30	30
	SD	1.65015	1.22474	2.02967	2.64879	.50401	1.72507	1.16658	1.53914
P	Mean	2.1333	3.3667	**5.5000**	4.7333	4.3667	3.5333	4.2333	2.9333
	N	30	30	30	30	30	30	30	30
	SD	.89955	1.09807	.86103	1.08066	1.09807	1.52527	1.33089	1.36289

The extreme values for left adjectives are shown in Red, and right in Blue.

4.2 Principal Component Analysis

Principal Components Analysis was conducted to extract major factors in describing color emotion for plastic eyewears. The Correlation Matrix was employed to extract Eigenvalues that greater than one, and then using Varimax of orthogonal axis to minimize the number of variables for each factor that has high loading of variations and to simplify factors to get the best interpretation.

Three factors were extracted to explain variations with total volume of 74.548 percent. Table 2 shows the results of Principal Component Analysis.

Table 2. Principal component analysis

Component	Eigenvalue			Squares sum loading		
	Sum	Variance %	Cumulative %	Sum	Variance %	Cumulative %
1	2.880	35.998	35.998	2.880	35.998	35.998
2	1.967	24.591	60.589	1.967	24.591	60.589
3	1.117	13.960	74.548	1.117	13.960	74.548
4	.889	11.107	85.655			
5	.521	6.510	92.165			
6	.345	4.316	96.481			
7	.178	2.225	98.706			
8	.104	1.294	100.000			

Recently, many scholars have actively studied the emotion of colors. Japanese scholar, Professor Oyama argued that there are three basic elements in analyzing the psychological factors for color perception: evaluation, potency, and activity [8].

The analysis of the factor loading values in Table 2 revealed that the three components are in line with the findings of Professor Oyama: "evaluation", "activity" and "potency". The purpose at this stage is to categorize emotional adjectives with factor analysis, so the factor loading values are used for determining which factor dimension it belongs to but not for filtering factors.

Table 3 shows the loading values for each adjective pairs while Table 4 depicting that Rational-Emotional, Elegant-Vulgar and Common-Unique are "Evaluative", Young-Old, Casual-Formal and Soft-Strong, are "Potency" while Avant-garde-Traditional and Poise-Lively being "Activity".

4.3 Emotional Factor Analysis for Color Plastic Eyewears

Table 5 shows the summary of the emotional factor analysis for the 10 color plastic eyewear samples.

Table 3. Loading values of the cognition factors for colors

Emotional Adjectives	Factors		
	1 (Evaluation)	2 (Potency)	3 (Activity)
Avant-garde - Traditional	.356	.356	.789
Soft - Strong	-.796	-.011	-.073
Rational - Emotional,	.865	-.116	-.108
Common - Unique	.690	-.510	-.353
Poise - Lively	-.130	-.653	.488
Young - Old	.300	.741	-.287
Elegant - Vulgar	.857	.210	.180
Casual - Formal	-.232	.740	.026

**Extraction Method: Principal Component Analysis.*

Table 4. Naming of the components and the composition factors

Mental Cognitive Dimensions Named		
Component	Dimensions	Composition Factors
Component 1	Evaluation	Rational / Emotional, Elegant / Vulgar, Common / Unique,
Component 2	Potency	Young / Old, Casual / Formal, Soft / Strong,
Component 3	Activity	Avant-garde / Traditional, Poise / Lively

Table 5. The summary of the emotional factor analysis for the 10 samples

Sample 1 (Red)		
	Analysis of Cognitive Factors	**Semantic Interpretation**
Evaluation	Rational - Emotional (mean=5.0667) Common - Unique (mean=5.8667) Elegant - Vulgar (mean=4.7333)	Red frame feels emotional, representative of unique, but slightly vulgar sense
Potency	Soft - Strong (mean=5.5333) Young - Old (mean=3.7667) Casual - Formal (mean=2.1)	Feels a little strong, casual look and most young sense
Activity	Avant-garde - Traditional (mean=1.6667) Poise - Lively (mean=6.1667)	Full of lively and avant-garde sense
Sample 2 (Pink)		
	Analysis of Cognitive Factors	**Semantic Interpretation**
Evaluation	Rational - Emotional (mean=5.3333) Common - Unique (mean=5.7333) Elegant - Vulgar (mean=3.9667)	Pink frame sensibility, very unique, non-vulgar sense
Potency	Soft - Strong (mean=3.2) Young - Old (mean=3.3) Casual - Formal (mean=2.3667)	Impression of soft, casual and look young
Activity	Avant-garde - Traditional (mean=1.8667) Poise - Lively (mean=6.1)	Full of lively and avant-garde sense

Sample 3 (Yellow)		
	Analysis of Cognitive Factors	**Semantic Interpretation**
Evaluation	Rational - Emotional (mean=4.9333) Common - Unique (mean=4.6333) Elegant - Vulgar (mean=4.6333)	Yellow frame sensibility, some unique, but slightly vulgar sense
Potency	Soft - Strong (mean=3.4667) Young - Old (mean=2.3333) Casual - Formal (mean=2.3)	Feels a little soft, full casual look and most young sense
Activity	Avant-garde - Traditional (mean=3.1) Poise - Lively (mean=5.1)	Slightly avant-garde and the lively

Sample 4 (Orange)		
	Analysis of Cognitive Factors	**Semantic Interpretation**
Evaluation	Rational - Emotional (mean=4.4) Common -Unique (mean=5.5667) Elegant - Vulgar (mean=4.7)	Orange frame sensibility, very personalized, but slightly vulgar sense
Potency	Soft - Strong (mean=3.5) Young - Old (mean=3.6) Casual - Formal (mean=3.5)	Feels a little soft, casual look and most young sense
Activity	Avant-garde - Traditional (mean=2.9333) Poise - Lively (mean=4.6)	A little avant-garde with lively sense

Sample 5 (Green)		
	Analysis of Cognitive Factors	**Semantic Interpretation**
Evaluation	Rational - Emotional (mean=3.9333) Common - Unique (mean=5.4333) Elegant - Vulgar (mean=5.5667)	Green frame is very personalized, but it appears to the most vulgar sense
Potency	Soft - Strong (mean=5.3333) Young - Old (mean=3.0333) Casual - Formal (mean=2.1667)	Feel strong, look young and full of a sense of leisure
Activity	Avant-garde - Traditional (mean=2.4) Poise - Lively (mean=5.2333)	Full avant-garde with lively sense

Sample 6 (White)		
	Analysis of Cognitive Factors	**Semantic Interpretation**
Evaluation	Rational - Emotional (mean=3.8667) Common - Unique (mean=3.7333) Elegant - Vulgar (mean=2.6333)	White frame feels a little rational, a little unique, and looks noble
Potency	Soft - Strong (mean=3.5333) Young - Old (mean=2.5333) Casual - Formal (mean=3.2667)	Feels a little soft, casual look and most young sense
Activity	Avant-garde - Traditional (mean=1.7333) Poise - Lively (mean=4.3333)	Full of lively and avant-garde sense

Sample 7 (Blue)		
	Analysis of Cognitive Factors	**Semantic Interpretation**
Evaluation	Rational - Emotional (mean=4.1) Common - Unique (mean=4.1667) Elegant - Vulgar (mean=4.9667)	Blue frame slightly vulgar sense and somewhat unique
Potency	Soft - Strong (mean=3.5333) Young - Old (mean=2.7333) Casual - Formal (mean=2.7333)	Feels a little soft, casual look and most young sense
Activity	Avant-garde - Traditional (mean=2.2667) Poise - Lively (mean=5.5333)	Full of lively and avant-garde sense

Sample 8 (Indigo)		
	Analysis of Cognitive Factors	**Semantic Interpretation**
Evaluation	Rational - Emotional (mean=2.7667) Common - Unique (mean=3.3333) Elegant - Vulgar (mean=5.0667)	Indigo frame the most rational and popular, but slightly vulgar sense
Potency	Soft - Strong (mean=4.4667) Young - Old (mean=3.4667) Casual - Formal (mean=2.1)	Feels a little strong, casual look and most young sense
Activity	Avant-garde - Traditional (mean=2.3) Poise - Lively (mean=4.2667)	Full of lively and avant-garde sense

Sample 9 (Black)		
	Analysis of Cognitive Factors	**Semantic Interpretation**
Evaluation	Rational - Emotional (mean=3.1333) Common - Unique (mean=3.8667) Elegant - Vulgar (mean=2.5333)	Black frame feels rational, common, and noble
Potency	Soft - Strong (mean=5.5) Young - Old (mean=3.3) Casual - Formal (mean=4.9)	Feels strong, looks a little young and formal
Activity	Avant-garde - Traditional (mean=4.3667) Poise - Lively (mean=1.4333)	Feels traditional and very stable

Sample 10 (Purple)		
	Analysis of Cognitive Factors	**Semantic Interpretation**
Evaluation	Rational - Emotional (mean=5.5) Common - Unique (mean=4.7333) Elegant - Vulgar (mean=4.2333)	Purple frame feels very emotional, somewhat vulgar sense and unique
Potency	Soft - Strong (mean=3.3667) Young - Old (mean=3.5333) Casual - Formal (mean=2.9333)	Feels soft, looks somewhat young and casual
Activity	Avant-garde - Traditional (mean=2.1333) Poise - Lively (mean=4.3667)	Full of avant-garde and lively sense

5 Conclusions and Suggestions

This study investigated 10 color eyewear samples with eight adjective pairs of Kansei image, and found that there were significant differences among them. Which indicated that plastic eyewear with different frame and temple color will affect users' psychological awareness of the products.

The results show that the red frame has the most "avant-garde" sense, the most "strong" as well as "unique" oriented; pink frame is "soft"; yellow frame feels most "young"; green frame is "vulgar"; indigo frame showes the most "popular" and "rational"; black frame has "traditional" feel, and the most "stable", "noble" and "formal" at the same time; while purple frame represents the most "sensational".

On the whole, the plastic eyewear gives the avant-garde feel, looks young and casual. The results can serve as a reference to Taiwan's manufacturers for producing the right colors to fit user's individual needs.

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A Strategy for Customer-oriented Human-centric Product Conceptualization

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Abstract. A functional-commercial analysis strategy (FCAS) is proposed to facilitate customer-oriented and human-centric product concept generation and selection. First, general sorting is utilized to elicit the initial product platform, which is then used to generate initial design options of a specific product. After that, designers contribute importance ratings on the functional-commercial criteria with regard to the design options, which are elicited using repertory grids. In order to make a trade-off between cost- and time-related concerns, these ratings are first employed to reduce the number of initially-acquired design options, and then used as the input features to the restricted coulomb energy (RCE) neural network. The RCE network is first used for classifying these design options into different patterns, i.e. cost-time-pair. The classification results can subsequently serve as the bases for the selection of the preferred design options. A case study on wood golf club design is conducted to demonstrate the proposed method.

Keywords. Concept generation, concept selection, human-centric, customer-oriented, general sorting, repertory grids, restricted coulomb energy neural network.

1 Introduction

For customer-oriented human-centric product concept generation, it has been established that a unified design space for product platform and product families is essential. Product platform is a scheme by which the functions of a product are assigned to physical properties that formulate diverse design options, i.e. design alternatives of a product family [1]. Based on this understanding, several strategies have been developed to realize systematic product platform modelling. These strategies, which adopted functional decomposition, include topological design [2], function-form structure [3] and integrated component design [4]. Moreover, previous research revealed that the selection of best design option is extremely important for making design decisions in product conceptualisation [5]. Although

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existing approaches attempted to address the possibilities of preference selection of product concepts, they concentrated mainly on the functional (human-centric) perspective, which is not yet comprehensive enough for product conceptualisation.

As a result, the commercial (customer-oriented) perspective of product concept development has attracted the interest of researchers from both academia and industry [6]. With regard to the commercial perspective, project cost and time duration can vary greatly depending on the selected design options, especially in the early stage of product conceptualization [7]. In general, to improve time-efficiency related to project scheduling requires minimizing the time duration that meets the project constraints, e.g. resource limitations and delivery date. Other studies have also suggested that criteria such as cost-efficiency should also be considered concurrently to coordinate both project completion and cost saving at product conceptualizing stage [8]. In this regard, cost- and time-related issues relating to design options are important in narrowing down the number of initial design options and conducting commercial feasibility analysis.

2 System Architecture

Based on the notion that the integration of functional and commercial perspectives for product conceptualization is desirable, a framework of the functional-commercial analysis strategy (FCAS) is proposed in this study. The framework (Figure 1) is divided into two major inter-linked domains: functional analysis, and commercial analysis. Underlying the functional analysis domain is a process to narrow down the design solution space from a large number of design options, i.e. design variants or alternatives of a product family, into preferred options. The commercial analysis domain operates concurrently to assist in analyzing cost- and time-related choices of product concepts. In this respect, an implemented FCAS incorporates the following scenarios (Figure 1):

1. Designers or domain experts using general sorting to elicit the initial product platform of a specific product. Design attributes can be obtained based on the product platform via hierarchical representation. Meanwhile, initial design options are formed by combining various alternative values.
2. In the same manner, the cost- and time-related criteria groups are elicited using repertory grids and then represented through a multivariate method. The designer importance ratings on both criteria groups with regard to each design option are respectively used as the input features to the restricted coulomb energy (RCE) neural network for evaluating classification results.
3. To narrow down the number of initial design options, a cost-time-pair, which is a trade-off between project cost- and time-related criteria resulted from the RCE network, is then used as an index for selecting preferred design options.

The proposed strategy can be treated as a design knowledge management process from a knowledge handling viewpoint. Accordingly, the FCAS embodies three cohesive components: design knowledge acquisition, representation, and evaluation modules.

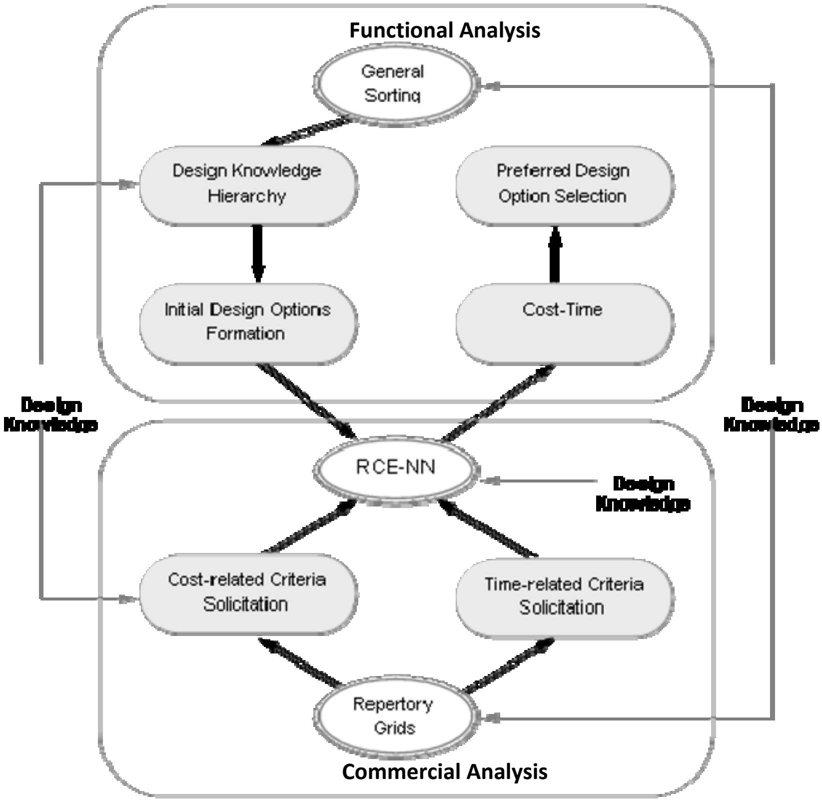

Figure 1. Illustration of the FCAS

3 System Modules

3.1 Design Knowledge Acquisition Module

In this module, general sorting and repertory grids are adapted to simultaneously acquire design knowledge. They are employed to elicit design attributes regarding a product platform for functional analysis and design criteria relating to cost and schedule issues for commercial analysis, respectively. The details of these two techniques are presented below.

(i) *General sorting*

In the classic form, the technique involves the following 3 steps [9].

STEP 1: The items can be obtained from the designers, related literature, and other sources such as historical records. The result of this step is a list of terms used for the specific problem.

STEP 2: An elicitor asks designers to sort the terms into different groups until no terms can be divided any further. The elicitor then determines the reasons or criteria by which designers grouped or separated the terms.

STEP 3: Once sorted, the terms are organized into a hierarchical structure. More than one hierarchy may be required if many terms are used.

(ii) *Repertory grids*

In its classic form, the technique comprises the following steps [10].

STEP 1: Selection of a group of elements that represent the relevant aspect of the domain under study.

STEP 2: Elicitation of significant constructs through a triadic elicitation method. This involves presenting sets of 3 elements and asking how 2 are similar to each other and thus different from the third. This provides one pole of a construct. The other pole is elicited either by asking in what way the third item was different or asking what the opposite of the pole just elicited is.

STEP 3: Evaluation of all the items individually in respect of each of the elicited constructs. Frequently this evaluation takes the form of a rating value. A grid is constructed in which the sides are formed with the poles of the constructs, and the top with the elements. Cell values represent the ratings for each item on each construct.

3.2 Design Knowledge Representation Module

Design knowledge solicited via general sorting and repertory grids techniques are represented in the forms of a design knowledge hierarchy (DKH) and cost- and time- related criteria, respectively. The details are provided as follows.

(i) *Design knowledge hierarchy*

A design knowledge hierarchy (DKH) [11] is adopted to represent designers' knowledge for product platform formation via general sorting technique. This DKH, which organizes the designers' knowledge registered, comes with a four-level top-down designer-directed architecture for decomposing a specific product concept. In this multilevel taxonomy, each design attribute stemmed from the high-level product concept can be decomposed into several sub-attributes. The resulted individual sub-attribute contains several alternative values. Initial design alternatives can be selected from different combinations of alternative values for different parts to form a specific product family.

(ii) *Cost- and time-related criteria*

In order to proceed to commercial analysis with a compromise between cost- and time-efficiency, cost- and time-related criteria are used for selecting preferred design options. Accordingly, two sets of criteria (cost-related and time-related) in strong relation with product life-cycle considerations are elicited by designers using the bespoke repertory grids technique. Cost-related criteria may include product price, material, performance, volume, quality, customizability, innovativeness, marketability, sustainability and affectivity. On the other hand, time-related criteria may include product lifetime, modularity, reliability, upgradeability, complexity, flexibility, lead-time, use-time, supply-chain and user-friendliness.

3.3 Design Knowledge Evaluation Module

In this work, the RCE network is used as an adaptive pattern classification engine for quantitative reasoning and decision-making.

(i) *Algorithm of RCE network*

The RCE network generally consists of three layers: the input layer, the hidden layer, and the output layer. The input layer is fully interconnected with the hidden layer. The hidden layer is partially interconnected with the output layer, which offers the response of the network to the activation patterns such as output patterns of weak, moderate and strong level. Moreover, each hidden unit projects its output to one and only one output unit. Mathematically, the activation function of j^{th} hidden unit is given by [12]

$$z_j(\boldsymbol{x}) = f(\xi) = f[r_j - D(\boldsymbol{\mu}_j, \boldsymbol{x})] \tag{1}$$

where μ_j is a parameter vector called center, r_j is a threshold, and D is the pre-defined distance between μ_j and x, e.g. Euclidean distance.

The j^{th} hidden unit in the RCE network defines the unit's influence region with location at μ_j and size of r_j. f is the threshold activation function and is given by

$$f(\xi) = \begin{cases} 1 \quad (\mathit{fire}) & \mathit{if} \quad \xi \geq 0 \\ 0 \quad (\mathit{inactive}) & \mathit{otherwise} \end{cases} \tag{2}$$

The RCE network training involves two mechanisms: unit commitment and modification of hidden unit threshold. Initially, a random sample pattern x^1 is selected from the training set. The allocated hidden-unit centre, μ_1, which projects to its output unit z_1 representing the class of x^1, is set to x^1. Its threshold r_1 is set to a pre-defined maximum size of influence region r_{max}. Next, a second random example x^2 is fed into the current network.

(ii) *Specifying RCE network*

The training process continues till no new units are allocated and the size of the influence region of all hidden units converges. After training, the classification proceeds using the trained network. The designer importance rating assigned to cost- and time-related criteria is used as an input to an RCE network to estimate the preference levels to cost and time aspects of the project, respectively. A cost-time-pair, a trade-off between project cost and time duration resulted from the bespoke RCE network, is subsequently used as an index of selecting preferred design options. The reliability of the RCE network output such as weak, moderate or strong level for project cost and time duration with respect to each design option may be affected by the features and the volume of data used for training.

In RCE network, each output unit performs a simple OR function on the input arriving from the hidden units connected. The classification strategy pertaining to output activation and related decision-making is described in Table 1. In particular, if 'Identified' situation has been detected, there are three possible RCE network classifications: weak correlation (State 0), moderate correlation (State 1), and strong correlation (State 2). On the other hand, 'Unidentified' and 'Uncertain' situations correspond to different output activations (Table 1). Except for the 'Uncertain' and 'Unidentified' situations, the possible situations of time-cost-pair regarding each design option based on the combination of RCE outputs for project cost and time duration can be obtained. The decision-making scheme is activated when one or more than one cost-time-pairs are activated or fired as 'S-S', the design options with regard to these pairs can be selected as the preferred options. Otherwise, no significant preferred design options are detected.

Table 1. Classification strategy regarding output activation of the RCE network

Possible Situation	State 0 (W)	State 1 (M)	State 2 (S)	Decision-Making
1	**0**	**0**	**0**	**Unidentified**
2	**1**	**0**	**0**	**Identified**
3	**0**	**1**	**0**	Identified
4	**0**	**0**	**1**	Identified
5	**1**	**1**	**0**	**Uncertain**
6	**1**	**0**	**1**	Uncertain
7	**0**	**1**	**1**	Uncertain
8	**1**	**1**	**1**	Uncertain

Notes: 0 stands for inactive and 1 stands for fire, W, M and S denotes weak, moderate and strong level respectively.

4 Case Study

Product concept generation and selection of wood golf clubs is used as an example to illustrate the proposed FCAS. A four-level DKH was first elicited using general sorting for product concept generation of wood golf club design. As shown in Figure 2, the DKH comprises a number of design attributes, relevant lower-level sub-attributes and alternative values. Based on the morphological configuration, design options could be obtained by combining different alternative values.

As for commercial analysis, cost- and time-related criteria in strong relation with project cost and time duration were elicited by designers using repertory grids. A triadic elicitation method was employed to elicit salient design criteria more broadly. Cost-related criteria included product quality, product safety, recycling consideration and production volume. Time-related criteria included user-friendliness, product affectivity, design complexity and design innovation. Thereafter, the designer importance ratings (from 0.1 to 1.0 with 1.0 represents the most important rating) are assigned to the cost- and time-related criteria, respectively, and then used as the input features to the RCE neural network. For instance, if 10 cost- or time-related criteria are graded with respect to 80 typical design options generated from the DKH, an input matrix of 10×80 dimensions will form the input features for cost and time considerations, respectively.

The network's output is the pattern for a specific design option regarding those input features of cost or time perspectives, respectively, such as weak level (State 0), moderate level (State 1) and strong level (State 2), as explained in section 3.3. After training, the classification proceeds using the trained network. There are two possible output patterns: one selected from any of the three classifications (State 0, 1 or 2) and the others denoted 'Uncertain' or 'Unidentified' due to the output activation shown in Table 2. A cost-time-pair, a trade-off between project cost and time duration resulted from the bespoke RCE network, is subsequently used as an index for selecting preferred design options. In Table 2, 'Others' amongst cost-time-pair indicate that either one or both output patterns have been detected as 'Unidentified' or 'Uncertain'. Only the 'S-S' pair was used for design decision-making, i.e., 6 out of 80 design options were activated as preferred options.

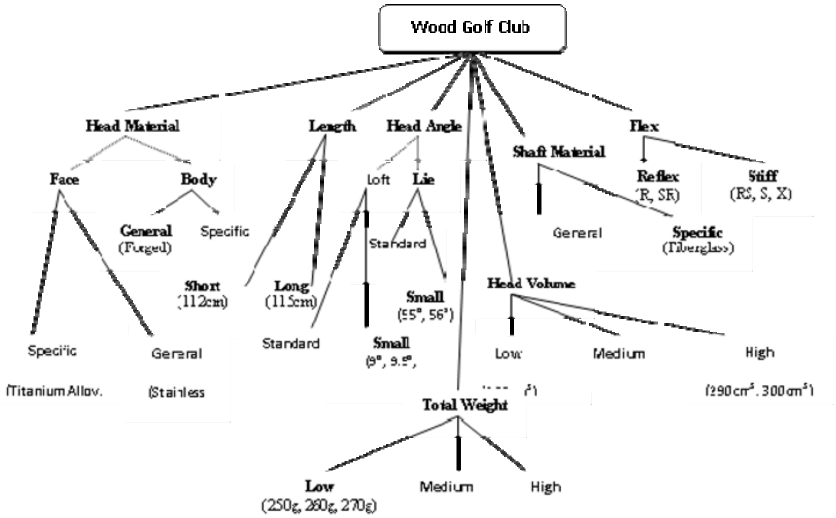

Figure 2. Representation of the DKH

Table 2. Classification results from the RCE network

C-T-P	S-S	S-M	M-S	S-W	W-S	M-M	M-W	W-M	W-W	Others	Total
Number	6	9	7	5	4	16	11	10	7	5	80

Notes: C-T-P stands for cost-time-pair; W, M and S denotes weak, moderate and strong level respectively; others include unidentified or uncertain situations regarding either cost- or time- output.

There are logical correlations among option values regarding different product orientations to which design options are typically elicited. Summarized in Table 3, it was found that: 1) the preference selection of design options revealed that the coordination of cost- and time-related issues was pertained to different considerations from corresponding sub-criteria involved in product life-cycle cost- and time-efficiency; and 2) six design options were chosen as preferred options, which contained quite different alternative values from each other.

It appeared that the 6 preferred design options covered various customer preferences, i.e. for female beginner golfers, older male golfers, and younger golfers, respectively. Thus, this strategy could be employed in an effective manner in the case of a relatively broad coverage of customer orientations was detected.

Table 3. Alternative values of preferred design options

Alternative Value Design Specification	Preferred Design Option					
	# 1	# 2	# 3	# 4	# 5	# 6
Head Material (Face/Body)	Ti Alloy/ Casting	Ti Alloy/ Forged	Stainless Steel/Forged	Ti Alloy/ Forged	Ti Alloy/ Forged	Maraging Steel/Forge d
Length (cm)	115	112	115	115	115	112
Head Angle (Loft/Lie^0)	$9^0/55^0$	$10^0/56^0$	$11^0/57^0$	$11^0/57^o$	$10^0/55^0$	$12^0/57^0$
Total Weight (g)	270	250	300	290	280	270
Head Volume (cm^3)	260	280	300	300	270	290
Shaft Material	L Carbon	L Carbon	Carbon	Carbon	Carbon	Fibreglass
Flex	X	SR	S	RS	S	R

Notes: L denotes light; S denotes stiffness; R denotes reflex; X denotes extraordinary stiffness; SR is the level between R and S; RS is the level between S and X.

5 Conclusions

Product conceptualization is regarded as a key activity in new product development in which product concept generation and selection plays a crucial role. Although numerous studies have been conducted to address the selection of preferred product concepts, most of these studies concentrated mainly on the functional perspective, which is far from comprehensive enough. Therefore, a functional-commercial analysis strategy (FCAS) has been proposed in this study. A case study on wood golf club design has been conducted to illustrate the FCAS proposed. Utilising this strategy, the impacts have been dissolved pertaining to knowledge acquisition, representation, and evaluation for product platform generation, and preference selection of product concept while making a trade-off among functional and commercial perspectives as well as cost- and time-related issues. It is envisaged that the proposed strategy can be deployed for more effective product conceptualization in today's competitive globalized business environment.

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Investigating Persuasion in Sustainable Design to Change Behaviour and Attitude

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Abstract. Sustainable design is critical to our life and is considered a future trend. On the basis of human-centered design method, we have utilized a persuasive design prototype as a research tool to investigate the potential users' perspective on sustainable concept. With the findings we were able to understand the influential factors of sustainable design with respect to food-mileage concept. Furthermore, we foresee that these findings can be referenced for future design/research regarding attitudes and behaviour change.

Keywords. Persuasive Technology, Social Influence, Behaviour Change, Human-Centered Design, User Experience, Food Mileage, Sustainability

1 Introduction

The global economy growth and advancements in novel technologies are rapidly changing our society and lifestyles. In the era of consumption, today's lifestyle readily suffices the demand of ever-growing consumption of goods. The environmental implications of the global spread of mass consumption for resource use are staggering, the environmental problems regarding sustainability is indeed the major issue that the world is facing at present. The advancements in international shipping and refrigeration techniques nowadays have transformed the goods transporting. With this, the massive amounts of food import have become part of our life which we take for granted. In 2005, 86.5% of total worldwide energy consumption was derived from the combustion of fossil fuels which produce carbon dioxide [5] and has led to a significant increase in concern for environmental issues. Long distance food transportation is a major consumer of the fossil fuels, increasing greenhouse gas emissions which contribute to global climate change.

Due to modern technology, food can be imported easier than before. "Food mileage" is defined as the distance food travels from where it is grown to where it is ultimately purchased by the consumer or end-user [14]. Higher the food mileage higher the fossil fuel consumption, thus, in our day-to-day life, food mile is one of the vital issues concerning environmental sustainability. However, the concept of

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"Low Food Mileage" and "Local Production for Local Consumption" is currently still unfamiliar and new to people. Most consumers do not understand today's complicated global food system and much of the food production and processing occurs far away from where they are consumed [15]. However, it has become customary that people buy imported goods in supermarkets for daily consumption. Even if some people are concerned about the environment, there is no seemly service platform facilitating environmental protection and sustainability on grocery shopping and home cooking.

Being a part of the engine of capitalism, the consuming behaviour and our lifestyle driven by the "need" to acquire more stuff hold profound implications. There is no doubt that individuals play important roles in local environment, yet it is likely to neglect the severity of environmental implication while the consequences are not striking or closely related to our life. Consequently, even though people have the eco-awareness in their mind, "eco-friendly" is still a beautiful slogan rather than an actual action that they will carry out every day. The same as consumption, sustainability is a critical issue that should be well formed [3]. Sustainable Design (Eco-Design) that originated from the introspection in the environmental damage reflects designers' moral values and social responsibility. It is an important trend in the near future which is not only concerning an element in the brand image but also a social responsibility that designers have to take.

The objective of this study is to focus on observing the mental model change under the framework of persuasion in eco-design, as well as understanding that how the persuasive design is influential to people's mindset. We expect to reveal different outcomes that different persuasive design approaches bring about at the certain stages – that is, in the genre of the interaction design, regarding inculcating sustainable attitudes, which is the most effective? Which is the most acceptable? Which generates engagement? Which influenced not only the behaviours but also the mindset? Through this study we expect to collect the design directions regarding the susceptibility towards sustainable design based on the findings as appropriate references in the future research/design.

2 Theoretical Background and Related Work

2.1 The Research Scope of Persuasion

The grounding theory of this study is social science and psychology theories with respect to persuasive technology and the psychology of persuasion. Persuasion signifies changing people's attitudes and behaviours with intent, that the act of "persuasion" must be an intentional act, include in a message, and be accepted by free-will [13]. Through different media, persuasive techniques attempt to influence one' ideas, behaviours and attitude toward any issues.

2.2 Captology: Persuasive Technology

Currently, there have been studies that explored the application of persuasive technology to environmental sustainability. Mobile platforms such as SmartTrip [10] and GreenScanner [16] are served as a kind of persuasive tools [8], which are utilized to establish users' expectation by providing information, advice, and simplified operation. These designs may be able to result in immediate responses and positive feedback, yet the context that whether and how the attitude of environmental protection is rooted in users' mind was still insufficient.

Captology coined by Fogg refers to persuasive technology which is broadly defined as using computers to change people's behaviour and attitude, categorised by the dimensions of functional roles as either tools, media, and social actors. [8]. Computer as *Persuasive Tools* provides people with new ability or power, reduces barriers (time, effort, costs), provides information, advice [8]. As *Persuasive Media* it provides first-hand learning, insight, experience, and it promotes understanding of cause/effect relationships and motivates. It usually works effectively on tricky user groups to present ideas which are difficult to persuade by providing experiences. Technologies can also function as social actors to create relationships. It establishes social norms; invokes social rules, dynamics, and expectations; provides social support to influence people via social cues [8]. The aforementioned are the main issues this research intends to explore.

2.3 The Psychology of Persuasion

The six weapons of influence theory proposed by Cialdini have suggested six approaches of how to influence users' attitude [4]. Buss [7] has argued that the skills used to make others more compliant have something to do with our understanding of others, our own social status, and the nature of requests. The associated factors include that people are more likely to be compliant, in good moods [9]. Fehr and Gächter [6] have also demonstrated that the potential for reciprocal actions by participants increases the rate of contribution to the public good, providing evidence for the importance of reciprocity in social situations. People tend to do things that they see other people are doing, and believe what other people identify with. We intended to explore how the designs were aided to promote sustainable concept and to examine the influence from others.

2.4 People, Other People and the Environment

Besides the aforementioned Social Influence Theory, in terms of influencing by the external surroundings, earlier studies [11] had argued that people perform much learning by watching and copying other people. By imitating the observed behaviours the observers would fossilize the acquired behaviours and obtain positive reinforcement. The studies were further expanded [2] and called Social Cognitive Theory (SCT). Under this framework he believes that how people motivate and regulate their behaviour is a process of constant interaction between individuals and their unique social environment. From this theoretical perspective, human functioning is viewed as the product of a dynamic interplay of personal, behavioural, and environmental influences [1]. Based on this theory, we intend to observe the pattern of how the users interact with the others and the external environments and explored the application and matching of design approaches.

3 Method

The study focuses on identifying the user's contextual response to the persuasive and influential factors of sustainable design. We applied methods on the basis of human-centered design (HCD; or user-centered design, UCD) in the prototyping design process which users influence how the design takes shape. [12] The targeted subject is efficiency-oriented career mother aged 30 to 50. Rapid Prototype was adopted in this research with the scenario-based method, followed by the in-situ prototyping testing and in-depth interviews conducted in the selected community-based supermarket near the residential area.

3.1 Food Mileage, Supermarkets and Sustainability

Environmental issues related with sustainability in daily life are extensive. The concept of food mileage was brought in as the concept for the research tool in this study owing to its characteristic of close-relation and importance to our daily life. The influenced aspects of the public to green design were discussed in the platform use focusing on the issue of food mileage. Moreover, supermarkets were chose as the context for conducting the *in-situ* user testing because it is where the food purchasing (high and low food mileage included) behaviour usually happens.

3.2 The Personas

People have different level of sustainable attitude. In order to understand the potential target user deeply, we adopted persona - a user-centered approach to create a personality profile during the preliminary study process. 11 individuals were interviewed at this stage regarding their lifestyle and the exposure, the value towards sustainable concept. Through the interviews, we were able to identify the primary persona – working mother – adult female who has a stable job and whose youngest child is under 18. They are both a busy full-time worker and a housewife who shoulders two major responsibilities. They do not have much time strolling in supermarkets after work during weekdays or on weekends and their concept of environmental protection is rather traditional such as “less use of plastic bags”, or “recycling”. More importantly, they consider environmental protection really essential but do not actually put it into practice at usual due to: (1) Taking extra time and not easy to fully put into effect; (2) Incomprehensive how environmental protection is implemented and the implication; and (3) Conception of sustainability at times far-fetched in daily life.

3.3 Mixed-fidelity Prototype

According to the context and the users that we addressed, a prototyping system "SuperEco" (Figures 1, 2) was developed as a testing tool in our study. The features as persuasive approaches in the system were defined from the persuasive theoretical framework described in Chapter 2. Catering supermarket customers, SuperEco is an eco-design based service design. It includes an on-screen platform that is attached on the shopping cart and on few of physical displays, signboards in the supermarket so as to encourage users to purchase low food mile products, as well as influences people's attitude towards sustainability. The design approaches were developed from the insight of the aforementioned theoretical background.

Figure 1. (left) Screen Showing Low Food-Mile Try-Out Dishes

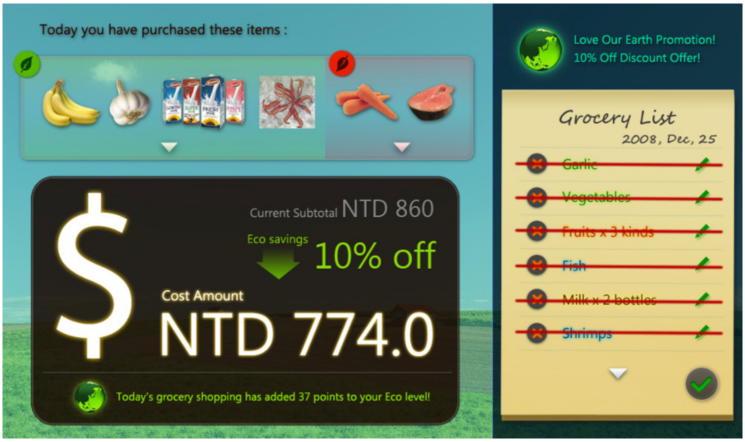

Figure 2. Screen Showing The Low Food-Mile Discount Feedback At The Cashier

3.4 In-situ Scenario-based User Testing & In-depth Interview

After the prototype is established, eight working mothers, aged 30-50 were recruited in the user testing. All participants have the habit of purchasing regular foodstuff in the community-based supermarket for more than three years.

The testing was carried out in a local community-based supermarket and was audio-recorded. The testing time was approx. 50 minutes to an hour and NTD$200 cash was given as the reward for each person. “In-situ scenario based user testing” was adopted in this study to provide the user with simulated experience in the context. Platform concept, scenario instruction were described to the participants, they were also told to provide feedback by as much how they usually feel shopping in the supermarket as possible. To better understand the interaction and the context between users and the persuasive platform, semi-structured in-depth interview is also adopted throughout the user study.

4 Results

In this section we present the results of the in-depth interviews in the user testing. The methodology - Affinity Diagram was adopted to examine the data collected from the qualitative interviews.

4.1 Affinity Diagram (Hereafter as A/D)

A/D is used to investigate the affected aspect and the influential context. The transcript was converted into statements and sorted into 3 super headers as follows.

4.1.1 Influencing the Intention

Before the users accept the concept, there are some influential factors to raise intention in the first place. To attract their interests, fun, eye-catching persuasive tools will bring about curiosity, while simplified process will be more easily to accept. Besides, persuasive media to transmit the concept in complete and clear way and provide the sense of joint participation resulted from others’ participating behaviour (social proof) will make positive impact and raise the identity, as well as to unknowingly influence people in the context.

4.1.2 Influencing the Behaviour

After the concept is introduced to the users, whether they will take action or not depends on if their practical needs can be satisfied (e.g. low food-mile products are competitive) and if the supermarkets actually care so (e.g. various encouraging ways that the supermarket is making effort). They will try to participate, meanwhile, to check the trueness and decide whether it is worthwhile continuing.

4.1.3 Influencing the Attitude

To root the concept and change people’s attitude requires reliable, credible and trustworthy persuasive media, tools or social actors. These kinds of approaches will construct trust and guarantee so that the users will feel comfortable to become followers, then promoters. And the incentives/positive feedback/encouragement will bring about self-praise, self-satisfaction as thus to reinforce the engagement (reinforcement in social cognitive theory).

5 Discussion

5.1 The Persuasive Approaches and the Corresponding Responses

5.1.1 Users who like spark of freshness but dislike trouble

" Lower the burden; simplify environment setting" is one of the most critical approaches among persuasive tools, and in our research, this principle also works on people effectively in sustainable design. Before the users started to accept the ideas (attitude not rooted), it is able to form an instant attraction to the participants. The interviews revealed that they similarly responded that they are curious towards interesting things; they want to try new things; and they notice eye-catching at the first glance, etc. Those responses showed that presenting "spark of freshness" is appealing. However, it is notably that this kind of approach would only trigger their "idea" while what really induces them to participate is its convenience and easy to approach.

5.1.2 Cultivate trusts through learning

During the new experience for the user, by transfusing the new idea, new knowledge can be learned effectively. Under the nurture of the context for sustainable development, "Learning" itself is no longer a mean of the information transmission, but a way to enable user to dig in deep into the issue. On the other hand, the persuasive media played as rational and objective role during the construction of attitude, therefore, on the contrary, the user are likely to receive information comfortably and willing to get involved in the context. In addition, it is uncovered that by educating the user, they will be aware of their space for improvement. These information, which were built on their existed attitude are readily matched and effected to their existed attitude.

5.2 The Influential Factors Among the Community

5.2.1 Ambience is Inspiring:

The influence of surroundings plays a role as a stimulant rather than initiation in this study. All users indicated clearly that even though ambient information[1] will not directly affect the behaviour for a newbie, it can successfully elicit their curiosity and guide them to experience the vibrant ambient of theme activities from

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[1] Ambient information means that messages received in the arena are transmitted from matters in the surroundings.

the arena. Besides, from the interviews, we can see that purchasing food ingredients is more likely a goal oriented[2] activity, and it has more to do with personal preference. Thus, if the exterior environment at the time and other people's behaviour has no direct relation to it, they will be inclined to make their own decisions and concern about their own needs.

5.2.2 The Sense of Joint Participation is Necessary:
Similar to the environmental factor, the commonality between sense of mutual participation[3] and ambient information is that they can elicit the users' curiosity and are willing to see what activities that others are participating. It is not only interesting to the users, but it will also arouse a feeling for them that other people understand what is happening currently, and elicit them to get to know it by themselves. In terms of doing something eco-friendly, they also tend to hope others to join in with them together. In addition, the accuracy in determining the sense of mutual participation is a very important key. In the begging stage of knowing these concepts, the highly accurate number of participants is merely an obscure idea for them, while the introduction of a broader concept means more for them. Thus, we can conclude that the influence of sense of mutual participation on sustainable concept will vary according to the users' understanding and experience. That is to say, to start in a broader manner can help transmit messages and arouse users' concern, e.g. other people have also bought this item. After the users have such an idea, the influence of a concrete number and message[4] will be far more important.

6 Conclusion

Through this study, we applied design approaches based on persuasive technology and the psychology of persuasion regarding behaviour change as a research tool to investigate the users' responses and how they are effected in the context of sustainable services. Through the human-centered evaluation process, the involvement of the users enables us to obtain the real context of the influencing factors and their preliminary ideas toward sustainable design. Yet this study is only the primary discussion, and provides basic suggestions to design projects that focus on changing people's attitudes. In the future, there can be further studies on the practical fields or implement of the activities that closer to the real use scenarios.

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2 Users are here today not just for randomly visiting, but for a certain activity.
3 It means the feeling of participation from others in the arena.
4 For example, how many people have bought this today?

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The Consistency Between the Real Affordance and the Perceived Affordance–in the Case of Gripping a Mug

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Abstract. In our daily life, those products which are misapplied frequently are always because they does not provide a proper clue for users. If they did, however, another question is whether human beings could perceive it intuitively. There still exists a fuzzy zone to explain the difference between the real affordance and the perceived affordance. The purpose of this study is to discuss how human beings perceive the characteristic of physical sizes. This study uses mug as an example to show that the handle scale and size would affect the way human beings reach out fingers to grip a mug. We found that when people trying grip a mug unconsciously or directly, the length of the handle is the most important factor that would affect their real affordances and behaviors.

Keywords. Affordance, perceived, multiple scale sizes, mug

1 Introduction

“Affordance” is created by Psychologist, James J. Gibson in 1979 in the domain of biological psychology. The original Gibsonian affordance permits that: the creatures don’t have to perceive how to afford the environment (Gibson, 1979). Later, Donald Norman applied Gibsonian affordance into product design field, interpreting that human would interact with products according to the affordance which is given by the object (Norman, 1988). Afterward, Norman redefined and adjusted his theory continuously. He admitted that the concept of “affordance” in biological psychology and that in the design psychology exists some differences. As a result, he proposed that Gibsonian affordance is “real affordance”, and the one he defined is “perceived affordance”. Moreover, researcher found that “perceived affordance” might not be completely matched to the “real affordance” (Sasaki M.,2004).

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One key point Norman suggested in his book is that realizing what "affordance" is can help people to design a better product for users to use it easily (Norman, 1988). However, according to the original definition of Gibsonian affordance, the affordance is related to the creatures' physiological sizes and the objects' sizes. That is to say, the affordance might be affected by the ratio of components' sizes of a product. This might be the reason why people always feel confused and misapply some products. As Ming-Sung Lin and Sheng-Houng Lin mentioned that the meaning of affordance did not change suddenly (1997). Instead, the affordance might change according to the product's physical scales and sizes. There still exists a fuzzy zone to explain the difference between the real affordance and the perceived affordance. The purpose of this study is to discuss how human beings perceive the physical scales and sizes of products.

Taking mug for example, mug is usually used to hold very hot beverages such as coffee and hot chocolate. If people accidently knock over the mug because of the gap between these two different affordances, they might get scald with the hot beverages. Hence, designing a proper affordance seems to be an important issue in this case. Thus, the result of this study could help designers to find out the proper ratio range to reduce the gap between real affordance and perceived affordance. Let users' expectation can match the reality to reduce misapplying of products.

The main hypothesis of this research is that there is a gap between the "real affordance" and the "perceived affordance". And if the gap exists, we think the gap is caused by the ratio of components' sizes of a product. An experimental, 2×3 within-subjects factorial, pretest-posttest design was used to test the hypothesis.

2 Methodology

2.1 The experimental sample

Figure 1. The six experimental models

Although there are many variable would affect the way how people grip mugs, we think the most salient features of the mug is the thickness of the mug and the size of the handle. Hence, this experiment contained 6 sizes of mugs (as shown in Figure 1), including two levels of "the thickness of the mug", i.e. 3 mm and 6 mm; and three levels of "the length of the handle", i.e. 50 mm, 65 mm, and 80 mm. These sizes of the mugs are defined by a rough research of the most frequently seen sizes in the existing markets.

2.2 Participants

In total, there are eighteen students participated in this study. Twelve of them are female and six are male. Most of their age are about 18~19 years old.

2.3 Gripping Postures

According to the hypotheses which were mentioned above, the behaviors will change because the affordance gives different meaning along with the change in the ratio of components' sizes of a product. In order to measure the changes, we define how participants might grip the mugs, as different gripping postures which are shown in Table 1.

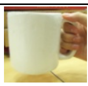
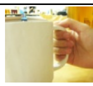
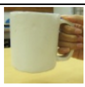
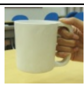
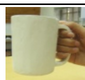
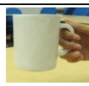
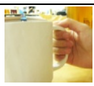
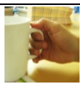
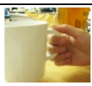
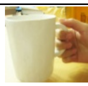
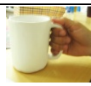
As the common sense, usually people grip a mug by using at least two fingers; and five fingers at most. The gripping postures are defined as "how many fingers the participants use to grip a mug".

Table 1. The percentage of how many fingers the participants use to grip a mug

Two fingers	Three fingers	Four fingers	Five fingers
20%	40%	60%	80%
			

2.4 Experiment processes

Table 2. The recording table of the experiment

subject	age	The width of palm	M1	M2	M3	M4	M5	M6
NO.1	19	80mm	 80%	 80%	 40%	 80%	 60%	 40%
NO.2	19	80mm	 80%	 80%	 60%	 80%	 80%	 40%
NO.3	19	70mm	 80%	 60%	 40%	 40%	 80%	 40%

This experiment is divided into two parts. First of all, let the participants pick up these six mugs naturally one by one. To avoid the "carry-over effect" during the experiment, the six mugs were shown in a Latin square random order. Instead of telling them "please grip the mug from the desk", we told them "please smell the favor of the drink". The purpose is to observe the "real affordance" when people want to approach something through gripping the mug. In order to capture how the participants react to the real affordance, we took photographs of the gripping postures during the experiment. Table2 is an example of the records. In Table2, the first three columns contain the basic information about the participants. From the forth to the last columns record the gripping postures when the participants grip the mug without thinking.

In second experiment, participants only allowed to perceive and think that how to grip these mugs and then told the researchers how they intended to do. The answers we expect are something like "how many fingers I want to grip the handle" or "what kind of the way I expect to do". In this stage, we want to understand the "perceived affordance" when human look at the products.

3 Results

3.1 Variables

There are three dependent variables and one independent variable in this experiment, as listed below:
Dependent variables: (1) the thickness of the mug; (2) the length of the handle; (3) we ask participants to grip or not to grip the mugs in different stage of experiment. The third one can also be considered as the subconscious gripping and the visual estimating.

Independent variable*:* (1) the width of participants' palm

3.2 Repeated Measure ANOVA

We suppose a pretest-posttest experiment and try to find that: is the "perceived affordance" consistent with the "real affordance" when participants try to grip the mug? The first thing we have to confirm is which variables would affect the real affordance. In the second part of experiment, another variable is included. The way we ask participants to grip or not to grip the mugs would affect the result of the gripping postures. This new factor is the reason which causes the difference between the "real affordance" and the "perceived affordance". In that way, there would be too many factors to consider about, and even it's not sure whether these factors have significant effects or not. In this situation, we have to analyze the interactions of the effects by comparing the differences between the "real affordance" and the "perceived affordance". Thus, we use the repeated measure ANOVA to exam this hypothesis.

The source of effects can be divided into three parts. First is the covariance. Secondly, the Between-Group factor is the width of the subjects' palm. Third, the Within-Subject Factor involves the length of the handle, the thickness of the mug, to grip or not to grip the mugs during the test.

3.3 The Real Affordance

Through the information shown in Table 3, the statistical data suggests that all of the variables have no significant interactions with the results but the factor “the length of the handle” ($p=0.001<0.05$).

On the other hand, according to these statistical data of table4, we can find that there is no significant differences between “ the thickness of mugs” and “the width of palm” with the gripping postures. However, the factor “the length of the handles” had very significant effects ($p=0.001<0.05$). This result indicates that the different length of the handles would affect the participants’ gripping postures obviously.

Table 3. Results of within-subjects effects among the gripping postures.

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
thicknes	92.342	1	92.342	.505	.489
thicknes * width	571.852	3	190.617	1.043	.404
Error(thicknes)	2557.778	14	182.698		
hdlength	7438.377	2	3719.189	19.603	**.000**
hdlength * width	658.148	6	109.691	.578	.744
Error(hdlength)	5312.222	28	189.722		
thicknes * hdlength	76.555	2	38.277	.171	.844
thicknes * hdlength * width	751.481	6	125.247	.558	.760
Error(thicknes*hdlength)	6285.556	28	224.484		

If we keep a closer eye on the aspect of the effect level, we can find some key points in the following figure (Figure 2). First of all, since the factor “the length of the handles” is independent with the factor “the width of palm”, we can focus on how these two factors affect the dependent variables---the gripping postures. In this profile plot, we can find that: if the width of palm gets increasing, the fewer fingers the participants might use to grip the mugs.

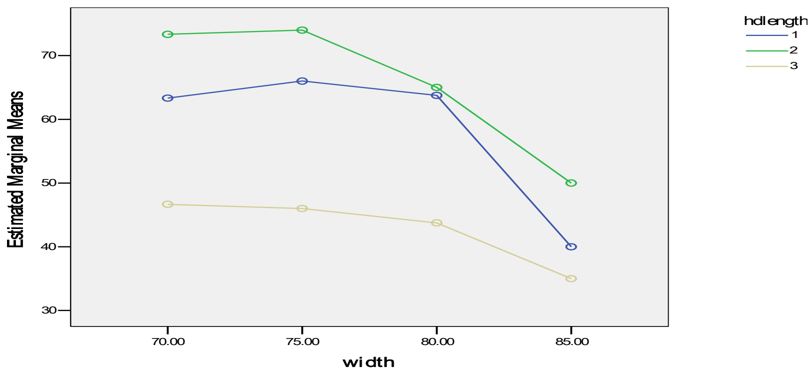


Figure 2. This profile plot shows the main effect of the handle’s length and the width of palm

The numbers of fingers that the participants used to grip mugs are listed in descending order: the middle size of the mug's handle (65mm) > the longest one (80mm) > the shortest one (50mm). The reason why participants use less fingers with the 80mm's handle than the 65mm's handle might be that if the length of the handle is getting larger, the space between the mug and handle will become too big to grip the mug firmly with five fingers. The mug might rotate around the fist and easily to be knocked over. But when the width of the participants' palm is close to 80mm, they almost used the same number of fingers to grip those two sizes of the handle --- 65mm and 80mm. Besides, no significant effect can be observed on neither "the length of the handle" nor "the width of participants' palm" to the gripping postures.

"The width of participants' palm" and "the thickness of mug" seem to have some interactions with the gripping postures (as shown in Figure 3) but none of them have a significant effect to the result. Moreover, in this experiment, the characteristics of handle size and the thickness of the mug are obviously have more significant effect on the gripping postures than the participants' palm size does.

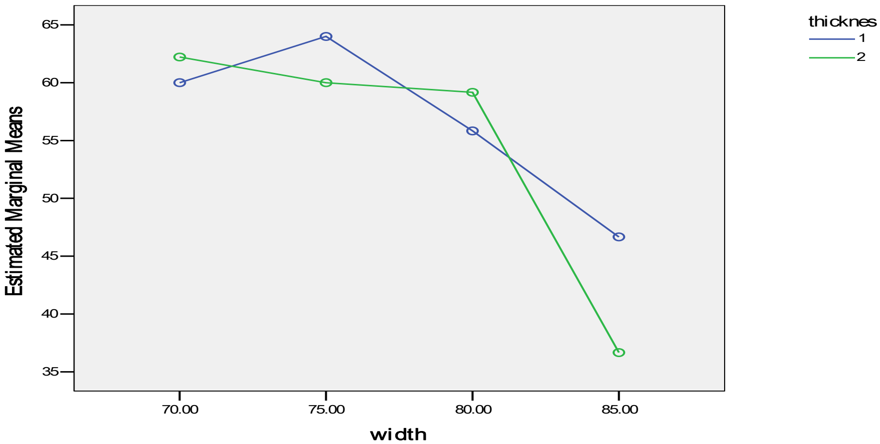


Figure 3. The factor "the width of the participants' palm" and "the thickness of the mug" has the interaction to the mug gripping posture.

3.4 The Real Affordance and the Perceived Affordance

In the following process, one more factor is involved in the analysis, i.e. the "experiment method" which refers to whether the participants are asked to grip the mug or not. In the methodology section, we discussed that there are two stages in this study. The first stage tests the real affordance and the second stage assesses the perceived affordance. In Table 4, the factor "the length of the handle" shows a significant effect on the gripping postures. Additionally, the other factors, which also have significant correlations with the gripping posture, are "the thickness of the mug" and "the length of the handle", and the "method" and "the length of the handle". Although the "experiment method" has some interactions with other factors, "the length of the handle" is still the main factor that affects the behavior of gripping a mug.

Table 4. Tests of Within-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
thick	3.216	1	3.216	.019	.893
thick * width	395.294	3	131.765	.765	.534
Error(thick)	2240.000	13	172.308		
length	19800.212	2	9900.106	71.545	**.000**
length * width	210.065	6	35.011	.253	.954
Error(length)	3597.778	26	138.376		
method	600.692	1	600.692	2.807	.118
method * width	535.425	3	178.475	.834	.499
Error(method)	2782.222	13	214.017		
thick * length	964.054	2	482.027	4.619	**.019**
thick * length * width	733.725	6	122.288	1.172	.351
Error(thick*length)	2713.333	26	104.359		
thick * method	25.818	1	25.818	.320	.581
thick * method * width	347.190	3	115.730	1.434	.278
Error(thick*method)	1048.889	13	80.684		
length * method	1556.259	2	778.130	6.353	**.006**
length * method * width	262.614	6	43.769	.357	.899
Error(length*method)	3184.444	26	122.479		
thick * length * method	128.185	2	64.093	.373	.692
thick*length*method*width	927.712	6	154.619	.900	.509
Error(thick*length*method)	4464.444	26	171.709		

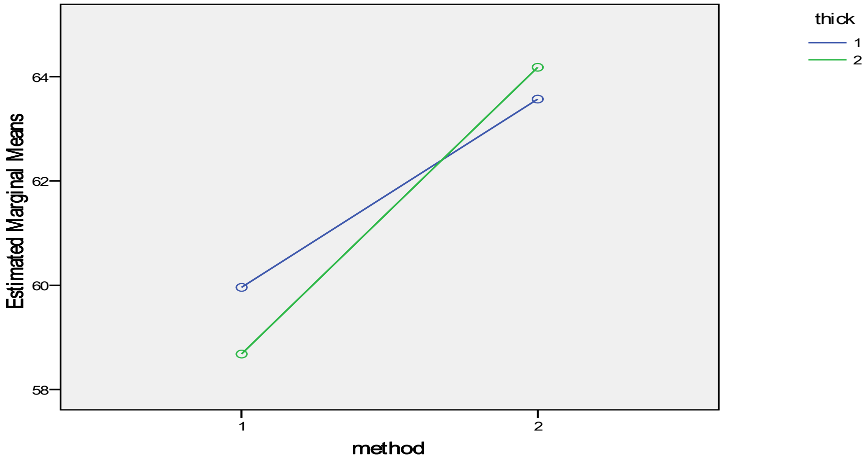


Figure 4. The correlation between "experiment method" and the "thickness of the mug"

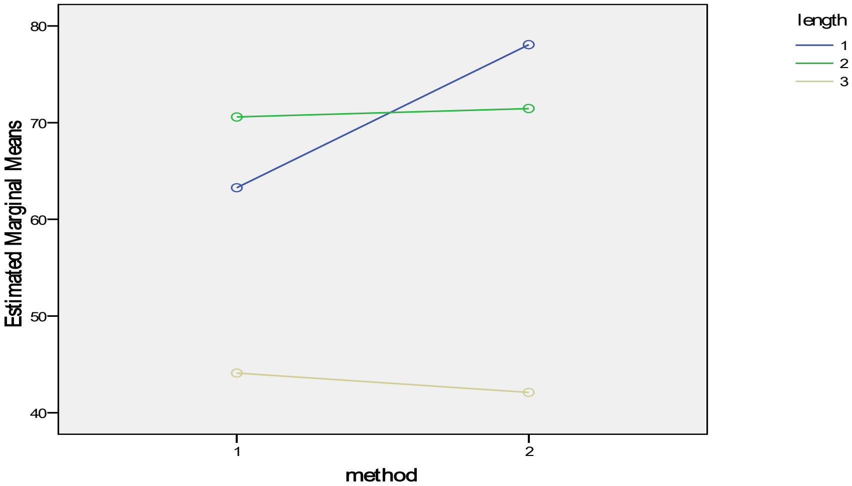


Figure 5. "The method" and "the length of the handle" have a correlation that when length decreases from large size (65mm) to the middle one(50mm), their correlation will become more independent in this range.

4 Conclusions

4.1 The Real Affordance

In this experiment, we find that the factor "the length of handle" has the most significant effect on the mug gripping postures. But, neither the effect of "the width of subjects' palm" nor "the thickness of the mug" is significant to the mug gripping postures. Besides, some other scales of mug are not considered in this study, such as height of the mug or the diameter of the mug. In addition, the ratio between the diameter and height of the mug or the ratio between the height of the mug and the length of its handle is not considered as well. These variables might eventually affect the way people grip a mug. Those variables could be involved in the future studies.

4.2 The Real Affordance and the Perceived Affordance

(1) The factor "the length of handle" and the other factors that interact with it, such as "the thickness of mugs" and the "method", are significant to the percentage of "how many fingers would be used to grip the handle".

(2) Compare to the within subject effect, between subjects effect (the width of palm) is not significant to the mug gripping postures. This means the effect of object's sizes is more significant than the creature's physiological sizes.

4.3 The Contrast

In the first part of experiment, we know that the factor "the length of the handle" significantly affect the percentage of "how many fingers participants would use to grip the handle". But in the second part of the experiment, beside "the length of the handle", there are also two factors, thickness and methods, when interacting with "the length of the handle" turn out to be significant that will affect the mug gripping postures. This kind of situations can lead to two important discoveries.

First of all, the "length of the handle" is the most significant factor and has the greatest effect on the gripping posture in both the "real affordance" and the "perceived affordance" stages of the experiment. In sum, when people grip a mug unconsciously or directly, the length of the handle is the most important factor that would affect their real affordance and behaviors.

Second, the effects of the interactions between multiple factors are more significant in the "perceived affordance" than the "real affordance". This result might indicate that if participants spend more time to interact with the product, they would have a better chance not to misapply an object with the perceived affordance.

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A Design Method of Product Family for Unpredictable Customer Requirements Using Fuzzy Sets

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Abstract. A modular structure recommendation method and component reducing method are proposed for the product family design. The customer's requirements and the product attributes are represented as a fuzzy set and a fuzzy variable using both a point-based and a range-based approach. On the basis of the fuzzy-based representation of the product and the customer requirements, candidates for the product family are calculated using a combination of components by taking range into consideration. An evaluation method is also proposed for clustering the solutions in the product family. A prototype system for a hand drill provides an example of the development and application of the design. The design results indicate that the proposed method can reduce the number of components from 23 to 14 and that it can lower production cost by 15%. On the basis of the clustering of the candidates generated in the product family plan, a modular structure is found to have common characteristics in highly-evaluated plans. The designer can achieve a modular structure as part of a highly-balanced module that can satisfy customer requirements and have a low cost. The design example concludes that the proposed method effectively finds a good modular structure in the product family.

Keywords. Modular Design, Fuzzy Set, Product Family, Clustering, Market Segmentation

1 Introduction

1.1 Various Customer Requirements and Product Family

The modular structure recommendation method can effectively shorten the development period and can reduce manufacturing costs despite the increased manpower requirements. The method facilitates the introduction of a variety of product families that satisfy the needs of diverse users in both niche and mainstream markets. In product design, having a flexible response to changing design variables is vital for creating an effective design that takes modulation and

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commonization into consideration. From the product viewpoint, the processes of modulation and commonization are equivalent to changing the existing components, because a variety of ideas need to be considered before an appropriate solution can be reached. The design method using a fuzzy set is one of the methods for solving problems associated with flexibility. It is utilized in designing a method to obtain a solution in the form of a wide set that takes various uncertainties into consideration by drawing a design using ranges instead of points [1]. It considers various uncertainties by giving each an amount that specifies the design solution and that specifies the required performance as a set.

1.2 Research Objective

This research aims to build an effective module structure that simultaneously satisfies customer requirements and reduces production costs in the development of a product family. Ultimately, we wish to acquire an effective module structure and to offer support for module classification. We focus on the modeling of a product that uses a fuzzy set and on its performance to develop a method for responding to a diverse range of customer needs. At the same time, we concentrate on the mechanism that creates a common decision-support structure for module classification by calculating and clustering various product family plans. To be more precise, we wish to simultaneously achieve fuzzy customer requirements and cost reduction by performing the following procedures:

(1) Model the relationship between the function, performance, and structure of a product by using a fuzzy set and a network.
(2) Propose a method that allows for the efficient and comprehensive calculation of a product family using fuzzy sets and their combinations.
(3) Extract the common module structures of excellent product families by narrowing the module structures using clustering.
(4) Decide the module structure (classification) that simultaneously satisfies optimization of a component structure and satisfaction of customer requirements.

In existing product family designs, Chen proposed the method that the product family and customer requirements were taken into consideration in product conceptualization [2]. Fujita et al. proposed a design method that allows for simultaneous optimization by focusing on customers' fuzzy needs in consideration of the combination structure of attributes [3] and modules [4]. On the basis of the method proposed by Fujita et al. for optimizing the combination and design attributes [3-5], and importance of improving the independence of the module structure [6-7], we propose a design support for a product family that considers the fuzziness of customer requirements and performance range using fuzzy classification based on our proposed method for maximizes variety and minimizes cost [8]. A customer experience based on the mass-customization and configuration using modules will contribute the Human Centric Design.

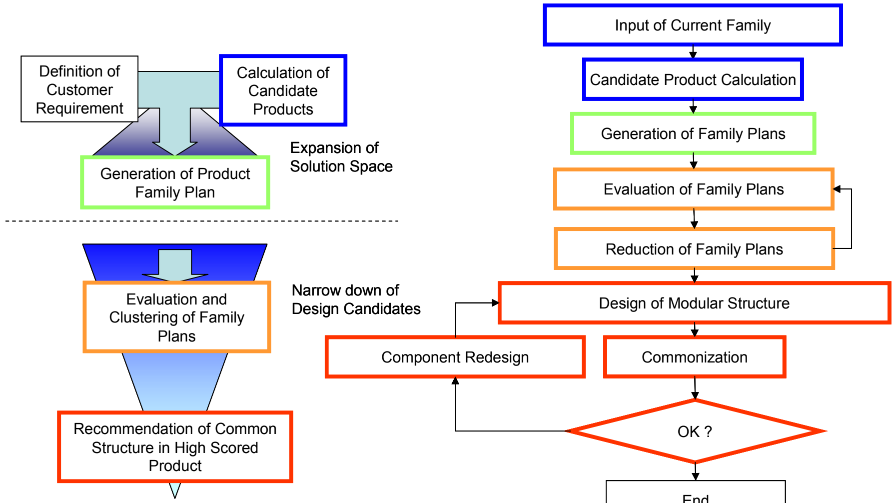

Figure 1 Overview and Flow Chart of Proposed Design Method

2. Design Method of Product Family

2.1 Overview and Flow Chart of Proposed Method

Figure 1 provides the system overview and flow chart of Proposed Method.
The first entry to the system is the area to improve: it is product information on the existing product family and that of its constituent components. The designer decides on and enters information on the performance that customers require from the particular product family. On the basis of the information on the existing product family that is entered, the computer calculates the combination of components adaptable to the performance in accordance with the established performance required by the customers. The system explores excellent plans that satisfy requirements at a high level and at low cost using solutions in the solution space. The system searches the characteristics that excellent solutions have in common using data mining.

The designer narrows the product family plans to be used as a base, with reference to the product families highly valued by the system. Using the narrowed down product family plans, the designer can decide on common components and the module structure with the help of characteristics that excellent solution groups have in common. By repeating the procedures for narrowing down and redesigning components, more appropriate common components and a module structure can be identified.

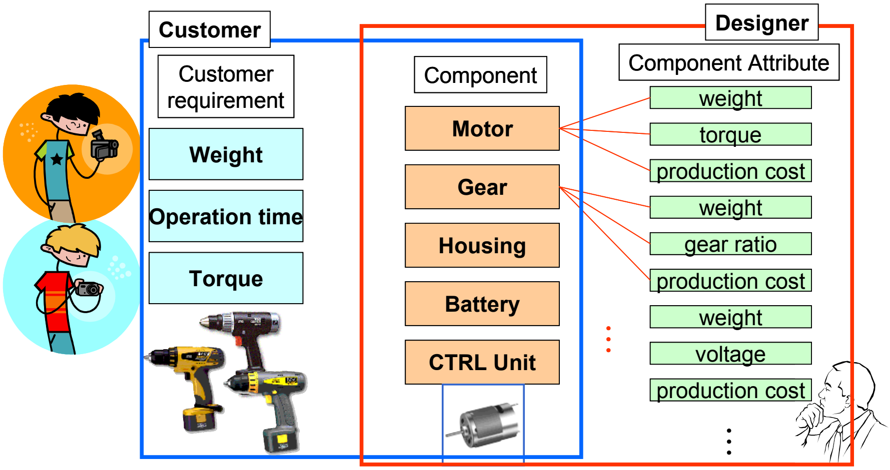

Figure 2 Representation Model of a Product and its Component Structure

2.2 Representation Model of a Product and its Component Structure

In this research, we represent product performance by considering it to be a combination of component attributes. For example, we know that the combination of lenses determines the picture quality of a digital camera; in a similar manner, we represent the product performance not by an addition of performance of each component but by the relationship between attributes using mathematical formulas and charts. Since the structure of a product is a set of components, a product is modeled as a set of the substance and attributes of components. Figure 2 shows the relationship between product performance and the attributes of each component.

In this research, a product is represented as a set of components. The computer represents the performance of a product as an attribute and its value that belong to a product, and the computer also represents components that constitute a products as a substance object, attribute, and its value that represent the performance and materials. The product model (including its hierarchical structure, behavior, and interfaces) conforms the model proposed by the authors.[10]

We aim to describe the performance of each component and of each product using a relational mathematical formula. For example, if the input torque, output torque, and reduction ratio of a simple product comprising a motor and a gear is y, t, and r, respectively, then the relational mathematical formula is $y = t \cdot r$.

2.3 Model of Customer Requirement and Component Performance

Since the customer needs identified in the marketing process cannot be precisely written down in words, it is hard to represent the required performance of a product using a point value. In addition, the specifications for a component and designable performance generally have a range. In this research, the range that is insufficient for representation by a point value is represented as a fuzzy set.

We define the function that is a set of performance attributes of a product as $h(x_f)$. Then, the relationship between customer needs and function can be represented as follows using the fuzzy set $s_{j,m}$ and membership grade $\mu_{j,m}$.

$$q_{c,j} = \sum_m \mu_{j,m}(h_j(x_f)) \quad (1)$$

Here, Σ_m is the logical sum of membership grades. For example, Figure 3 represents the membership function of the fuzzy set of the screw's tightening torque. The membership function for this fuzzy set can be represented as a function of h_j. For example, the fuzzy set of the product attribute in Figure 3 is represented as $h(x_f)$ in the equation (1).

3. Construction of a Prototype System and its Design

3.1 Design example using the proto-type system

We constructed a prototype system that implemented a function to verify the proposed method. In this chapter, we show that we can provide effective design support by showing the structure of the prototype system and its design.

Using the constructed prototype system, we design the product family for an electric drill screwdriver. An electric hand drill comprises a body, battery, control unit, gear, and current control unit (Figure 4).

3.2 Definition of the Product Family and Derivation of an Acceptable Product Group

We assume that the product family to be designed comprises five products (lineups). The components to be constructed vary with each lineup, and each of the lineups has different characteristics. The system calculates virtual lineups by combining the current components entered.

We assume that performance items required by customers include high tightening torque, low weight, and ability to run for a long duration. When we enter the required performance for each item as a fuzzy set, the system derives the acceptable product groups (Figure 4) under the condition that they satisfy the required performance. At the stage represented by Figure 4, 28 product groups were derived for product 1, 13 kinds for product 2, 10 kinds for product 3, 2 kinds for product 4, and 9 kinds for product 5. This range of product groups indicate the range of available products through combining the existing components, regardless of the commonization of components.

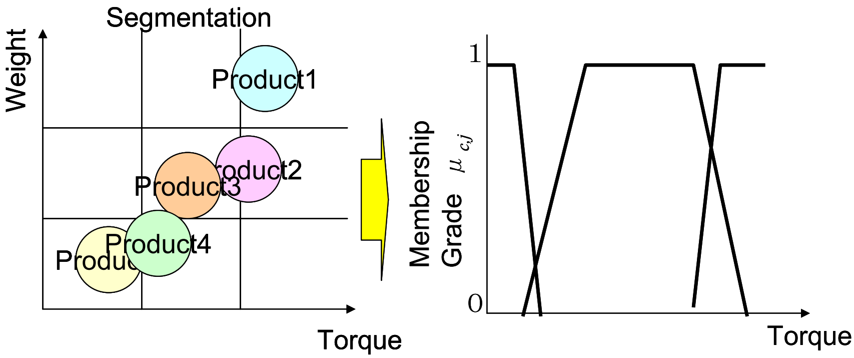

Figure 3 Model of Customer Requirement and Component Performance

3.3 Evaluation and Selection of Product Family

The designer selects the most excellent product family plan by analyzing the performance values and component structure of the product in the system. We used Viscovery SOMine, a data mining tool package, and an SOM [9] to select product family plans, and used the performance of each product as the index of clustering.

The designer narrows the number of product family plans by repeating the clustering and analysis of each cluster. The product family plan analyzer provides the product family plan map that analyzes all the entered product family plans macroscopically and packages the following tools to analyze each product family plan from various angles.

- Customer satisfaction map for each product classified in the product family.
- Graph of the number of common parts shared by products
- Physical structure graph of the components of each product

These tools are integrated in a system in which they are interrelated. Therefore, tracing relations between them makes it possible to search commonized parts and modules as a product family. These tools offer the designer an environment that allows for the comprehensive evaluation of a product family.

In the above design example, we achieved a family plan that successfully reduced the number of components from 23 to 14 and cost by about 15% without causing a significant reduction in customer satisfaction. In addition, redesigning the component motor 4 created a lineup that eliminates the necessity of motor 5 and that satisfies new customer requirements, simultaneously. This result shows the possibility of optimizing the structure of a component and module by treating the requirement as fuzzy. At the same time, it also offers the possibility of developing commonization accompanied by cost reduction—by treating the performance range of a component as fuzzy.

Motor

	Weight	Torque
motor1	100	10
motor2	120	12
motor3	140	14
motor4	170	16
motor5	90	8

Body

	Weight
body1	100
body2	100
body3	120
body4	150
body5	90

Battery

	Weight	Voltage	Ampacity
battery1	200	9	1
battery2	300	9	1
battery3	180	9	0.5

Control Unit

	Weight	Voltage
controlunit1	50	9
controlunit2	50	9
controlunit3	50	9
controlunit4	50	9
controlunit5	50	9

Gear

	Weight	Red.Ratio
gear1	80	5
gear2	90	7
gear3	100	8
gear4	120	10
gear5	70	4

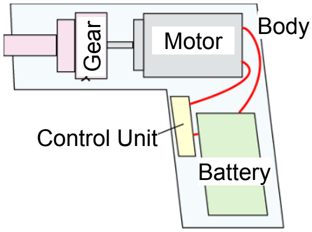

Figure 4 Design example: hand drill

3.4 Acquisition of the Common Platform Module Structure

The system searches the common characteristics of product family groups that are located in the same cluster and that are judged to be excellent. Through the search, it finds structures in the common module that comprise multiple components and the module commonly used by many product lineups, and presents them to the designer.

Figure 5 provides information on the structure of the common module acquired in this design example. It indicates that a module comprising three components (motor 1, body 5, and battery 3) was found commonly in three lineups and a module comprising two components (motor 4, body 5) was commonly used in another two lineups in the product family plan (the 6th plan) judged to be excellent. From the above results, the designer knows the module structure that is shared characteristically by excellent plans.

4 Conclusion

We discussed optimization of the component organization in a product family and also further optimization by treating not only the combination of components but also the required specifications and component performance as fuzzy in order to respond to the problem with module structure.

We proposed a model that represents customer requirements as a fuzzy set and the performance of components that organize a product as a fuzzy set, and subsequently, proposed a model that can define the relationship between product structure and product performance. On the basis of the model that represents product function and organization as fuzzy, we proposed a method to generate and evaluate excellent product family plans and verified its effectiveness by using an example of a hand drill. As a result, we reduced the number of components from

23 to 14 and cost by about 15% within the range while maintaining the same customer satisfaction level. In addition, we acquired the classification of a module commonly owned by excellent plans—by classifying plans similar to these excellent plants on the basis of cluster. This classification structure suggests the module structure that can optimize component structure and customer satisfaction simultaneously.

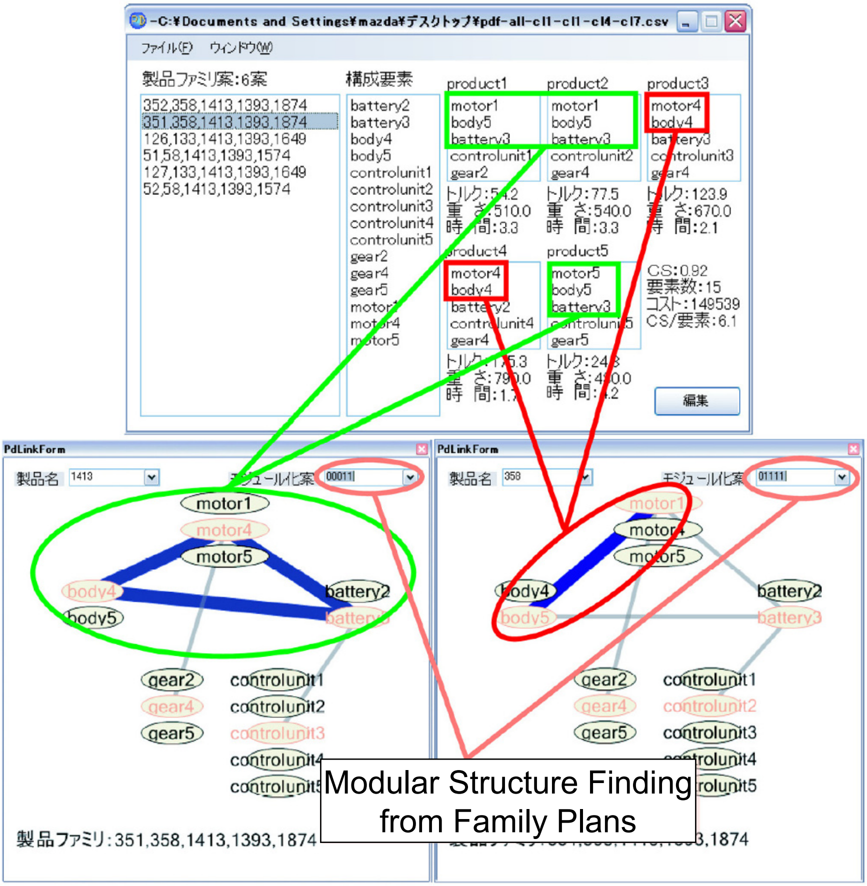

Figure 5 Common module structure inside high rating family plans

5 Acknowledgements

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A Modular Design Method for Scenario Embedded Product

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Abstract. A product with a long-life, such as a plant or ship, must be adaptable to future technology changes, regulations, and environmental changes. This paper proposes a design method for a future scenario embedded product to enhance a product's adaptability to various changes during its lifetime. The design method derives a modular structure between platform modules as constant sub-system and option modules as replacement sub-system. The modular structure is calculated based on a future scenario model represented by a network between events and versions, and a product represented model between components and interfaces. A prototype system is developed and a laptop computer is designed as an example. The design results indicate that the sequence of the scenario's events and branches is important for the scenario-embedded modular structure.

Keywords. Modular Design, Upgrade, Platform, Option, Lifetime Scenario Embedded

1 Introduction

In mass-produced products with a shorter lifetime, including automobiles, the platform which is common in several vehicle types is often used for a long period of time. Therefore, in order to protect their value, the design of such platforms/products should consider flexibility or adaptability in accordance with the changes in the external environment that these platforms/products may face in their lifetime. This study explores the method of designing a product in which various upgrade scenarios that can respond to future changes in the external environment are embedded in its planning phase. Focusing on the modular design to embed them, this study proposes a method of dividing the structure of a product into a platform module, which refers to an unchanging base that is affected little by future changes and to an option module flexibly replaced according to the scenarios of changes in future technology or the environment. By evaluating and comparing each plan found through the proposed systems—with respect to the possible various future scenarios—it helps to obtain the flexible module technically and costly feasible.

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The history of research on modular design began with the theory of complicated design[1-2] in the 1960s, when the focus was on the importance of modular design based on architecture that specified design rules[3-4]. By using modules that were functionally independent[5-7], the architectures were classified into open/closed types and integral/modular types[8-9] in order to show the importance of reducing the functional and structural interdependence. The research pointed out that the issues on modular design could be divided into the attribute design and selection of the common modules[10], and proposed a method of simultaneous optimization of the two.

It is difficult to predict possible technical and environmental changes in the distant future. Thus, in the form of scenarios, this paper uses various possible changes in future technology, the environment, or laws/regulations to examine a method where a variety of scenarios can be considered. Focusing on the possibility that an adaptable product can be developed for various futures if the common platform can flexibly respond to diverse scenarios without losing its value and if the modular structure that can easily replace components or modules at low cost is output, this study intends to help obtain a modular structure that is flexible to several predicted future scenarios.

2. Design of a Modular Structure for a Scenario Embedded Product

2.1 Consideration of Lifetime Scenarios in Design

Product lifetime is the period of time from a product's production through its use and eventual disposal. Recently, the lifecycle concept that a product can be reproduced through degradation and reused after its disposal has spread, particularly for mass-produced products. Likewise, a long-life product starts its lifetime after its sale, installation, or completion and functions through its use by the user, continues its function while maintenance is done, and, finally, is disposed of after the end of its functional and physical lifetime. This study uses the term "product lifetime scenario" instead of the term lifecycle for the purpose of considering made-to-order products, rather than mass-produced products.

In this study, scenarios of technical changes predicted in such a product's lifetime, or of the functional or structural changes made to respond to the environment, are defined as an upgrade scenario. An upgrade scenario specifies a future path for the product to be upgraded to respond to future changes in the external environment.

The flexible upgradability to such lifetime scenarios at a low cost and without the destruction of the product's fundamental structure is defined as the adaptability to the lifetime scenario. A product of high adaptability is regarded as a scenario embedded product. From these perspectives, a scenario embedded product should be the design action that embeds flexibility in the product at the planning phase for platform modularization so that it can respond to future changes.

2.2 The Modular Method for Scenario Embedded Products

To begin, an event such as changes in the external environment or technology (inflating oil prices, environmental regulations, etc.) is assumed. For such an assumed event, the structure of the product that may be appropriate for presupposing the event is roughly designed. Further, the product lifetime scenario is input by specifying the product after event generation as a node and the sequence of event generation as a link, according to the time and conditions for event generation. This is the information to be input to the system by the designer.

The system considers modular plans based on the information from the input lifetime scenario and from the product structure. The components and interfaces that construct the product are communized and the module partition structure is generated to create a product plan adaptable to an easy and flexible upgrade.

3. Evaluation of the Quality of the Module Amputated Structure

The module partition structure accounts for the possibility or cost of responding to changed scenarios in the future. To evaluate the adaptability of the module amputated structure with the computer system, the following viewpoints are required: (1) adaptability to the required scenario; (2) upgradability; and (3) maintenance of market competitiveness through future adaptability.

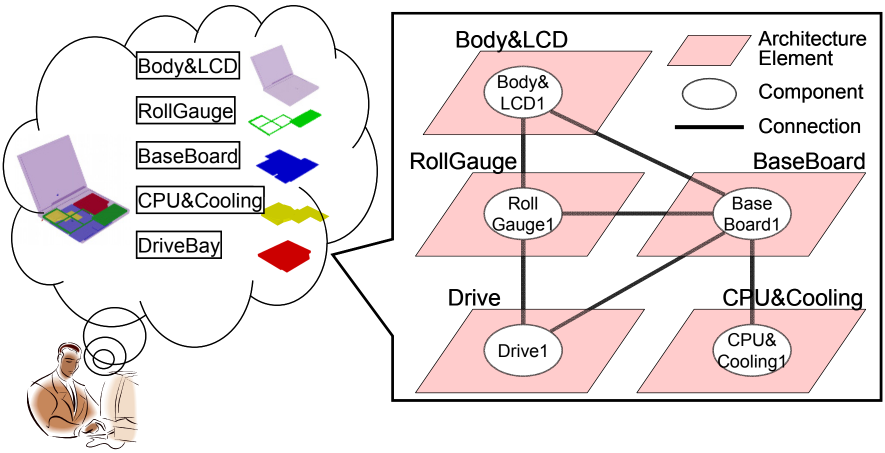

Figure 1 Representation Model of Product Structure

At first, the designer roughly designs a product plan appropriate for each assumed future event. The designer inputs the product assumed in each version of the upgrade scenarios, using the model from the product information (Figure 1), where the node is defined as a component and the link as the connection information (combinability). The designer inputs the version node and the configuration information in each version of the product. Figure 2 illustrates the expressed scenarios PC1 to PC3 as upgrade models.

This study proposes the following evaluation formulae as the evaluation indices corresponding to (1) to (3) above. The system ultimately visualizes each evaluation scores to propose a balanced plan to the designer.

(1) Required scenario adaptability $R^{scenario\ capability}$

The product module or unification structure changes the combinations available by components and modules, which determines whether they are adaptable to the required scenarios. An aversion node with a structure available as a product is defined as a transferrable version. Adaptability could be evaluated using a formula that sums all of the important products and the existence probability of the transferrable version nodes. Therefore, the formula (1) below is used for evaluation:

$$R^{scenario\ capability} = \sum_{i=1}^{n} V^I{}_i \cdot V^P{}_i \cdot \delta_i \,, \tag{1}$$

where $V^I{}_i$ = is the importance of the version node R_i,

$V^P{}_i$ = Existence probability of the version node R_i, and

$$\delta_i = \begin{cases} =1 \ (When\ R_i\ is\ adaptable) \\ =0 \ (When\ R_i\ is\ not\ adaptable) \end{cases}$$

The importance $V^I{}_i$ represents the potential demands of the market, for instance the expected number of the mobile computer. The probability $V^P{}_i$ represents the future likelihood of the version of the product. The likelihood is calculated by the multiplication of event probability, for instance the probability of the realization of the small fuel-cell.

(2) Upgradability $R^{upgrade\ cost}$

Upgradability is evaluated by the cost necessary for upgrading. This study splits up the upgrading cost with the elements from 1) to 3) below to provide a quote for each of them:

1) Cost for work necessary for degradation
2) Cost for disposing unnecessary parts
3) Cost for purchasing new components and/or modules
4) Cost for assembly for restoration

Here 1) degradation and 4) assembly are quoted through the link to disconnect (or connect) the network that expresses the product connection structure.

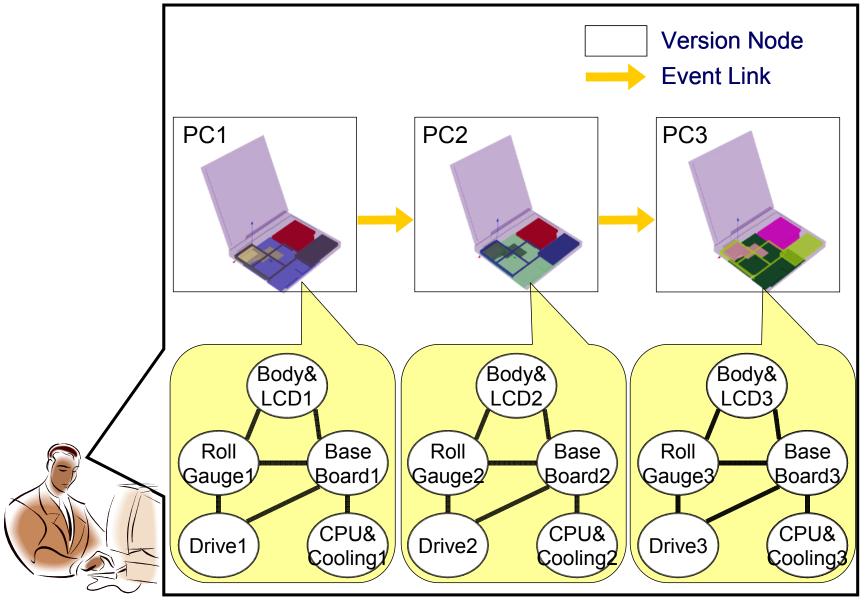

Figure 2 Scenario Model of Technology Change

Taking into account that the initial quality of a product is guaranteed, keeping the information at the time of the product's manufacturing to the maximum extent should be more highly regarded. In other words, a design is evaluated poorly if it requires many connections to be disconnected for upgrading immediately after manufacturing. Assuming the component or module to be extracted for degradation as c_k (where k represents the number of stages in the degradation process when the total number of stages to finish the intended degradation is n, $k = 1, 2, \cdots, n$), the link that requires disconnection to extract c_k as l_k^i (where i represents the link number when the total number is m, $i = 1,2, \cdots, m$) , and the work rate necessary to cut l_k^i as w_k^i, the upgradability $R^{upgrade\ cost}$ is evaluated through the formula (2) below:

$$R^{upgrade\ cost} = \sum_{k=1}^{n} \left(C_k + D_k + \frac{1}{k} \sum_{i=1}^{m} w_k^i \right), \tag{2}$$

where:

C_k = Cost for purchasing c_k

D_k = Cost for disposing c_k.

(3) Market competitiveness of a product $R^{competitive}$

As modularization or generalization considering the future itself accounts for raised costs, the evaluation of whether inclusion of such modularization or generalization as part of the sales price can keep the product competitive is required. Focusing on the cost competitiveness of a product and considering the cost raising factors to assure flexibility, the following three points can be included:

1) Increased cost for initial products
2) Cost for developing generalized parts
3) Cost for modularization

The cost for the initial manufacturing of products (upgrading excluded) can be evaluated by dividing the number manufactured by the sum of 1) to 3).

Figure 3 shows a detailed example of the upgrading process, which represents a scenario that upgrades the module E1C1 to E2C2, after upgrading the module D1 to D2. Upgrading of the module E1C1 involves the number of degradation stages k = 2 and the number of disconnected links i = 4 (1+3). The module to be disposed is C1E1, and the module to be purchased is C2E2.

As shown in Figure 3, the abovementioned evaluations—i.e., the number of degradation stages k, the number of disconnected links i, and the costs for components and/or modules to be disposed and purchased C_k and D_k—are the parameters variable according to modular structures. Hence, formula (2) can be regarded as a problem dependent on the network structure, and therefore would need to be minimized by specifying the module amputated structure as the design variable.

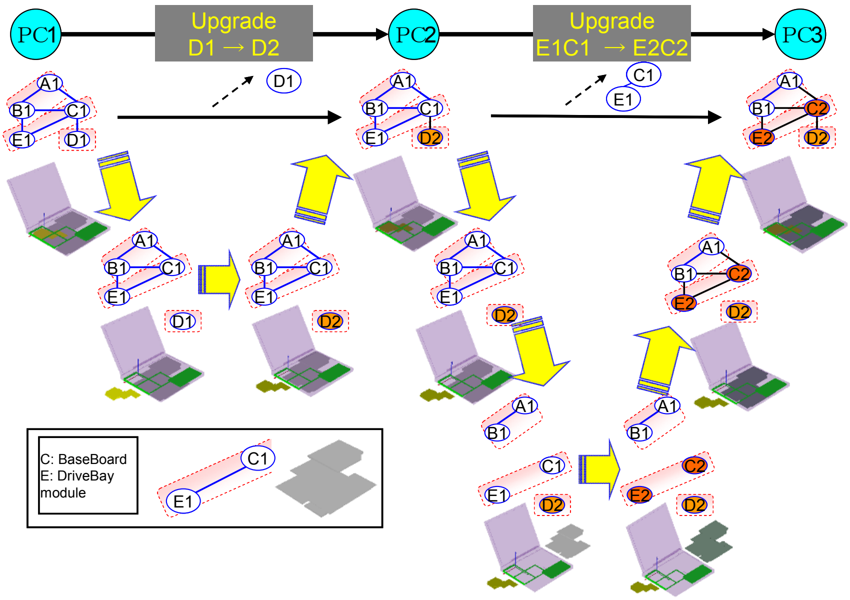

Figure 3 Model of Disassembling, Replacement, and Assembling process for Upgrading Design

4. Design Result and Discussion

4.1 Proto-type System and Design Example

A prototype system that implements the abovementioned design method was developed for the investigation of its application. For system establishment, Cincom Smalltalk 7.2 was used as the environment. The implementation system is equipped with various upgrade scenarios as well as a function that outputs a highly flexible module partition structure when the product structure corresponds to each version. As a design example, the system was applied to the product structure of a laptop, shown in Fig. 1.

4.2 Consideration of the Impact of Event Sequence

Figures 4 and 5 are the evaluation comparisons of the modular plans for the serial upgrade scenario with no branch. These show the application results of the same product structures and the same modular plans (i.e., Modular Plan A and Modular Plan B) to the two scenarios with different event sequences (i.e., Upgrade Scenario 1 and Upgrade Scenario 2). Different sequences mean that Upgrade Scenario 1 (Fig. 4) requires E1 to be upgrade to E2 first, and then D1 to be upgraded to D2, while Upgrade Scenario 2 (Fig. 5) conversely needs to upgrade D1 to D2 first before upgrading E1 to E2.

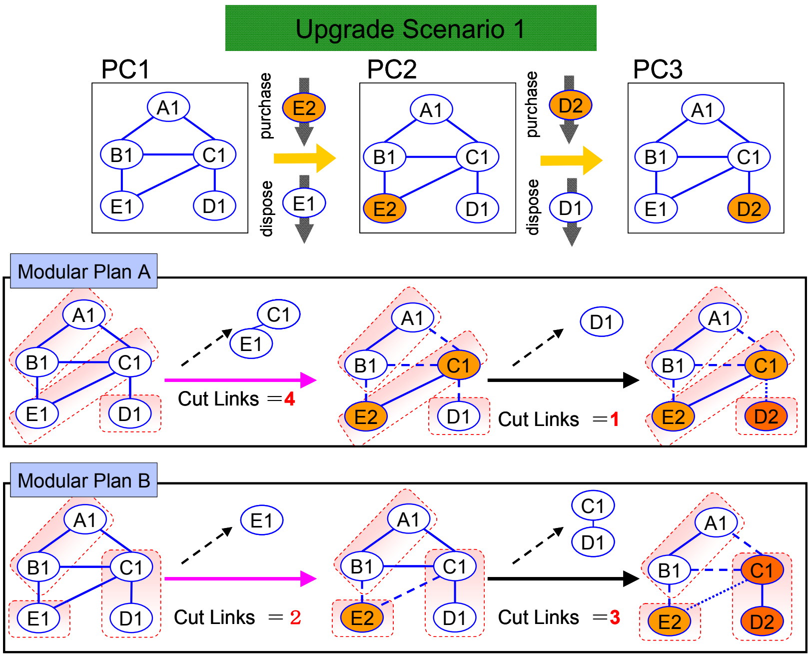

Figure 4 Best Modular Structure for Upgrade Scenario 1

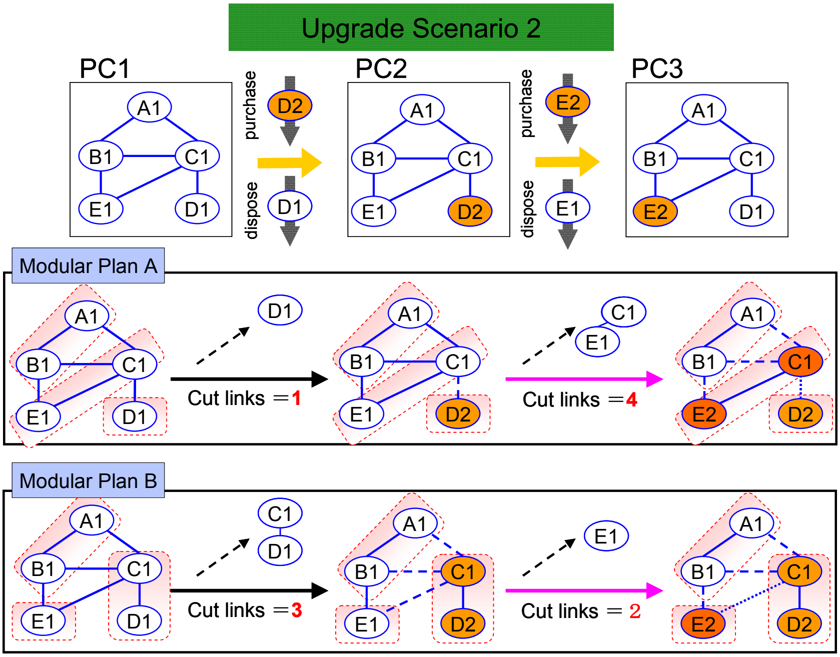

Figure 5 Best Modular Structure for Upgrade Scenario 2

To prepare modular plans, a modular structure design requires the calculation of the cut plans using the cut set from the product structure graph. As the examples of the modular structure shown in Figs. 4 and 5, the following provides two modular plans obtained through such calculation. To evaluate the quality of the abovementioned module partition structures (Modular Plan A and Modular Plan B), these modules plans are evaluated as shown in Section 2–4.

- Modular Plan A:

  This plan divides the products into three modules (A&B, C&E, and D)

- Modular Plan B

  This plan divides the product into three modules (A&B, C&D, and E)

The evaluations below can apply:

(a) In the Upgrade Scenario 1 (Fig. 4),

・ Modular Plan A

$R^{upgrade\ cost} = 4/1 + 1/2 = 4.5$

・ Modular Plan B

$R^{upgrade\ cost} = 2/1 + 3/2 = 3.5$

Hence, the method proposed in this study concludes that Modular Plan B, showing a better value in the Upgrade Scenario 1, is more appropriate than the Modular Plan A.

(b) In the Upgrade Scenario 2 (Fig. 5),

- Modular Plan A

  $R^{upgrade\ cost} = 1/1 + 4/2 = 3.0$

- Modular Plan B

  $R^{upgrade\ cost} = 3/1 + 2/2 = 4.0$

Thus, the method proposed in this study concludes that Modular Plan A. showing a better value in the Upgrade Scenario 2. is more appropriate than the Modular Plan B.

5. Conclusion and Future Works

This study proposed a method of designing a long-life product, or the platform structure necessary to be flexibly adaptable to possible changes in technology, environment, regulations, or other factors in an uncertain future. It also suggested the model that described the upgrade scenario based on events and versions. Upgradability was evaluated through the cost necessary for upgrading, and a system to evaluate the degree of compatibility of the scenario based on its adaptability to the event branch was established. Application to a laptop for investigation showed that the module partition was affected by the event sequence and branch for the scenario. The study finally reached the conclusion that the modular structures that input the complex future scenario using the implementation system could obtain a module partition plan that satisfied both the event sequence and branch and that embedded diverse lifetime scenarios.

The authors expect that the application of the proposed design method to developmental strategy could contribute to a solution to the problem of planning the developmental strategy of the product family or the component resistant to possible future changes in technology or environment.

6 Acknowledgements

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Version Control Management for Federated Service-oriented File Sharing

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Abstract. The major objective of the Service Oriented Computing Environment (SORCER) is to form dynamic federations of network services that provide for concurrent engineering systems: shared data, applications, tools, and utilities on a service grid along with exertion-oriented programming. To meet the requirements of these services in terms of design data sharing and managing in the form of data files, a corresponding federated file system was developed. The file system fits the SORCER philosophy of interactive exertion-oriented programming for distributed collaborative applications, where users create service-oriented programs and can access data files in the same way they use their local file system. However, there was no efficient management of file explicit versions during complex design in related concurrent engineering systems. Thus, a separate Version Control Management Framework was developed to fit with the SORCER metacomputing philosophy and to manage effectively versions of all files in a uniform way.

Keywords: version control management, service-oriented architectures, metacomputing

1 Introduction

Building on the OO paradigm is the service-object oriented (SOO) paradigm, in which the service objects are distributed, or more precisely they are remote objects that play some predefined roles. Before we delve into the proposed new metacomputing and metaprogramming concepts, the introduction of some terminology used throughout the paper is required:

- A ***computation*** is a process following a well-defined model that is understood and can be symbolically expressed and physically accomplished (physically expressed). There are many ways of expressing a process in a logic circuit, function, algorithm, message, protocol, network topology, virtual organization, etc. Four orthogonal classes of computations can be distinguished: *digital* vs. *analog*, *sequential* vs. *parallel* vs. *concurrent*, *batch* vs. *interactive*, *monolithic* vs. *distributed*. A computation can be seen as a purely physical phenomenon occurring inside a system called a ***computer***.
- Computing requires a ***computing platform*** (runtime) to operate. Computing

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platforms that allow programs to run require a *processor*, *operating system*, and *programming environment* with related tools to create symbolic process expressions—***programs***. Usually, a computation is physically expressed by a processor and symbolically expressed by a program created in the relevant programming environment. Thus, a computation is the *actualization* of a program by operating system on its processor.

- A ***distributed computation*** allows for sharing computing resources usually collocated on several remote computers (compute nodes) to collaboratively run a single complex computation in a transparent and coherent way. In distributed computing a computation is divided into subcomputations that execute on a collection of compute nodes. Thus, in distributed computing, computations are decomposed into programs, processes, and compute nodes. A ***metacomputer*** is an interconnected and balanced set of compute nodes that operate as a single unit, which is accessible by its computing platform (*metaprocessor*, *metaoperating system*, and *metaprogramming environment*).
- A ***metacomputation*** is a form of distributed computation (a computation of computations) determined by *collaborating computations* that a metacomputer can interpret and execute. In *metacomputing* computations are decomposed into *services*, *service providers,* and *processors*. The *service provider* selected at runtime by a metaoperating system defines a required service—a metainstruction being a provider's program. A collection of all service providers selected and managed for a metacomputation is called a ***virtual metaprocessor***.
- A ***metaprogram*** is an expression of metacomputation, represented in a *programming language*, which a *metacomputer* follows in processing shared data for a ***service collaboration*** (*workflow*) managed by its *metaoperating system* on its virtual *metaprocessor*.
- A ***service-oriented architecture*** (*SOA*) is a software architecture using loosely coupled service providers that integrates them into a distributed computing system by means of service-oriented programming. Service providers in service-oriented programming are made available as independent service components that can be accessed without a priori knowledge of their underlying platform, implementation, and location. While the client-server architecture separates a client from a server, SOA introduces a third component, a service registry. The registry allows metaoperating system to find service providers with no need to define their static locations on the overlay network.

Therefore, every metacomputer ***requires a platform*** that allows software to run utilizing multiple autonomous computing nodes that communicate through a computer network. Different distributed platforms can be distinguished along with corresponding metaprocessors—virtual organizations of computing nodes. SORCER [10], [13] is a metacomputing platform for concurrent engineering applications.

In SORCER a *service provider* is a service object that accepts requests from service requestors to execute a collaborative work. A specification of the collaborative work is called an *exertion*. An exertion *exerts* the service providers dynamically federating (virtual metaprocessor) for its service collaboration. A *task* *exertion* is an elementary service request—a kind of elementary remote metaroutine, being a program, executed by a service provider. A composite exertion, called a *job exertion*, is defined in terms of tasks and other jobs—a kind of metacoroutine executed by collaborating providers managed by the metaoperating system. The executing exertion is a SOO metaprogram that is dynamically bound to all relevant and currently available service providers on the network. This collection of collaborating providers identified in runtime is called an *exertion federation*. The overlay network of all service providers is called the *service grid* and the exertion federation forms a *virtual metaprocessor* at runtime. The metainstruction set of the metaprocessor consists of the operations defined by all service providers in the service grid. Creating and executing a SOO program in terms of metainstructions requires a completely different approach than creating a regular OO program [9], [10].

The SORCER environment provides the means to create interactive SOO programs and execute them as complex concurrent engineering applications. Exertions can be created using interactive user interfaces downloaded directly from service providers, allowing the user to execute and monitor the execution of exertions in the virtual metacomputer. The exertions can also be persisted for later reuse. This feature allows the user to quickly create new applications or programs on the fly in terms of existing tasks and jobs. SORCER introduces federated method invocation based on peer-to-peer (P2P) and dynamic service-oriented Jini architecture [5].

SILENUS [1], [2] builds on top of the SORCER philosophy and provides data reliability and availability in the form of file replication. However, once a file version is created and replicated there is no management of these replica versions (revisions). Thus, to manage the versions of replicas a separate framework was developed called FVS (**F**ederated **V**ersioning for service-oriented file **S**ystem).

This paper is organized as follows: Section 2 briefly describes the SORCER metacomputing system; Section 3 presents federated file system methodology; Section 4 describes the version management architecture; and Section 5 provides concluding remarks.

2 SORCER

SORCER (Service Oriented Computing EnviRonment) is a federated service-to-service (S2S) metacomputing environment that treats service providers as service objects with well-defined semantics of a federated service-object oriented architecture. It is based on Jini [5] semantics of services in the network and Jini programming model with explicit leases, distributed events, transactions, and discovery/join protocols. While Jini focuses on service management in a networked environment, SORCER focuses on exertion-oriented programming and the execution environment for exertions [10]. SORCER uses Jini discovery/join protocols to implement its *exertion-oriented architecture* (EOA) using *federated method invocation* [10], but hides all the low-level programming details of the Jini programming model.

In EOA, a service provider is a service object that accepts requests from service requestors to execute collaboration. These requests are called service exertions and describe *service data, operations* and provider's *control strategy*. An *exertion task* (or simply a *task*) is an elementary service request executed by a single service provider or a small-scale federation managed by the receiving provider for the same service data. A composite exertion called an *exertion job* (or simply a *job*) is defined hierarchically in terms of tasks and other jobs. A large-scale federation managed by the SORCER OS executes a job. The executing exertion is dynamically bound to all required and currently available service providers on the network. This collection of providers identified in runtime is called an *exertion federation*. The federation provides the implementation for the collaboration as specified by its exertion. When the federation is formed, each exertion's operation has its corresponding code available on the network. Thus, the network *exerts* the collaboration with the help of the dynamically formed service federation. In other words, we send the request onto the network implicitly, not to a particular service provider explicitly.

The overlay network of all service providers is called the *service grid* and an exertion federation is in fact a *virtual metaprocessor*. The metainstruction set of the metaprocessor consists of all operations offered by all service providers in the grid. Thus, an exertion-oriented (EO) program is composed of *metainstructions* with its own *control strategy* and a *data context*. The data context describes the data that tasks and jobs work on. Each service provider offers services to other service peers on the object-oriented overlay network. These services are exposed *indirectly* by operations in well-known public remote interfaces and considered to be elementary (tasks) or compound (jobs) activities in EOA. Indirectly means here, that you cannot invoke any operation defined in provider's interface directly. These operations can be specified in a requestor's exertion only, and the exertion can be passed on to any service provider via the top-level `Servicer` interface implemented by all service providers called *servicers*—service peers. Servicers do not have mutual associations prior to the execution of an exertion; they come together dynamically (federate) for a collaboration as defined by its exertion. In EOA requestors do not have to lookup for any service provider at all, they can submit an exertion, onto the network by calling:

```
Exertion#exert(Transaction):Exertion
```

on the exertion. The `exert` operation will create a required federation that will run the collaboration as specified in the EO program and return the resulting exertion back to the exerting requestor. Since an exertion encapsulates everything needed (data, operations, and control strategy) for the collaboration, all results of the execution can be found in the returned exertion's data context.

Domain specific servicers within the federation, or task peers (*taskers*), execute task exertions. *Rendezvous* peers (jobbers and spacers) [10] coordinate execution of job exertions. Providers of the `Tasker`, `Jobber`, and `Spacer` type are basic *system providers* of the SORCER operating system; see Figure 1. In view of the P2P architecture defined by the `Servicer` interface, a job can be sent to any servicer. A peer that is not a `Jobber` type is responsible for forwarding the job to one of available *rendezvous* peers in the SORCER environment and returning results to the requestor.

Thus implicitly, any peer can handle any job or task. Once the exertion execution is complete, the federation dissolves and the providers disperse to seek other collaborations to join. Also, SORCER supports a traditional approach to grid computing similar to those found, for example in Condor [15]. Here, instead of exertions being executed by services providing business logic for invoked exertions, the business logic comes from the service requestor's executable codes that seek compute resources on the network.

Grid-based services [13] in the SORCER environment include `Grider` services collaborating with `Jobber` and `Spacer` services for traditional grid job submission. `Caller` and `Methoder` services are used for task execution. Callers execute conventional programs via a system call as described in the service context of submitted task. Methoders can download required Java code (task method) from requestors to process any submitted data context accordingly with the code downloaded from the network. In either case, the business logic comes from requestors; it is a conventional executable code invoked by Callers with the standard Caller's data context, or mobile Java code executed by Methoders with a matching data context provided by the requestor.

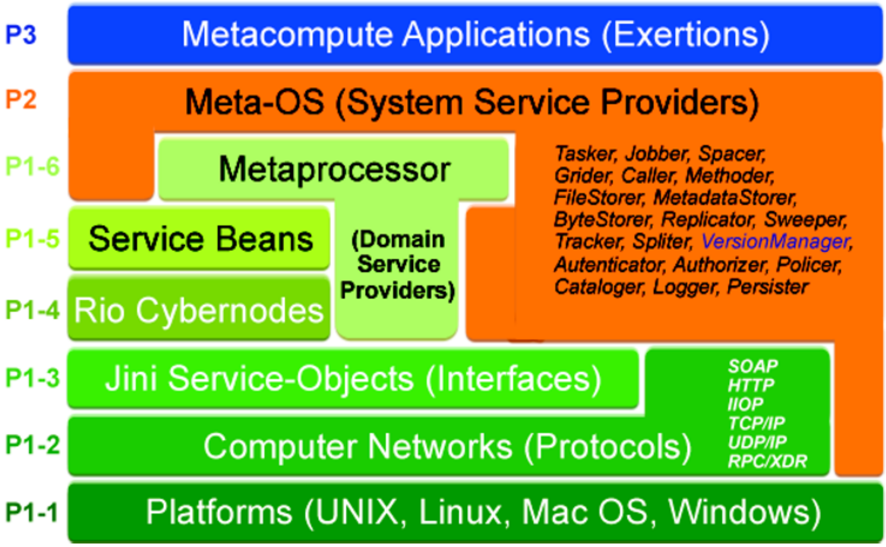

Figure 1. SORCER platform: metaprocessor (green shades), meta-OS (orange), programming environment-exertions (blue).

3 SILENUS File System

SILENUS [1], [2], [16] is a federated file system, which builds on top of the SORCER philosophy. It provides dynamic access to files referenced in data contexts of exertions. SILENUS consists of several services that federate together to provide the functionality of the file system. Each service may be replicated on as many hosts as needed. These services may be categorized into gateway services, data services, and management services. The service-oriented nature of SILENUS makes it very easy for someone to create new functionality for the file system by implementing additional services.

The SILENUS file system makes a few assumptions about the data being stored. First, file metadata is very small. Second, file data is relatively large therefore it should be replicated for reliability and availability but not onto every data store [1], [2].

1. Data services

The data services consist of a metadata store service and a byte store service. The metadata store service stores attributes that can be derived from the files themselves. This includes name, creation date, size, file type, location, etc. The metadata service provides functionality to create, list, and traverse directories [2].

The byte store service is used for storing the actual file data. It does not provide for storing attributes about the file but does allow for retrieving attributes of a file e.g., retrieving the file size and checksum to verify integrity of the file. Stored files are usually encrypted but may be stored unencrypted for performance reasons [2].

2. Management services

SILENUS includes several management services such as the SILENUS Façade, Jini Transaction Manager, Byte Replicator, and other optimizer services. The SILENUS Façade manages the coordination and provides a dynamic entry point between the metadata stores and byte stores [1], [2]. The Façade also provides a zero install user interface, through the use of a Service UI [7], which allows the users to view the files in the system similar to the way they would view files in a traditional file system.

The Transaction Manager is a Jini standard service that the SILENUS Façade uses to ensure two-phase commit semantics for file uploads and downloads. The Byte Replicator and other optimizer services are used for autonomic administration. The optimizer services may make decisions on where to move files, which services should be started or shutdown, and where to store replicas. Each optimizer service is a separate component so it makes it very easy for and administrator to create more optimizer services. In traditional file systems an administrator has to provide some management of the data but in SILENUS an administrator may select which kind of optimizer services to deploy and where to deploy them [1], [2]. This also makes SILENUS highly scalable.

3. Gateway services

The gateway services provided by SILENUS are client modules that provide access to the SILENUS file system. Some examples of gateway services are the

NFS Adapter, JXTA Adapter, WebDAV Adapter, and Mobile Adapter. The NFS Adapter provides a mapping from the NFS protocol to SILENUS for older UNIX systems that do not have WebDAV support. A WebDAV Adapter was developed to provide support for newer operating systems that support WebDAV such as Windows, Mac OS X, and newer versions of UNIX [1], [2]. These are just a few of the gateway services that have been created. The service-oriented nature of SORCER makes it very easy for someone to create new services for SILENUS.

4 Version Control Management Architecture

An important element in the modern CE process is version control (also known as revision or source control). Cooperating designers commit their changes incrementally to a common source repository, which allows them to collaborate on data without resorting to crude file-sharing techniques (shared directories, drives, emails). Source control tools track all prior versions of all files, allowing designers to "time travel" backward and forward in their data to determine when and where changes are introduced. These tools also identify conflicting simultaneous modifications made by two (poorly-communicating) team members, forcing them to work out the correct solution (rather than blindly overwriting one or the other original submission).

The FVS (**F**ederated **V**ersioning for service-oriented file **S**ystem) system is collaboration of three services described below. The FVS architecture in the form of the UML component diagram is depicted in Figure 2.

4.1 FVS Version Manager

The FVS Version Manager is similar to SILENUS metadata store. It contains metadata information of various versions of files. Metadata information of federated versioning system includes information about:

a. all changed paths
b. log message
c. name of the author of the commit
d. the timestamp when the commit was made
e. special character describing how the path was changed ('A' - added, 'D' - deleted or 'M' - modified).
f. information about SVN ENTRY UUID
g. information about committed revision number
h. information about SVN ENTRY CHECKSUM

Each version of file contains a file name and unique Version ID (VID). FVS uses this service same way as SILENUS metadatastore does except the FVS Version Manager points to the FVS tracker rather than the SILENUS tracker. The version management service is responsible for storing all the metadata information for the managed files. Metadata information is stored in a database running in this service. The version management store provides attributes for the files stored in the file system. The analogy in a traditional storage system is the file system. The metadata information creates the well-known hierarchical structure. Files in the version management store are identified by UUIDs and VIDs. The metadata provides mapping from and to file names. Version manager services are synchronized while connected. All version manager services contain the same information. Should a version manager services be disconnected while its information changes, it will be resynchronized when it is connected back to the other metadata version manager services.

As in internal database, an embedded Berkeley database is used. Using an embedded database makes installation much easier; it does not require the installation of external database management system. The database access itself is implemented using the data access object pattern [6] for extensibility and support for other database management systems if needed.

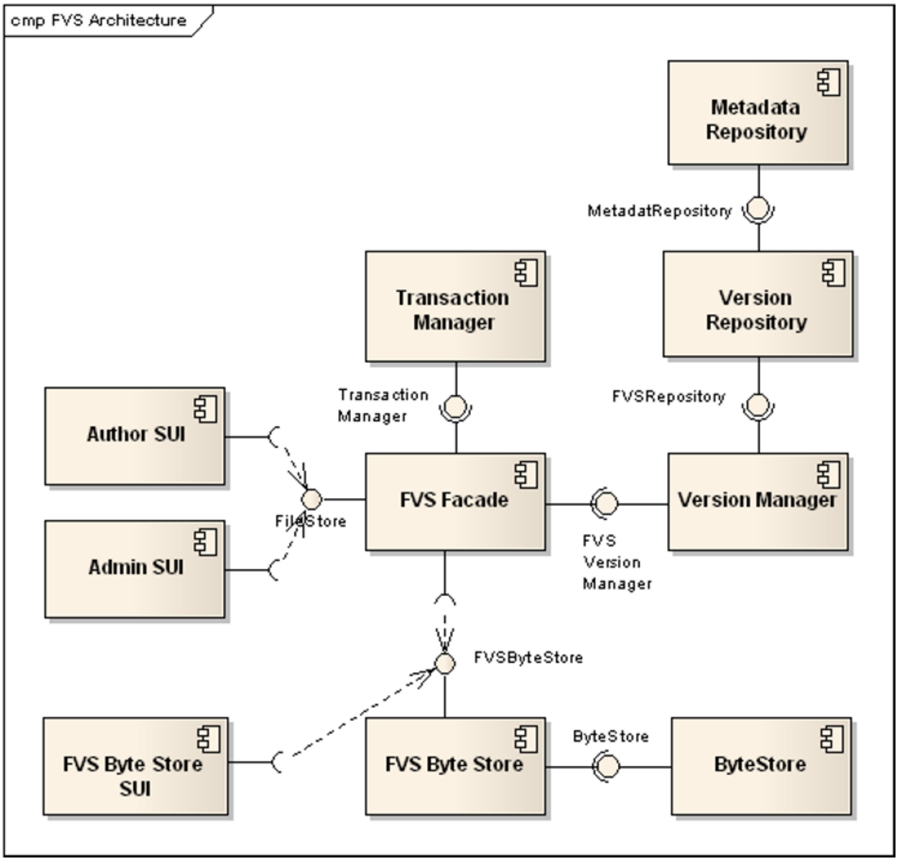

Figure 2. FVS Architecture; SUI-Service UI [7].

4.2 FVS Byte Store

The FVS byte store service persists file content of all versions within the SIELNUS file system. A byte store service holds no metadata information about the files; it maintains other than physical data that can be calculated directly from the files it stores, such as file size or checksums. Even file names are replaced with a type of UUID and VID when stored to one of these storage nodes. A byte store service provides the ability to store and retrieve file data based on the file's UUID and VID, which can be obtained from a version manager.

The ID of the byte store and an entry ID in the byte store identify files in a byte store uniquely. These ID numbers never change. This makes the file storage independent from file metadata such as the file name. The byte store services provide nothing but support for file storage. The advantage is that this service can be then optimized for performance. Unlike the version manager, the byte stores are not synchronized. File data is much larger than file metadata. Would the file data be replicated on every node the storage capacity would be filled very quickly? It is the job of the optimizer services to provide file data replication.

4.3 FVS Façade

The FVS Façade service acts as an entry point to the file system and provides access to basic file system operations. Its main function is to coordinate with the various services found on the network, combining the abilities of each to perform requested tasks on the behalf of a user.

FVS includes the FVS Façade service that helps coordinate the other services to provide the flexible file system functionality. For example, when a user wants to download a file, the façade service contacts with version manager to get the version and storage location of the file, then it contacts the given FVS byte store to begin transferring the file data to the user's local machine.

The FVS Façade is split up into two parts: a provider and a smart proxy. In contrast to a dumb proxy that provides business logic to requestor only on the provider side, a smart proxy provides business logic on the both: the requestor and provider. The FVS Façade provider is responsible for doing a lot of background processing and service discovery that end-user machines should not have to manage. In particular, the FVS Façade provider will check with a Registrar service to find any available version manager available on the network and for reliability would maintain a cache of proxies for each required service that is found. When a FVS Façade proxy is requested from the network (for example, by a service browser), the Registrar service provides the smart proxy registered by the FVS Facade provider. The FVS Façade proxy is the component responsible for doing much of the coordination between the different services to perform versioning system operations. When the Façade smart proxy obtained from the Registrar service, the proxy provides a Service UI [7] (the FVS user agents, see Figure 2) to allow the user to interact with the file system via a file browser. The proxy asks its parent FVS Façade provider for a version manager proxy from its cache to allow the FVS Facade proxy to browse and display the file system to the user. When a user asks to save or store a file to the file system, the FVS Facade proxy obtains the necessary service proxies to carry out the transactional request.

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6 Conclusions

Till now through the course of FVS research, several file version systems have been examined to investigate how they are setup, what sort of computing environments they use, and what additional functionality they provide. Several modern day file versioning systems are unable to effectively cope with a high volume of very large files, especially in a metacomputing environment where several federations may want to access the same set of files concurrently.

By leveraging Jini network technology, SORCER allows for various services to run on a network, dynamically discover each other, and collaborate with one another to provide larger overarching services to the end user. Through the use of such services, it is possible to break a file system and a version system down into its separate functional parts (services), and then have these functional parts collaborate with each other to provide file version system capabilities. SORCER allows for these services to be managed, maintained, and even used in a consistent manner, and with the use of smart proxies, there is no need to install such services on every machine that will use them. Through the use of dependency injection, small and simple configuration files can be used to launch various services in a variety of different ways in a fairly simple manner. Autonomic provisioning services can also help to regulate the health of service-oriented federations by making sure that all the required services for a metaprogram are available at all times.

FICUS [16] was designed to utilize SORCER and SILENUS as a basis for creating a service-to-service based file system with file tracking and file splitting capabilities. FVS extends the FICUS functionality by adding file version control management capabilities.

FVS provides dedicated, cohesive and decoupled FVS version manager to maintain file history for the FVS service requestor. The Version Management store contains all versions for each file and persists those versions using the SILENUS [1] framework. So we can easily roll back to earlier version of file based on retained history of files.

Adding the file versioning capabilities the FVS framework helps to enhance and expand the benefits provided by SILENUS. Replicating significantly large version files in their entirety on different storage nodes may not be feasible because it may be difficult to find any storage nodes with enough free space to hold the entire file. By splitting such file version up, fractions of the version of a file can be stored much more easily across multiple machines. An increase in file replication can help to increase version system reliability in the event that a storage node goes down. Since split file versions are stored across multiple storage nodes, each of the nodes can contribute bandwidth to download the file for reassembly rather than relying on the shared bandwidth of a single file server. This means that multiple parts of a large file version can be downloaded from multiple sources simultaneously rather than retrieving the full file from a single server where bandwidth may be shared among all the connected clients.

Since file version can be downloaded from multiple sources at once, bottlenecks in transfer speeds are fewer as the same file can be provided by a different FVS service collaboration. Splitting files into chunks can also help to reduce the cost of transfer errors. When transferring a full file to a single source, an error in communication can often mean that the entire file has to be transferred again. However if a file splits then a communication error occurs; only part of the file would need to be retransferred. Overall, FVS provides many benefits by using a service-oriented architecture when compared to the client-server model employed by many versioning systems in use today.

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Part IV
Knowledge Engineering

Ontology-Based Approach in Hybrid Engineering Knowledge Representation for Stamping Die Design

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Abstract. This work is concerned with building Knowledge Based Engineering Applications aimed at Small and Middle Enterprises (SME). In the article an analysis of shortcomings current approaches is presented. In addition an innovative point of view at the building of such tools is demonstrated and a general framework for dealing with knowledge is proposed and discussed. Development of a tool to support stamping die design for an automotive supplier as a case study is presented. The main concept assumes an application which consists of two kernels: knowledge base and retrieval system. The retrieval system is a control module which retrieves required information from knowledge base. In proposed solution knowledge is represented with means of two different approaches: ontological knowledge base, which is dedicated for declarative knowledge and procedural knowledge, which is represented in advanced parametrically-driven associative geometrical models. Such a knowledge base is readable for both a computer agent and expert. The solution bridges the gap between human oriented knowledge and formal knowledge models and is aimed at solving synthetic and deductive tasks, especially configuration design.

Keywords. Knowledge Based Engineering, Knowledge Based System, Knowledge Representation, Deductive Reasoning, Computer Aided Design, Ontology, Ontological Knowledge Base, Declarative Knowledge and Procedural Knowledge

1 Introduction

Knowledge Based Systems are intelligent tools which base on techniques of Artificial Intelligence. Descipline which deals with developing KBS is defined as a root discipline of Knowledge Based Engineering (KBE). KBE is concerned with the whole process of constituting knowledge based applications for engineering in order to support design engineer in routine work. The main goal of KBE is to support the design engineer in his routine duties with the intention to provide more time for innovation. Engineering teams can use this support to capture and reuse the knowledge and experience of their engineers, together with manufacturing best practice, legislation, costing, and other rules relevant to the product development [2]. According to authors of [13] statistical evaluation of engineering process signifies that about 80% of the whole engineering process is routine work. The rest consists of creative tasks.

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The total time reduction can be achieved with means of knowledge based applications for solving routine tasks. The fundamental component of such systems is still knowledge. Knowledge - similar to data and imformation is basic principle of inteligence. Differences between them are to find in [10][11][12].
For knowledge storage different approaches are used. To the most popular belong the first order logic, rule based approach, semantic networks, object and frame oriented representation and ontology. The last - ontologies specify common vocabulary along with some specification of the meaning or semantics of the terminology within the vocabulary [1][3].They are used by computer and information science community for representation concepts and relationships among them within discourse domain in formalized manner. Ontologies found broad utilization in many disciplines such as knowledge representation due to their explicit specification of shared conceptualization [5] e.g. artificial intelligence, the Semantic Web, software engineering, medical informatics and information science. Whereby, conceptualization describes an abstract, simplified view of the world that we wish to represent for some purpose [1]. Researches have been using them to address challenges of different representation of the same information and of different interpretation of different meanings.

Although ontologies are broadly applied for knowledge representation, their implementation for KBE is still in infantile. Additionally, methodologies which are applied for building Knowledge Based Systems (KBS) or KBE are usually defined for big companies; examples of such methodologies are CommonKADS [12] or MOKA [13]. Small and Middle Enterprises (SME's) are not being taken into account as a customer for methodology for building KBE. There are only a few papers which have drawn attention to the problematic; one of them is [6]. The focus by SME's for methodology for KBE is concentrated not only on reusability, flexibility and interoperability but above all on simplification. Such methodology must be comprehensive, easy to apply and first of all no expensive. In order to meet such requirements the most time-intensive part of developing KBE – knowledge capturing should be simplified with keeping the high level of quality.

2 KBE – Related Issues

The amount of facets concerning knowledge in association with KBE is enormous. Their analysis would be beyond the scope of this work. However, some aspects concerning the issues of knowledge, strongly associated with KBE will be considered in next parts of the article. This issues identification resulted from literature researches in KBS, Information Theory, Design Theory and practical experience gathered during carrying out different KBE-projects for industry. Roughly tackling the problematic, three following issues have been noticed and realized:

- knowledge representation,
- high failure rate of KBE solutions and
- high maintaining costs of KBE systems.

Knowledge representation is crucial issue for KBE because the content constitutes its core. It is the foundation stone for every knowledge based application and therefore the broadest field in KBS. The issues concerning knowledge representation can be divided into following subject matters: complexity, geometry, dealing with different kinds of knowledge, methodology, knowledge and information represented in informal manner, dealing with knowledge holders as well as administering knowledge model which should be interoperable, flexible and comprehensible. Issues concerning the three phenomena are listed in Table 1.

Table 1. Main issues in KBE and their possible solutions

group of issue	issue	solution
the issue of representation	- complexity	- small chunks of knowledge; afterwards putted together
		- hybrid knowledge representation (knowledge kinds' differentiation)
	- geometry	- formal representation of knowledge model – features based and parametrically driven CAD models
		- hybrid knowledge representation, differentiation between declarative and procedural knowledge
	- different kinds of knowledge	- differentiation between declarative knowledge and procedural knowledge
		- hybrid knowledge representation (knowledge kinds' differentiation)
	- methodology	- formal representation of knowledge model – features based and parametrically driven CAD models
		- hybrid knowledge representation (knowledge kinds' differentiation)
	- informal	- knowledge models constructed with the help from experts
	- people-centered	- maintaining process executed by experts, quite easy to change
	- interoperability	- common approach
	- flexibility	- common approach
		- maintaining process executed by experts, quite easy to change
	- comprehension	- reflection of real system, expert-friendly knowledge model format
high failure rate of KBE solutions	poor knowledge quality	- capturing and formalizing of knowledge by experts
	interaction expert – knowledge engineer	- maintaining knowledge base by experts
high maintaining costs	- reprogramming required for new standards releases - knowledge engineer familiarization with domain of discourse – long acquainting time – necessity of collaboration between expert and knowledge engineer	- maintaining process performed by experts
		- formalized knowledge model readable for both computer and expert
		- knowledge model represented as extern source for control system (not embodied in the application) - - maintaining process performed by experts

Beside the problems of technical nature like already pointed out knowledge representation also qualitative and economical issues were identified. High failure rate of KBE solutions belongs to the first group and is commonly caused by two reasons: poor quality of knowledge models and necessity of interaction between an expert and knowledge engineer. The last group of problems coming up in KBE is of financial nature – high maintaining costs - reprogramming required for new standards releases - knowledge engineer familiarization with domain of discourse – long acquainting time – necessity of collaboration between expert and knowledge engineer.

The Table 1 consists also of proposed general solution of given problem. Without discussing every issue precisely following information might be retrieved from this table. In order to develop a methodology for SME for KBE engineering knowledge must be expert-oriented, such representation should take into account different kinds of knowledge (especially tacit and explicit) and different kind for it representation. A specially trained expert should be allowed to make modifications on knowledge base. Knowledge base should be divided into two parts: procedural knowledge base and declarative knowledge base. As known, all declarative knowledge corresponds to explicit knowledge and procedural knowledge to tacit knowledge [8]. Apart from that KBE application for SME should take into account different customers' standards and frequency of their revisions (easy, cheap and fast to modify).

3 Hybrid Knowledge Representation – System Architecture

In accordance with the above listed assumptions the architecture for knowledge based system with separate hybrid knowledge representation was worked out (**Figure 1**). This system is defined for deductive reasoning. Another destination of the system is to solve synthetic tasks, especially configuration design.

The crucial item of the application is ontological knowledge base which contains knowledge required to generate a set of parameters for configuration design. An ontological Knowledge Representation System (KRS) should facilitate interoperability among Ontological Frame-Based Systems by providing Application-Programming Interface (API). Knowledge Representation System should be equipped with Open Knowledge Connecivity Protocol to enable interoperability among such systems e.g. Ontolingua, Loom and Protégé.

Another part of knowledge repository for design process is procedural knowledge base. Procedural knowledge base is system-dependent, it depends on CAD environment in which it is carried out.

The third component of such application is retrieval system. Retrieval system's function is to manage information workflow from input to output and to retrieve desired information.

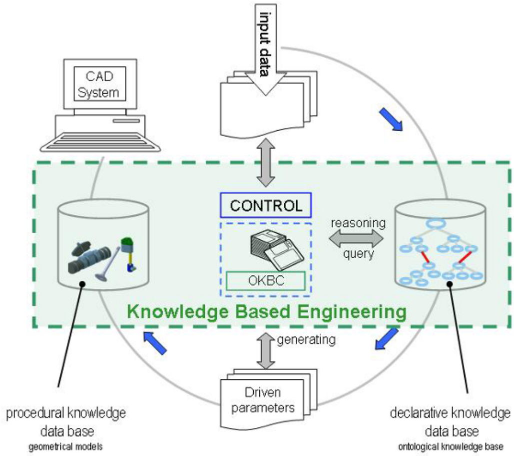

Figure 1. System Architecture of Knowledge Based Engineering System with Hybrid Knowledge Representation.

The architecture depicted in the **Figure 1** represents the main vision of Knowledge Based Engineering Application with heterogeneous Knowledge Representation format. There are many possible variants of components list and algorithm for this system. However, the list of components is restricted by the technology built in the components. It means that in case of declarative knowledge base for Knowledge Representation Systems (KRS) can be used only by those which support Frame-based ontology construction with OKBC – Protocol.

4 Case Study

Sheet-metal forming, particularly stamping (meaning – to force downward) is subtopic for manufacturing method for changing the shape of sheet-metal by applying presses. The procedure is broadly applied in autombile mass production thanks to high efficiency degree [4]. One component of the car body is usually manufactured in several stages.

Designing 1st and 2nd direct trims (second and third stage) was regarded to be the most complicated activity. In these operations scraps are removed and the holes pierced in the car body component. Designing the trim packets does not count to the difficult activities but it is concerned with carrying out several hundreds of steps to complete the tasks. Trimming packets are used to pierce small holes. Depending on the hole size different punch and button are used. Besides the whole variety of punch sizes, different shapes of holes and mounting methods must be taken into account. To design one trimming packet hundreds of parameters must be taken into account. Considering the variety of different characteristics of trimming packets and the fact that every customer has different approaches and standards to design them, several thousands values must be juggled to define the final form of TP. Every part of the car body has certain number of small holes. Such a part like inner engine hood panel contents commonly 30 – 40 small holes and designing and setting up parameters only for one TP miy take up to 1.5 hours. An exemplary die of 1st direct trim with trimming packets is shown in **Figure 2**.

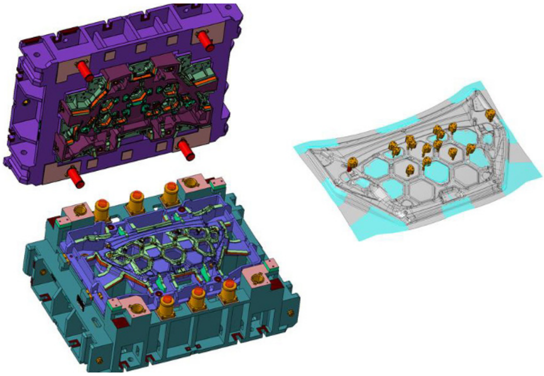

Figure 2. 1st direct trim and trimming packets

As pointed out in the prior section, there was a need for developing a tool to support a designer in generating of trimming packets. The main goal was to reduce design time. The goal reduction should be achieved by applying a computer for solving routine tasks. The designer's job should be reduced to filling in the "holes table" parameters describing the holes' characteristics. Holes table is a spreadsheet or text files which would contain all information about the holes manufactured in one operation.

Apart from the time reduction the new application should fulfill following requirements:

- CAD environment - CATIA V5.
- Low maintaining costs; if possible maintenance carried out by authorized per-son:
  - If possible maintenance without reprogramming;
  - Easy access to knowledge.
- Applicable for variety of customers.
- Not fixed output, modifiable by designer.
- Extendible.

For building the application following tools were applied: Protégé – for creating declarative knowledge base, CATIA V5 for procedural knowledge base and JAVA as programming language for the control system.

5 Conlusions

An application for supported design of trimming packets in stamping die design was developed. The program's destination was to support the designer in routine tasks of designing, positioning and ordering the trimming packets for stamping dies. Thy system bears analogy to general purpose Knowledge Based System in terms of consisting of two kernels: knowledge base and retrieval system. The application was developed in accordance with the main concept of knowledge based engineering application with hybrid knowledge representation. The secondary goals of the system were as follow:

- using given CAD environment for designing trimming packets - CATIA V5.
- minimizing maintaining costs for versioning the application by enabling carrying out the maintenance by authorized person:
- applying the system for many customers.
- enabling modifying the knowledge base by designer.
- being prepared for potential extensions.

The application for supported design of trimming packets in stamping die design met the requirements of Product Requirements Document (PDR) and contributed to reduction of the total design time. Thanks to applying the tool the total design time was brought down by 6%; the process of designing the trimming packets scaled down to approx. 10-15% of previous value (reduction 85-90%). In the presence the saved time is being used for more innovation in die design and for further optimization of the whole process of the stamping die designing. The requirement from PDR about reducing maintaining costs by versioning the application be authorized designer has not been proven so far. This arises out of the situation that the standards of customers haven't changed yet. However in the ending phase of the application development during training for authorized designer such situation was analyzed. It was pretended having several possible scenarios of changes: such as new parameter set, new type of standard element and new customer. It was stated that if the general rules of designing the trimming packets will not change, it should be manageable to carry out the upgrade of the knowedge base without programming skills.

Another important point was the fact that during the process of building the application one adhered to common steps of the guideline for constructing KBE's: identify, justify, capture, formalize, package, activate – known from MOKA. The general view of players and their roles involved in the developing procedure is to take from CommonKADS Methodology. Although the schema assumes six players (Knowledge Manager, Knowledge Engineer, Knowledge Developer, Project Manager, Knowledge Provider, Knowledge User), in the project of developing the application for supported design of TP's only four were involved. This arose out of the matter that involved people were able to bear responsibilities for more than one role. So, the responsibilities of general knowledge manager, knowledge engineer and knowledge developer were joined and theirs tasks carried out one of the authors of this work.

Knowledge base is a very innovative feature of the knowledge based approach. The application bases on the fundamental principles for KBE and uses homogeneous knowledge base: ontological for declarative knowledge and informally represented geometrical templates for procedural knowledge. This approach showed many advantages for inferring deductive tasks which were strictly related to designing synthetic system, particularly configuration design. In case of trimming packets the proportion of declarative knowledge to procedural might assessed approx. or 60% of declarative knowledge and 40% of procedural. This fact had a big influence on the worked out approach. Manual dealing with trimming packets without supporting tool did not belong to difficult activities but it required a lot of static information. Using the approach for such tasks with similar declarative to procedural knowledge ratio may definitely bring many profits.

Ontological knowledge base built in Protégé seems to be very intuitive and user-friendly. Handling with the system requires knowledge of ontology building and domain of interest but does not pose any problems. The procedural knowledge base is highly sophisticated and advanced. Dealing with it requires high level of knowledge of both the domain and the CAD-environment. In accordance with first observations the application should meet the requirements from PDR concerning maintenance process. An authorized engineer should able to modify the knowledge base. The complexity of both parts of knowledge base from loose interviews seems to be comparable; however, the ontological part seems to be more comprehensive and intuitive.

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Documentation and Management of Product Knowledge in a System for Automated Variant Design – A Case Study

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Abstract. A business strategy based on customized products with a high level of variety requires systems for efficient generation of product variants. The development of a system for automated variant design is a significant investment in time and money. To maintain the system's usefulness over time, frequent updating of design rules and execution control will normally become a necessity. Significant efforts are required for maintenance and adapting an established system to changes in product technology, new product knowledge, production practices, new customers and so forth. Another important aspect that has been identified, is the reuse of the system encapsulated generic product family descriptions, for example design rules, when developing a new product family. In this paper a case study is presented with the objectives to provide an understanding and an insight into a real industrial case. A focus is put on the documentation and management of product related knowledge for the purpose of revealing problems related to the current state of practice at the company to identify areas for improvements. The results are based on the experiences from a case study at a company with long experience of systems for automated variant design.

Keywords. Design automation, documentation, traceability, case study

1 Introduction

Many companies base their business strategy on customised products. To enable such a strategy they make use of advanced application systems for automating the work of generating product variants based on different customer specification, i.e. they develop and use design automation systems. This technology then becomes not only a means of improved efficiency but also a method for drastically reduced lead times, improved offer precision, quality assurance, performance and a higher degree of customer adaptation. The establishment of a design automation system is a significant investment in time and money which is expected to give revenues over many years. For a design automation system to maintain its usefulness over

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time, frequent updating of design rules and execution control will normally become a necessity. Experience indicates that significant efforts are required for adapting an established knowledge based system to changes in product technology, new product knowledge, production practices, new customers and so forth. Reuse of the system encapsulated generic product family descriptions, for example design rules, when developing a new product family is perceived to significantly increase the efficiency in system development and is a means to reduce the market introduction lead time. The focus of this paper is a case study carried out at a company with long experience of systems for automated variant design. The objectives are to provide an understanding and insight into a real industrial case and more specifically study the documentation and management of product related knowledge for the purpose of revealing problems related to the current state of practice at the company to identify areas for improvements.

2 Supporting system development and knowledge documentation

For this work the contributions in the domains of product configuration, design automation and knowledge based engineering (KBE) are most relevant as they are focused on specific applications. Hvam et al [7] describes a complete and detailed methodology for constructing configuration systems in industrial and service companies. They suggest an iterative process including the activities: analysis of product portfolio, object-oriented modelling, object-oriented design and programming, among others. Every activity results in a description of the problem domain with different levels of abstraction and formalisation. Two strategies are proposed for system documentation, either by using a product variant master and associated CRC (Class Relationship Collaboration) cards or by using the class diagram of a formal model and associated CRC-cards. The original content and structure of the CRC-cards have been further developed by Haug and Hvam [6]. The layout of the CRC-card has been revised and the content has been extended. Haug et al [5] have developed a prototype system for the documentation of the CRC-cards, the product variant master and the class diagrams. A procedure for development of design automation systems has been outlined by Rask [8] where issues about documentation and maintenance are addressed by emphasizing the need and importance of routines regarding versioning, verification and traceability. A possible means to support the updating of the knowledge-base proposed by Rask et al [9] is to strive for a design automation system implementation that allows the revision and the documentation to be executed at system runtime. Stokes [10] describes a methodology for the development of knowledge based engineering applications called MOKA, Methodology and software tools Oriented to Knowledge Based Engineering Applications. Two central parts of the methodology are the Informal and Formal models. The Informal model is used to document and structure knowledge elicited from experts, handbooks, protocols, literature etc. The Formal model is derived from the Informal model with the purpose to model and structure the knowledge in a fashion suitable for system specification and programming. Claesson [1] have introduced and developed the concept of configurable components for supporting platform-based product development. One element of the configurable components is a function-means model set including functional requirements, constraints, and design solution. The purpose with the inclusion of a function-means model is to provide design rational for the encapsulated design solutions. This could support the understanding of the system and thereby enhance system adaptation and maintenance.The issue with providing traceability and design history documentation for products generated by the use of executable design algorithms is discussed in Sunnersjö et al. [11]. A system is proposed to be based on files incorporating design knowledge and executable statements. These files are managed by a PDM system and they are manually executed for the creation of design variants based on different customer specifications. Principles for an automated execution using a predefined workflow based on the Dependency Structure Matrix (DSM) method is presented by Sunnersjö et al. [12]. A model for management of manufacturing requirements is presented by Elgh and Sunnersjö, [4]. The subject was further explored and Elgh [2] introduce principles for the modelling and management of manufacturing knowledge in design automation systems with an associated information model. The information model incorporates default links and runtime created links between manufacturing requirements, manufacturing resources, knowledge objects [3] and product items. The knowledge objects include pointers to the implementation of the knowledge (e.g. a spreadsheet file or a parametric CAD file). The principles have been applied and used when developing a prototype system for automated variant design.

3 Case study

Information about the case company was gathered by meetings, demonstrations of applications, reviews of documents and in-depth interviews. Eight respondents with different positions were interviewed in total using a standardized questionnaire with open-ended questions. The result from the case study includes a description of the company’s means of providing special products at the cost of standard products. Further, the documentation and the management of product related knowledge at the company are revealed followed by an analysis and a problem discussion.

3.1 Business model and means for custom engineered products

The company develops and manufactures products for the mechanical industry. It is a global company represented in many countries worldwide. Manufacturing is located at several production units and for customer support there are a number of productivity centres. The product catalogues with standard products contains ten thousands of articles. Each individual product structure is not complex but a large number of variants exist and the catalogues contain only the most frequent variants. It is of vital importance for the company to, beside the standard products, provide special products based on different customer demands. These custom engineered products represent an essential part of the delivered products. Custom engineered products are customer specific and a request for quotation of a custom engineered product is guaranteed to be replied within 24 hours including design drawings and a final price. All the necessary documents and manufacturing programs are automatically generated when the bid is accepted by the customer. Besides the standard and custom engineered products, the product space includes products that are supported by manufacturing and special engineered products.

Automation of different activities started at company in the late 80's. The automated activities include: process planning (workflow in production), design with CAD (3D-models and drawings), production preparation with CAM (tool paths' to CNC machines), steer information to production cells, and measuring preparation (creation of programs to CMM machines). The automation of these different activities has resulted in a stream-lined process for quotation and order preparation, from customer specification to NC programs, Figure 1.

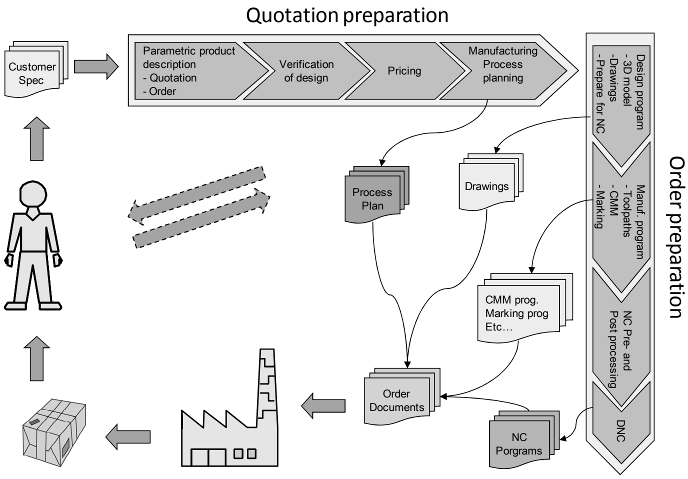

Figure 1. Automated process for quotation and order preparation

By means of in-house developed applications, the process is executed automatically requiring no manual interaction. This enables the company to provide custom designed tools rapidly and efficiently in the same way as standard tools. For custom engineered products the quotation and order process includes:

- Automatic calculation of price and delivery time based on situation in the production units for each quotation.
- Automatic generation of CAD-models, drawings, NC-data and process planning for each order.

3.2 Development process and its main tasks

The principle development process deployed at the company, from marketing to application programs, differs from a traditional product development process as it is aimed at describing a product space by rules and digital models, Figure 2.

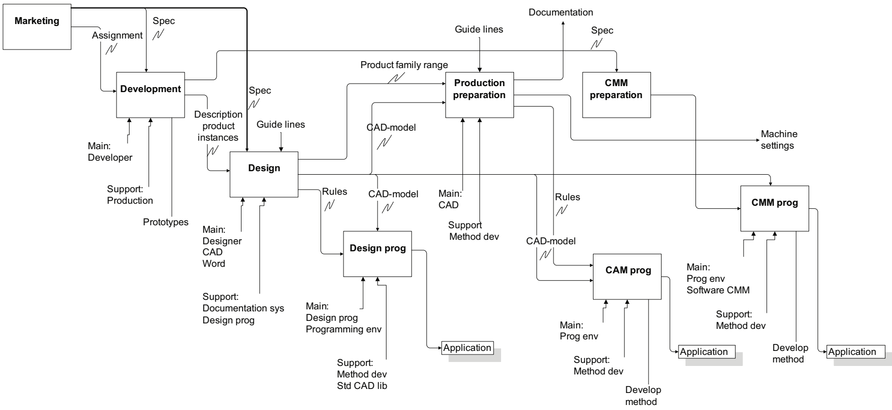

Figure 2. Company development process

In the development task, individual instances of a planned product family is developed and verified, including for example structural analysis, functional tests, CAD modelling and building prototypes. Based on these instances, a design space of the product family is defined and described by rules and associated 3D solid models. The rules are documented and structured as expressions, tables and figures. The rules are required input to the design programmers who prepares the 3D models with information (e.g. geometries, datum features and named surfaces) to be used when creating programs for product design as well as programs for CAM and CMM. Design programming includes the adaptation of the product family description for the system used for application development, actual coding in that system and verification of application. The principles are the same for CAM and CMM programming. CAM and CMM programming are preceded by CAM and CMM preparation. The three applications of executable product and manufacturing descriptions, describing a solution space – not just single instances – are loaded into a main system that manages the execution process of individual quotations and orders.

One essential means used in the quotation and order preparation is the design programs for the different product families. The outputs from the design programs includes variant specific: 3D models configured for CAM preparation and CMM preparation; quotation drawings, assembly and manufacturing drawings; customer data (e.g. drawings and 3D model). A design program consists of a number of rules that are executed in a sequence resolved by an inference engine. The design programmers have during the years used different systems for rule specification. The current environment is developed at the company and includes a rule engine. Currently, the company is working on the next generation of programming environment which will be base on an object oriented approach.

3.3 Documentation and management of product related knowledge

In this case study the identified documentation was classified as either product related or process related. Product related documentation includes: object documentation describing the result of an activity (e.g. a description of a parametric CAD model), object process documentation which describes the work related to the object (e.g. considerations, tests, analysis, decisions, assumptions etc.), and guide lines regarding the product design considering some specific aspect (e.g. manufacturing and environment). Process documentation, on the other hand, is related to a specific product development project including documents for project management, meeting protocols and other documents used for sharing information between project members. Process documentation is stored and managed using a project database. Object documentation and guidelines are stored, managed and published on a company internal portal. The design engineers provide the material regarding the product design that is to be published on this portal. No central system for storing and managing object process document exists to date. Some individuals make notes in documents or in programming code for personal use or to be used by other group members. An overall summary of the in-depth interviews gives that:

- The purpose of documentation in general and project documentation in specific is not seen by all company employees.
- The quality of the documentation is very varying.
- The corporate project database is used for finding work prerequisites and to learn from earlier projects.
- It is perceived, by the respondents, hard to find project documents for non project members.
- The information in the corporate project database is coarse and not easily accessible for non project members, especially when the project has been closed. The system is mainly used to find specific individuals for consultation regarding, by example, reuse of product descriptions.
- The documents are weakly connected to the different product families.
- Specific geometries, CAD models, are reused to some extent but design rules and principles are seldom reused.
- It is difficult for individuals who has developed good solutions to share these solutions. The reason given for this is that there is no present system for such documentation.
- The access to information is seen as most difficult by design engineers and design programmers.
- Actual testing is used as method for checking validity and quality when reusing different types of product descriptions in an application.
- A general view is that reuse could be augmented at the company and improved documentation could support this. However, it is important that documentation can be easily done.

4 Discussion and concluding remarks

The objectives with this work were to provide an understanding and insight into a real industrial case regarding documentation and management of product knowledge in a system for automated variant design. Further, the work was intended to reveal problems related to the current state of practice at the company to identify areas for improvements. Current documentation at the company is mainly focused on describing the final results of different activities answering "What?" questions. To reuse a rule in a new context (another product family) requires more information, for example scope, range, simplifications and underlying assumptions. Such information might be enough if the rule is to be used as it is, but if the rule has to be modified and adapted to specific circumstances even more information is required to support the adaptation while ensuring the validity of the rule. In general, there is a need of principles and methods to travel in the reverse direction through the different knowledge layers in the development process, from the final utilised (and system implemented) knowledge, to its associated background knowledge, Figure 3.

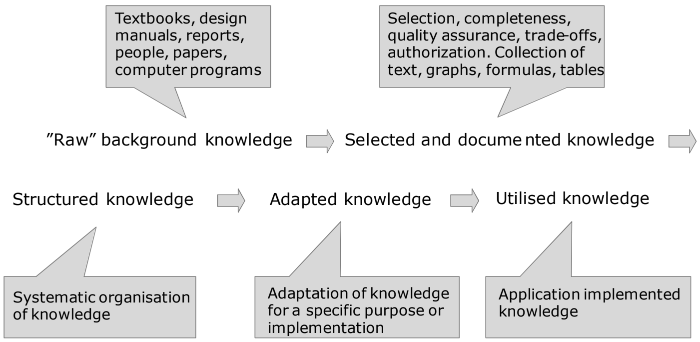

Figure 3. Different knowledge layers in the development process.

Documentation is commonly, by both researchers and practitioners, considered as an important enabler to support maintenance, adaptation and reuse of product descriptions encapsulated in systems for automated design. On the other hand documentation is a wide term and is commonly viewed as a non-value adding activity. The reason for this could be that the purpose, objectives and users of specific documentation is not defined and communicated. Two aspects that affect the value is time and organizational context, and the long-term corporate value can be difficult for individuals to understand if it is not clearly communicated. Further, it is important to support high quality documentation by providing systems, templates and guide lines to enable traceability, facilitate the work, focus on the purpose, ensure the completeness and prevent information overload. The searching possibilities and access to documentation are very limited at the case company to date and have to be improved. To support maintenance, adaptation and reuse of rules constituting a design automation system requires conceptual models, principles, methods, and tools for documentation, traceability and validation. This will be subject for future work. However, the initial strategy is to introduce two new concepts for describing design rational, one for the product instances (PIR) and one for the product family (PFR). These concepts are associated with templates consisting of predefined fields, keywords and headings for effective and efficient entering of information. PIR can be linked to decision supporting documents (e.g. computations, simulations, protocols, standards and guide-lines). PFR is linked to PIR as well as to relevant decision supporting documents. Utilised UDFs (user defined features), generic CAD-models and design rules are also linked to PFR. The program code is to be divided into blocks or objects pointing at associated UDFs, generic CAD-models and design rules. The intention with the templates is to facilitate and support high quality documentation, while the links provides traceability. The infrastructure for system realization will be built upon an information model and the technology provided by a data base.

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Knowledge Base of Computer-Aided System for Design of Safe Ship Power Plants

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Abstract. This paper deals with a computer-aided system for the design of the ship power plant safe for its operators. The system consists of two modules: the system of the hazard zone identification in the ship power plants based on their preliminary design and the expert system aiding design of the most dangerous zones from the operator's safety point of view. The first mentioned system is presented in this paper. The issues connected with ways of identification and assessment of hazard zones in the ship power plants are described. In particular, problems connected with knowledge acquisition from experts and its representation in the system knowledge base are presented.

Keywords. Knowledge base, design, safety, ship power plant.

1 Introduction

Expert systems are computer programs that are derived from artificial intelligence (AI) research. AI's scientific goal is to understand intelligence by building computer programs that exhibit intelligent behaviour. The primarily aim of the expert systems is to aid an expert in making decisions about a certain problem. Knowledge-based systems can generally be defined as computer systems that store knowledge in the domain of problem solution. Human experts rely on experience as well as on knowledge. This is the reason why problem-solving behaviours cannot be performed using simple algorithms. Experience can be regarded as a specialized kind of knowledge created by a complex interaction of rules and decisions. The term expert system is typically used for programs in which the knowledge base contains the knowledge used by human experts, which use additional information sources to solve the problem. Despite the availability of expert system applications in many scientific areas, the limited numbers of studies can be cited regarding with the marine and shipboard systems [1], [2], [3], [4], and [5].

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A system containing such a deductive database has been set up at the Gdynia Maritime University. The main task of the developed system is to assist in the design process of the ship power plant, which should be safe for its operators.

The specificity of such complex technical systems allows us to state that all their spaces can be more or less dangerous for operators carrying out any operational or maintenance tasks. For this reason, these plants should be well-designed to minimize the possible hazards to their operators. Both the complexity of modern ship power plants and the increased requirements concerning the operator's safety contest the conventional design methods. One of the possible ways of solving this problem is to provide the designers with appropriate tools. They should allow them to consider all aspects of the operator's safety during the design process, especially at its early stages. The computer-aided system supporting design of the safe ship power plants could be considered as such a tool. The computer-aided system developed at Gdynia Maritime University consists of two main modules:

– the system of hazard zone identification in the ship power plants based on their preliminary design,
– the expert system aiding design of the most dangerous zones from the operator's safety point of view.

This paper deals with the first mentioned module. The general concept of both modules was presented in [6].

2 Identification of Hazard Zones and Risk Assessment

In our approach, we have assumed that the hazard situation can appear only in a specific place of the ship power plant, where the operator carries out the operational or maintenance activities according to the defined operational or maintenance procedure. This means that the hazard situation can appear where the following triplet exists simultaneously: 'an operator – a ship machinery component – an operational or maintenance activity'. Every of such triplet is called a hazard situation. If we assume that the operator's characteristic features (qualification, strength, health, etc.) are consistent with the existed requirements then the *Elementary Hazard Situation* (*EHS*) will be only depended on the type of ship machinery and the kind of the operator's operational or maintenance activity to be carried out. If we exclude the operator from further consideration then the *EHS* will take the form of the following duality: 'a ship machinery component – an operational or maintenance activity'. Every ship machinery component together with a set of all operational or maintenance activities to be carried out with this component during realizing the various procedures constitutes an element of the hazard zone. The collection of these elements of the hazard zone constitutes a set of *EHS*.

'The operational or maintenance procedure' is a set of operational or maintenance operations having the goal of realizing complex operational or maintenance tasks, for example: fuel bunkering, overhaul of centrifugal separators, etc. 'The operational or maintenance activity' is a set of the operator elementary actions having the goal of realizing an elementary operational or maintenance task, for example: shutdown of valves, disconnection of couplings, etc.

One of the main tasks in developing a system for the hazard zone identification is to select the decision-making variables. They allow the system user to determine the potential hazard zone for operators. The method based on information available at the stage of the ship power plant preliminary design makes possible:

– selection of a set of factors dangerous and harmful to operator,
– their conversion into a set of the input variables of the considered system.

In our approach, we have distinguished 6 functional (type of working medium; pressure of working medium; temperature of working medium; vibration and noise level; type of working movement; parameters of electrical energy) and 4 operational factors (type of operational, maintenance, supplying and safety checking procedures) as the input variables of the considered system.

The main task of the system user is to attribute (based on his knowledge, experience and intuition) the suitable symptoms (states) of these variables in a process of solving the chosen task of the hazardous zone identification. If their different symptoms come true then they could trigger off the determined hazards for operators.

The risk for operators is evaluated for every distinguished *EHS* by selection of input variables with the determined values.

Nowadays qualitative methods of risk analysis are commonly used. They are easier to use and require much less the detailed information than quantitative methods. However, in a bibliography concerning issues of a risk assessment hardly any methods can be found that use fuzzy logic.

In the presented system, the risk assessment is based the subjective assessment by experts. This means that both the probability of the risk and the scope of the possible consequences have been acquired from the experts in this field. To obtain this kind of subjective information, we have prepared a special questionnaire. The obtained results have been used to build the risk assessment system with the fuzzy knowledge base.

3 Structure of Fuzzy Knowledge Base

The fuzzy knowledge base consists of a set of rules and fuzzy variables. Therefore development of such a database required to carry out the following actions:

– determination of fuzzy set membership functions representing the risk level of an operator in the case of direct contact with the specified type of hazard (a functional factor),
– determination of fuzzy set membership functions representing the possibility of operator's contact with the specified type of hazard (a functional factor),
– determination of fuzzy membership functions for the resulting variable (a risk level of the operator),
– development of the inference rules connecting the different fuzzy variables.

In our approach, expert opinions have been applied to determine fuzzy membership functions for the specified functional factors. For this purpose, they were transformed into linguistic variables and fuzzy evaluations for individual states of these variables were attributed. Then, the appropriate membership functions for each linguistic variable were assigned.

The obtained data were used to set up the fuzzy sets in both the discrete and continuous spaces. Sets of temperature and pressure hazards are described in the continuous space. For values of these risks, the approximations were carried out and we received sets of triangular or trapezoidal shapes. For other hazards, due to the finite number of elements in the space, fuzzy sets were presented in the discrete form. Examples of discrete membership functions of operator's hazard level in the case of direct contact with that type of hazard and possibilities of operator's contact with hazards are presented in Fig. 1 and Fig. 2. Membership functions of fuzzy sets related to the pressure hazard are presented in Fig. 3. The membership function for the resulting variable (the operator's risk level) is shown in Fig. 4.

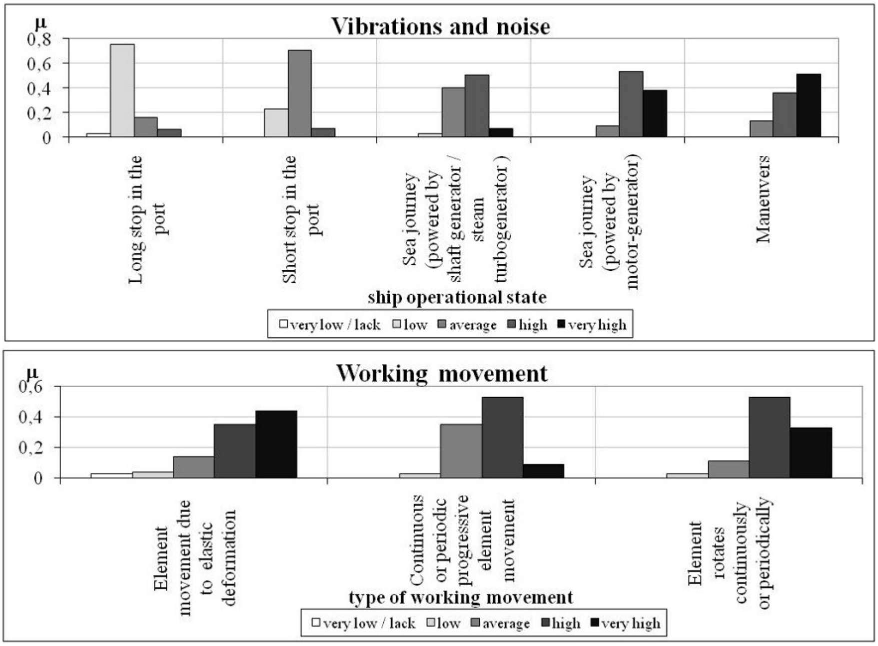

Figure 1. Discrete membership functions of the operator's hazard level in the case of direct contact with hazards

In the developed functions, a value denoted by μ represents the membership degree of individual states of functional factors in the fuzzy sets.

To compare fuzzy risk assessments for each *EHS*, the ordered linear range of operator risks from 0 to 5.0 was applied. Their risk assessment was carried out by fuzzy inference in the following steps:

- determination of:
  - the operator's risk level in case of direct contact with the specified type of hazard,
  - the possibility of operator's contact with the specified type of hazard,

– calculation of the aggregated indicator for assessment of a risk level triggered off by *EHS*,
– defuzzyfication allowing to assess the risk for *EHS*.

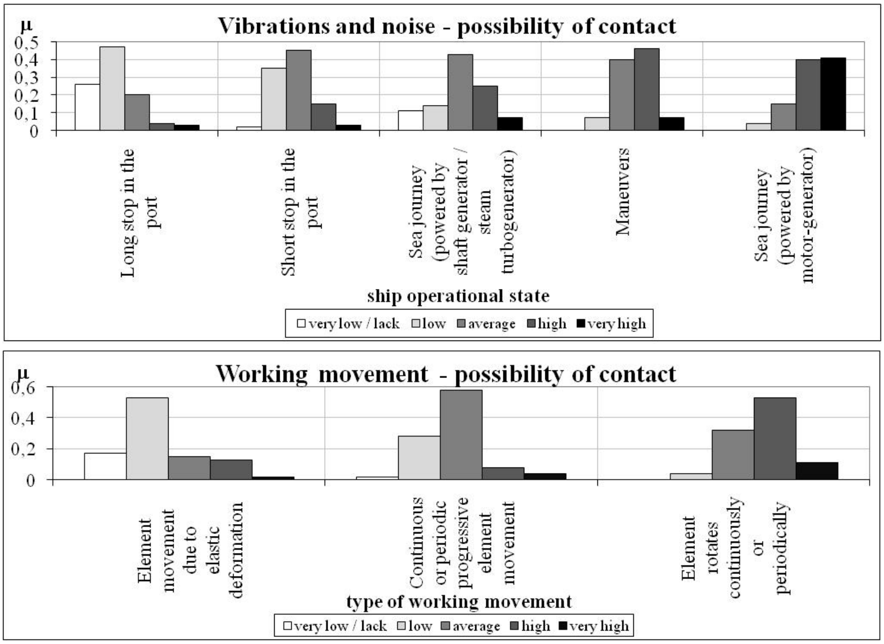

Figure 2. Discrete membership functions for possibilities of the operator's contact with hazards

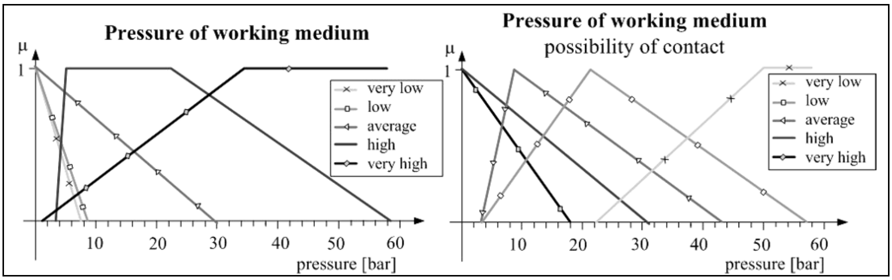

Figure 3. Membership functions of fuzzy sets related to the pressure hazard

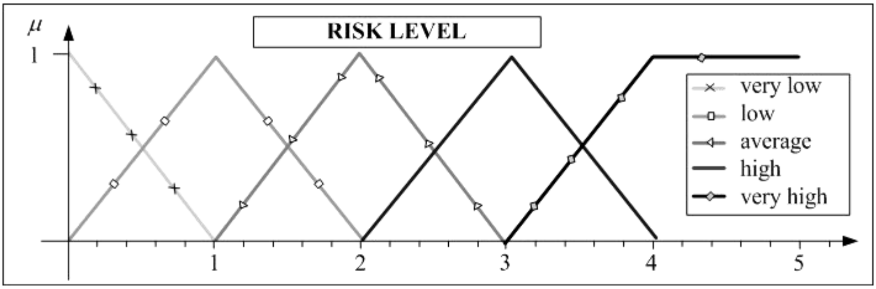

Figure 4. Membership function for the resulting variable

The system has been developed by using the programming language PROLOG LPA. This language has its own mechanism of fuzzy inference. The knowledge base developed for this system required adequate conversion of information obtained from experts. Based on the developed fuzzy sets (Fig.1, Fig.2 and Fig.3), fuzzy variables were set up for this purpose. An example of a fuzzy set representing the temperature hazard is presented in Table 1.

Table 1. Representation of fuzzy sets for the temperature hazard

```
fuzzy_variable(temperature) :-
[-50,250] ;
very_low, /\, linear, [-15,48,75] ;
low, \, linear, [-25,65] ;
average, /\, linear, [-15,65,150] ;
high, /\, linear, [5,80,220] ;
very_high, /, linear, [45,205].
```

Estimations of the hazard level and operator contact possibilities with the different types of risk are derived from membership functions based on a set of rules which are an essential part of the knowledge base. They have the form of a fuzzy matrix. Exemplary matrix of rules which allows to specify the operator's risk level in a case of the pressure hazard is presented in Table 2.

Table 2. Matrix of rules for the pressure hazard

```
  fuzzy_matrix( pressure_rules ) :-
   pressure    *     pressure_contact->
   risk_level ;
   high              *     low
   ->    low ;
   high              *     very_low              -
>  low ;
   very_high   *     low                         -
>  average;
   very_high   *     very_low              ->
   low;
  ...
```

These rules can be interpreted as follows: '**IF** the pressure hazard level (in the case of direct contact) is *high* **AND** the possibility of contact is *low* **THEN** operator's risk level is *low*'. The resulting values for the operator's risk level are obtained by fuzzy inference based on the Mamdani model. Only rules referred to the fuzzy sets related to the input data are considered. For the hypothetical input data $x_0=y_0=45$ [bar], the risk level related to the pressure hazard is presented in Fig.5. There are only two rules in the rules matrix activated for this data: rule 1 and rule 4. Each of these rules generates the fuzzy output set which, in turn, determines the operator risk level. Its value is a single number and it can be obtained by the defuzzyfication process. The most popular defuzzyfication method is the centroid calculation, which returns the center of area under the curve.

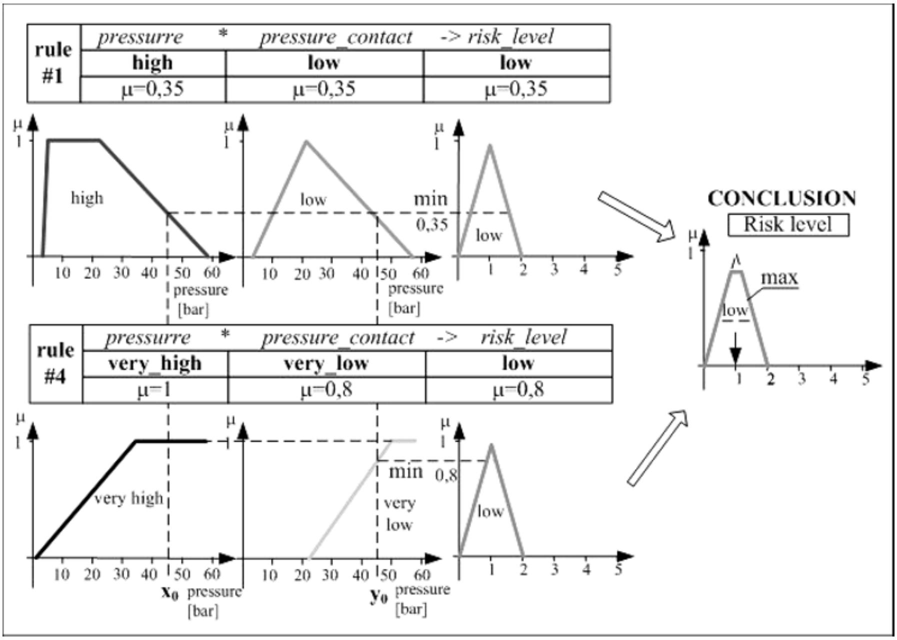

Figure 5. Example of Mamdani fuzzy inference method

Development of the matrix of rules containing twelve variables is very difficult. Therefore, these variables are grouped into 6 pairs setting up the hazard levels (in the case of direct contact) and possibilities of contact with the specified type of hazard. During the process of the fuzzy inference for each of these pairs, the fuzzy output sets are determined separately. In the final stage of inference, the "sharp" value is determined in the defuzzyfication process based on the sum of these sets.

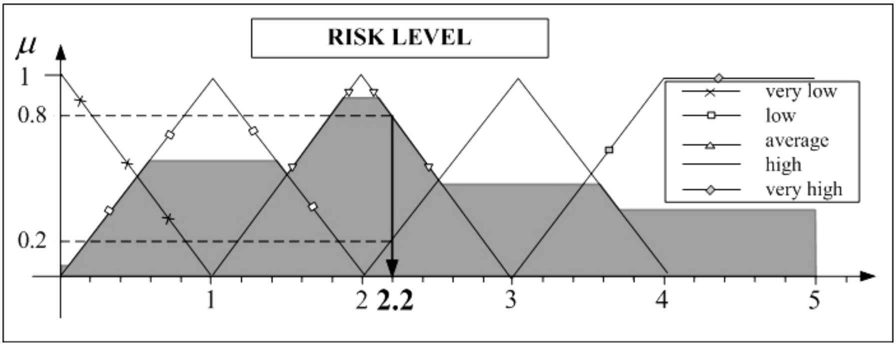

Figure 6. Final value of the risk assessment of EHS after defuzzyfication

To illustrate this fuzzy inference process of such a risk assessment, the heavy fuel transfer pump replacement is considered (Fig. 6). For example, if input values are:

- *type of working medium– heavy fuel,*
- *temperature of working medium - 150°C,*
- *pressure of working medium – 12.5 bar,*
- *vibrations and noise - manoeuvres*
- *type of working movement - element rotates continuously or periodically,*
- *parameters of electrical energy - conversion of electricity into mechanical energy or heat*

then the resulting risk level will be equal 2.2.
The output value corresponds to the *average* risk level in a degree 0.8 ($\mu = 0.8$) and to the *high* risk level in 0.2 ($\mu = 0.2$). This result can be used to assess the operator's safety during ship machinery design.

4 Conclusion

Considerations concerning application of a fuzzy logic approach in a computer-aided system for the hazard zone identification in ship power plants allow us to formulate the following conclusions:

- application of the fuzzy logic approach allows us to assess the operator's safety during ship machinery design especially at its early stage when information concerning dangerous and harmful factors triggering off hazard for operators can be imprecise and vague,
- traditional expert systems rely on exact thresholds in the conditions of their rules, however fuzzy logic smoothes out these thresholds by allowing rules to use qualitative descriptions in their conditions,
- use of the fuzzy logic toolkit decreases both the time-consuming process of preparing the knowledge base and its size in a significant way.

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Knowledge Management and e-learning for Underground Construction Projects

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Abstract. This paper describes a Knowledge management system (SGAC- Active Knowledge Management System) to manage the knowledge generated in a research project. This system aims both at organising project information during the project and at transferring this knowledge to other researchers from the same scientific domain so as to enhance e-learning. This paper approaches the problem of knowledge transfer from a case study angle. The system is developed inside "The Multidimensional City" project, which is a multi-disciplinary research project that promotes the development and implementation of Spanish technological innovation in underground construction. The SGAC system aims at achieving full integration of large set of contents created in research projects related to underground construction sites. Then, the project has developed several types of metadata for tagging and enriching contents. All this enriched information becomes the base of different e-learning courses in underground construction, promoting an updated education in this knowledge area and the dissemination of the results generated in the research project.

Keywords. Knowledge management, underground construction, research project.

1 Introduction

Currently, there are thousands of research projects running. The majority have a web page for the society to know about the project and an intranet for the partners to exchange documentation, planning and information. Once the project has finished, this information still remains in the web but it easily becomes old because nobody updates it.

This paper presents, on one hand, a tool developed to transfer the knowledge generated in a very big national research project: "The Multidimensional City" [16] and a tool to reuse these knowledge for e-learning. This system is called Active Knowledge Management System (SGAC) [14] and pretends, through a

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single access web portal, to promote the dissemination of the research results, to provide tools to make the knowledge management tasks easier along the lifecycle of the project and to provide useful and updated information to academics, researchers and industries in the underground construction field.

2 Background

2.1 Research knowledge transfer

It is well known that knowledge is generally difficult to transfer. There are countless examples of sound research projects never making it to the practice community, and of organizations in need of solutions typically ignoring academic research findings in developing management strategies and practices. There is a large gap between academic research and practitioners and can be found in nearly all disciplines. Beyer and Trice [3] conducted a literature review on research utilization and concluded that the: “most persistent observation … is that researchers and users belong to separate communities with very different values and ideologies and that these differences impede utilization”.

In recent years many research studies analyzed the knowledge transfer ([13], [15], [5], [7], [4], among others). But the task of transferring knowledge successfully is far from straightforward.

Traditionally, knowledge transfer is viewed as information that could be passed on mechanistically from the creator to a translator who would adapt it in order to transmit the information to the user. These classical models implied a hierarchical top-down relationship between the generator of knowledge who holds the resource (knowledge) and the user (receptacle).

To avoid this problem, the latest models to transfer knowledge from the research to practice communities are the communities-of-practice and the knowledge network model. The communities-of-practice are “groups of people informally bound together by shared expertise and passion for a joint enterprise” [17]. Because communities of practice generally focus on informal, voluntary gatherings of individuals based on shared interests, they are sometimes seen by organizations as “unmanageable” endeavours. Knowledge networks, on the other hand, which have more organizational support, are believed to contribute directly to the bottom line.

Concretely, in the construction sector, The European Construction Technology Platform [8] is the European community of practice. All European countries have their own national platform. In Spain, the construction platform is called *Plataforma Tecnológica Española de Construcción (PTEC)* [12]. These communities of practices include all stakeholders in the construction sector and are industrially driven.

2.2 The Multidimensional City project

The Multidimensional City is a Spanish strategic scientific-technological project from the *Ministerio de Ciencia e Innovación* PSE 10-2005. It is a multi-disciplinary research project that promotes the development and implementation of Spanish technological innovation in underground construction.

The Multidimensional City is a project endorsed by the "*Plataforma Tecnológica Española de Construcción*". The project´s partners integrate not only the on-the-field engineering experience and technical know-how of the industry, but also the research capabilities and conceptual innovation of the academic sector. The Multidimensional City is fully committed to contributing to an increased quality of life by reducing construction time and cost of planned and future underground infrastructures.

3 The system approach

3.1 System objectives

The Active Knowledge Management System (SGAC) pretends to be an access web portal to all the knowledge generated inside the The Multidimensional City project: promoting the dissemination of all the results obtained along the different research activities carried out by the project participants, not only along the lifecycle of the project but also once the project is finished; providing tools to make the knowledge management tasks easier along the lifecycle of the project, through the visualization of the reports evolution or the related documents; and providing useful and updated information to academics, researchers and industries in the underground construction field to be used in the preparation of e-learning courses and the learning in general.

On the other hand, the project results not only are interesting from a scientific or technologic point of view, but also from an educational point of view. For this reason an e-learning platform has been developed with the aim of taking profit of all the knowledge generated inside the research project, already introduced and classified in the SGAC system, to be included in e-learning courses for academics, researchers and industries in the underground construction field. The preparation of these e-learning courses will highly contribute to the dissemination of all the research project results.

3.2 System users

The main SGAC end users will be the project partners. These partners are mainly researchers from different centres, companies or universities who do research in different topics of the underground construction field. The SGAC will help all project partners to know what is being done in other sub projects by other partners, to manage the information they generate in their subproject and to disseminate their research results to all the community.

On the other hand, the e-learning platform is addressed to high education students, researchers and industry professionals, all of them in the underground construction field.

3.3 SGAC contents classification

Currently, the SGAC contains all the knowledge generated along lifecycle of the project. This knowledge comes from the results obtained along the research tasks developed, as well as all the information used and created along these research tasks. Therefore, reports and deliverables containing the work undertaken by all the project partners, presentations, published papers, images, states of the art, drawings, etc. can be found through the SGAC search tools.

In order to assure efficient searches and to accomplish the users' requirements, all this information has been enriched with different kinds of metadata. When analyzing the knowledge, the metadata to be incorporated in each information object (IO) was defined. With the aim to create an interoperable infrastructure with other possible databases, the system uses as a basis the LOM IEE 1484.12.1 Standard for Learning Object Metadata [9].

One of the most important metadata is the content metadata. This metadata contains different keywords related to the content of each Information Object (IO). These keywords are included inside a concept map of the underground construction field. To develop the concept map, different classification methods such as thesaurus for underground construction were analyzed ([1], [2], [6], [11], [10], etc.). From this analysis, it was decided to design the thesaurus basing on the ITA thesaurus, always bearing in mind the project purpose. Figure 1 shows the first level of classification of the "Content Thesaurus" which will be used in SGAC. It contains about 500 keywords in the underground construction field, grouped in three levels of classification.

Not only content metadata was organized in different classes and subclasses, but also media metadata. Media metadata contains keywords related to the type of information included in each IO.

3.4 E-learning platform contents

The e-learning platform contains some e-learning courses, a wide repository of images and videos, a repository of 3D models and a group of interactive three-dimensional scenarios, all of them related to the underground construction field.

Most of their contents come from the knowledge already included and classified in the Active Knowledge Management System (SGAC), assuring the transmission of up-to date information and promoting the dissemination of the results obtained in the research project between the underground construction community of practice. This exchange of information between the e-learning platform and the SGAC system is bi-directional, as all the contents specifically prepared for the courses (contents improved with external information) are introduced again inside the SGAC. Currently, a basic tunneling course is introduced in the e-learning platform and is being carried out by a wide group of engineering university students.

The e-learning platform provides a repository of images and videos, all of them classified in different categories and subcategories, coming from the Content thesaurus developed in the SGAC. On the other hand, each image and video has its own description. As before, all these images and videos are included, enriched with metadata and classified in the SGAC.

Moreover, the repository of 3D models is also available from the e-learning platform and it is pretended to be accessible from the SGAC.

And finally, the platform contains different interactive three-dimensional scenarios that consist of 3D visualizations where the student can select some of the objects and find out related information. These objects are called intelligent objects.

3.5 SGAC tools

The SGAC system is composed by two different tools, both of them accessible from the SGAC web portal (http://www.lcm-gac.es) with a previous user's validation: the Introduction of contents tool and the Search of contents tool.

The Introduction of contents tool enables the user, with a previous validation, to upload the desired IO to the system and enrich it with the defined metadata fields.

On the other hand, the Search of contents tool provides three different kinds of searches: Simple search, Filtered search and Conceptual search (see Figure 1).

Figure 1 Conceptual Search

The Simple search can search by title and/or description, by keywords from the thesaurus or by whatever field of metadata implemented in the tool. The Filtered search filters the results by their source (the subproject where the specific IO has been created), the format, the language and the year of creation. On the other hand, this kind of search enables the user to choose a Media keyword and a Content keyword. And finally, the Conceptual search enables the search of contents through the different categories and subcategories of both Media thesaurus and Content thesaurus. The results of any kind of search are displayed in a list, together with their title, description, source and year of creation.

3.6 E-learning platform tools

The e-learning platform is composed by four different tools, all of them accessible from the e-learning platform web portal (See Figure 2), with a previous user's validation: the e-learning courses platform, the repository of images and videos, the repository of 3D models and the interactive three-dimensional scenarios platform.

Figure 2 E-learning platform web portal

The e-learning courses platform currently contains a basic course of underground construction. This platform has been designed in a user-friendly way, enables the navigation between concepts and chapters of the same course and provides a wide range of visual and interactive materials, a part from the theoretical concepts.

The repository of images and videos contains a wide up-to-day images and videos in the underground construction field. All of them are classified in different categories and subcategories, coming from the Content thesaurus developed in the SGAC. On the other hand, they are also classified in the Media thesaurus, differentiating between image and video format. They are easily visualized in a list after selecting a category and a format. When selecting a specific image or video, the whole object is showed as well as a brief description of its content. As aforementioned, all these images and videos are included, enriched with metadata and classified in the SGAC.

Both the repository of 3D models and the interactive three-dimensional scenarios are also available and easily visualized in the e-learning platform, using a web system without any specific software. The interactive three-dimensional scenarios consist of 3D visualizations where the student can move in using the keyboard and interact with some of the objects that constitute the 3D model. These selectable objects are called intelligent objects. The student can select one of these objects to find out related information, such as its name, description, characteristics,... On the other hand, the system enables the student to move to the specific chapter of the course where the selected object is wider explained. Therefore, the student can choose the level of knowledge.

4 Conclusions

Currently, the majority of the research knowledge is shared in face-to-face interactions (project presentations, meetings, etc.) and it is dispersed in different supports (paper based, on line, etc.). With the development of the SGAC all this knowledge is centralized and accessible for all the project community from a unique web portal. All this information has been analyzed and codified with metadata to assure efficient searches and to accomplish the users' requirements. From the study of all this knowledge the users have realized that some of them are working in similar or complementary research areas. Therefore, the SGAC helps all project partners to know what is being done in other sub projects. On the other hand, the system is becoming a useful tool to manage all the knowledge generated in the project along its lifecycle.

As future steps, new and more user-friendly search tools are being developed for the SGAC system, new kinds of metadata (such as comments, punctuation,...) are being implemented, and all the contents that are recently being generated are being introduced and codified in the SGAC. On the other hand, as new contents are generated, new e-learning courses will be created and educational metadata will be used to create specific courses for all kinds of users and knowledge levels. As aforementioned, inside the research project The Multidimensional City, a big amount of research works in the field of underground construction is being carried out. All the obtained results not only are interesting from a scientific or technologic point of view, but also from an educational point of view.

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Knowledge-Based Engineering Review: Conceptual Foundations and Research Issues

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Abstract. Knowledge-Based Engineering (KBE) is a developing research field that studies technologies for capture and re-use product and process engineering knowledge to reduce time and cost of product development. KBE has held great promise since its inception, but evolution in the technologies and notions underlying KBE as well as significant challenges towards adoption have so far precluded its main-stream use. The main objective of this paper is to focus on research issues within KBE, pointing out the challenges and pitfalls that currently prohibit a wider adoption of KBE while suggesting possible solutions and avenues for further research. In particular, the case-based ad hoc development of KBE and the 'black-box' nature of many KBE applications, subsequent difficulties with knowledge re-use, and insufficient quantification of the benefits of KBE are significant challenges towards a wider adoption of KBE. Methodological and technological advances address some of these issues, and propositions are made to further both qualitative and quantitative analysis and evaluation of KBE applications.

Keywords. Knowledge-Based Engineering, Review, Knowledge Management

1 Introduction

Increasing design complexity coupled with decreasing time for New Product Development (NPD) and pressure to reduce cost to maintain competitiveness are driving the adoption of Knowledge-Based Engineering (KBE) in various industries, including aerospace. If performed correctly, the application of KBE may save up to 80% in development time for the recurrent design of specific components and assemblies [2].

Knowledge-Based Engineering has held great promise since its first applications in aerospace, roughly 25 years ago [3]. Despite reported advantages to the adoption of KBE, a breakthrough of KBE in the aerospace industry has so far remained elusive. The reasons for this are varied and complex. Part of the problem is derived from the realization that the KBE research field is still developing, with

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methodological and technological considerations constantly evolving [3-5]. Furthermore, the reasons for doing KBE and the inherent advantages have not been communicated optimally to audiences. Also, a number of considerable challenges must be overcome for KBE to truly become main-stream.

Given this, the main objective of this paper is to focus on research issues within KBE, pointing out the challenges and pitfalls that currently prohibit a wider adoption of KBE while suggesting possible solutions and avenues for further research. To achieve this, a review of 25 suitable research papers (including 16 case studies) from the period of 1995-2010 has been performed. The considerations from this review are supplemented with findings from the author's original research into KBE.

To achieve the aforementioned objective, the conceptual foundations of KBE will first be discussed, including a definition of terms, evaluation of methodologies and arguments for KBE adoption. Finally, the research issues at play in KBE will be evaluated: first, the challenges that KBE faces will be inspected, which is followed up by suggestions for addressing some of these challenges.

2 Conceptual Foundations of Knowledge-Based Engineering

In this section, the conceptual foundations of Knowledge-Based Engineering will be evaluated, which includes a concept definition, a methodological review and a rationale for KBE adoption.

2.1 Concept Definitions

Knowledge-Based Engineering is subject to a variety of interpretations and related definitions [1, 3, 7-10]. As Ammar-Khodja et al. [6] note: 'In reality, there is no unambiguous definition of KBE. However, most of them are similar'. The key aspects of KBE that can be summarized from literature definitions are *knowledge*, *engineering*, and *automation*. In discussing the definitions from Bermell-García & Fan and Chapman & Pinfold, Ammar-Khodja et al. [6] note that 'all these definitions agreed [*sic*] on the fact that the basic objectives that have to be supported by KBE are: to solve a particular design problem by a KBE application (short term), and to retain the domain knowledge required for solving design problems in the same domain (long term).' However, the definition of Cooper & La Rocca [3] adds a vital objective by recognizing the business need to reduce the time and cost of product development as an ultimate objective of KBE. Furthermore, this definition adds an important multi-disciplinary perspective, which corresponds to the concurrent roots of KBE. The definition of Cooper & La Rocca [3] is adopted here as the most accurate expression of the key elements and objectives of knowledge-based engineering:

> *The use of dedicated software language tools (i.e. KBE systems) for solving design problems by capturing and reusing product and process engineering knowledge in a convenient and maintainable fashion. The ultimate objective of KBE is to reduce the time and cost of product development by automating*

repetitive, non-creative design tasks and by supporting multidisciplinary integration in the conceptual phase of the design process and beyond.

2.2 Methodological Underpinnings of Knowledge-Based Engineering

A number of KBE methodologies are available to support the development of KBE applications and systems. By far the most well-known of these is the MOKA methodology: Methodology and software tools Oriented to Knowledge-based engineering Applications. This methodology, based on eight KBE Life-cycle steps and expressed in accompanying case-specific informal and formal models, is designed to take a project from inception towards industrialization and actual use [4]. The informal model consists of so-called ICARE forms: Illustrations, Constraints, Activities, Rules and Entities. The formal model uses MML (Moka Modelling Language, an adaptation of UML) to classify and structure the ICARE informal model elements, which are translated into formal Product and Process models. The MOKA methodology is illustrated in Figure 1.

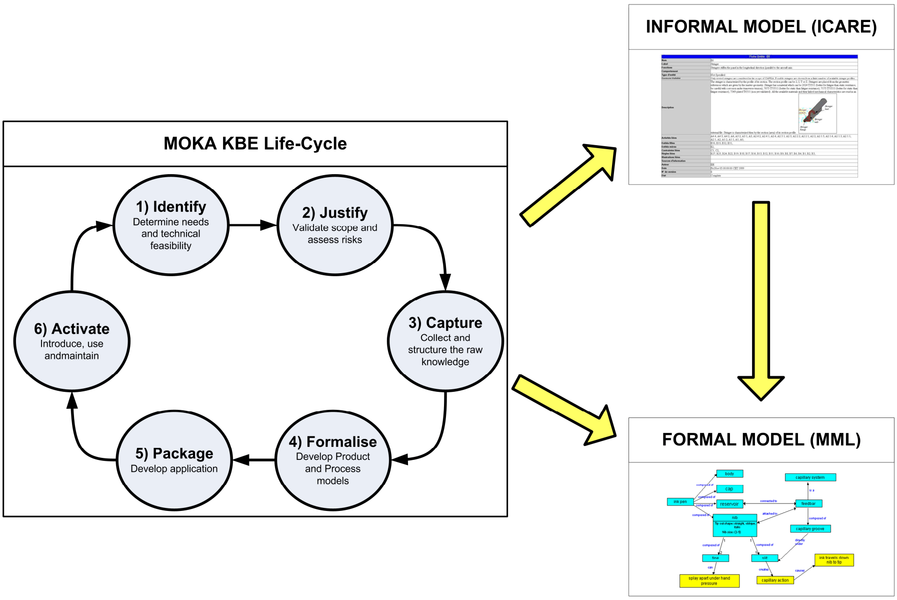

Figure 1 MOKA methodology

Another available KBE methodology is KOMPRESSA: Knowledge-Oriented Methodology for the Planning and Rapid Engineering of Small-Scale Applications [11; 12]. This methodology aims to support KBE implementation at Small to Medium Enterprises (SMEs) and shares many principles with MOKA, with which it was developed in parallel.

In response to perceived shortcomings of the previously introduced methodologies, the KNOMAD methodology has been devised by the authors of this paper [5; 13]. This methodology includes a multidisciplinary approach, extended provisions for knowledge normalization, organization, modeling, analysis and delivery, and more substantiation for individual methodology steps. More detail is available in the relevant literature [5; 13].

2.3 Rationale for Adopting KBE

There are a number of strong arguments for adopting knowledge-based engineering. Most of these arguments have their roots in the opportunities offered by the rationalization and automation of design in the conceptual and preliminary design phases. By now, a well-recognized feature of design is that a large percentage of the product's life cycle costs are committed by the end of the preliminary design phase (Figure 2). Estimates for committed cost range between 60% to 80% [14-20]. The decisions that drive these costs are made based on trade-offs. It would be most helpful if the design envelope would be explored to the fullest before making decisions with an extremely high impact on costs. However, the time-intensive nature of many routine design tasks – up to 80% of time is spent on routine tasks [21] – commonly prohibits a full exploration of options. This is illustrated in Figure 3.

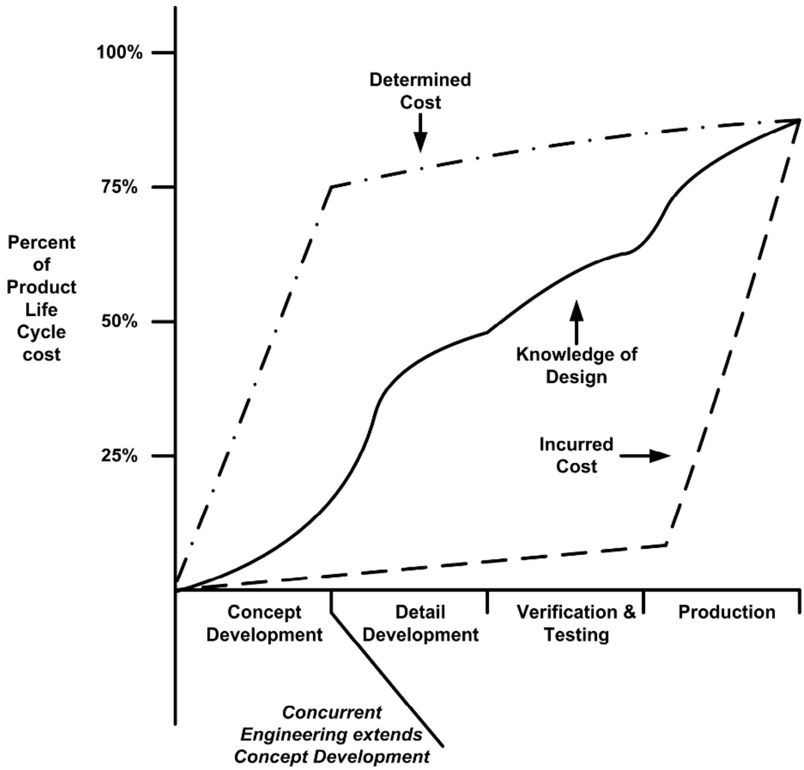

Figure 2 Product cost related to design process [20]

Figure 3 highlights one of the major advantages in adopting KBE. As the definition of KBE states, one of the hallmarks of the KBE approach is to automate repetitive, non-creative design tasks. Not only does automation permit significant time and cost savings, it also frees up time for creativity [1], which allows exploration of a larger part of the design envelope. This is helped by another advantage of KBE: it enables knowledge re-use (up to a degree, as the programming implementation sometimes prohibits re-use – see also Section IV).

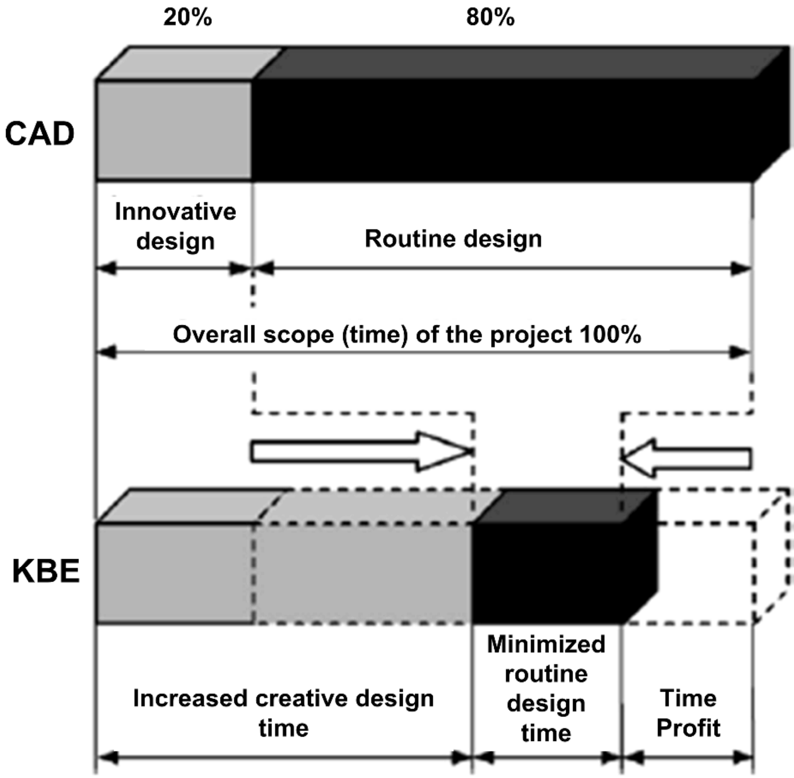

Figure 3 Achievable design time allocation by KBE adoption [22]

20% of a designer's time is spent in searching for the right information and knowledge, and 40% of all design information requirements are currently met by personal stores, even though more suitable information may be available from other sources [10; 23]. Clearly, knowledge re-use guided by an established KBE framework may save considerable time and effort. A related major advantage of KBE is the ability to leverage upon a shared knowledge base and offer domain-specific views of a design problem (as implicated in Van der Laan [1]). This helps in the understanding, acceptance and subsequent analysis efforts for involved design engineers. To bring home the message that KBE can result in considerable time and cost savings while allowing for more creative work in conceptual and preliminary design, the results from a limited number of KBE projects are summarized in Table 1.

Table 1 Selected KBE project results

Source	Subject	Effects
Van der Laan et al. [2]	Parametric Modeling of Movables for Structural Analysis	Up to 80% time savings in FE model generation (from 8 hours to 1 hour for specific instances)
Brewer [25]	Tooling design	73% lead time reduction
Chapman & Pinfold [8]	Automotive Body-In-White concept design	BIW mesh generation from 15 man weeks to 'minutes'.
Choi et al. [16]	Composite aerospace structure: cost and weight estimation	Rapid evaluation of cost and weight for composite structures; supports trade-off capability.
Kulon et al. [26]	Manufacturing process design: hot forging	New designs in hours rather than days or weeks. Supporting accessible knowledge base.

3 Research Issues in Knowledge-Based Engineering

Despite the potential gains to be made by adopting KBE, its actual deployment remains limited. This has both historical and contemporary reasons. A number of challenges results; these are presented here as research issues in KBE.

Historically, extremely high price tags for KBE development suites and the use of complex, expert developer oriented modeling languages prevented a wide-scale adoption of KBE [3]. However, advances in computer technology have resulted in a number of factors to alleviate these problems: powerful computer capacity is ubiquitously available at affordable cost levels, more suitable modeling languages have been developed, and Internet offers possibilities for rapid and flexible application deployment.

However, development of KBE applications is still very much case based and happens on an ad-hoc basis [7], a notion that is confirmed by the review of KBE applications performed in this paper. This is most clearly visible by the wide-spread non-adherence to KBE design methodologies. From the 16 papers describing case studies, 75 % did not explicitly adhere to a specific methodology. The practical impact of existing methodologies seems to be limited. The resulting case-based nature of KBE development is a significant roadblock. It can lead to knowledge loss due to poor modeling of the application and inadequacies in the used development language; it can cause knowledge misuse if the wrong kind of applications are developed; knowledge runs a danger of being under-utilized, due to an inability to share and reuse it at computer and human levels, and finally, maintenance costs will be higher due to non-standard development [7].

Another significant drawback of current KBE development is its tendency towards 'black-box' applications – many applications (e.g. those in [16, 17, 24, 26]) at best represent captured knowledge as context-less data and formulas. There is no explication of formulas and the actual meaning and context of the captured knowledge, let alone provisions for capturing design intent. Part of it this is undoubtedly due to the difference between knowledge sources and knowledge engineers: one thinks in 'real-life' products and processes, the other thinks in models and programming.

The previous drawbacks tie in closely with the difficulty of re-using knowledge in KBE systems. Case-based black box KBE applications do not particularly invite knowledge re-use. Aside from that, higher-level knowledge such as project constraint reasoning, problem resolution methods, solution generation strategies, design intent and supply chain knowledge [10] is often not captured, let alone re-used.

A final but major oversight of most KBE research up till now is the failure to quantitatively illustrate the advantages and costs of KBE. 81% of applicable case study papers do not mention the resulting time or cost advantages associated with KBE adoption, let alone the more sensitive information about KBE development cost. The performed use cases seem to offer an incredible opportunity to do so, so this oversight is frankly glaring.

Based on this discussion, a number of distinct KBE research issues and possible solution directions can be distinguished:

1. **Moving from case-based to methodology-guided development:** to further KBE research and development, it is advisable to move from case-based to methodology-guided projects. Obviously, methodology adherence cannot be enforced. Thus, the following critical question must be researched and answered: why are available KBE methodologies not used more often? Based on the answer to this question, existing methodologies may be subjected to improvement efforts or alternative methodologies may be posed (an early initiative to do exactly this is described in Curran et al. [5; 13]).
2. **Moving from 'black-box' applications to applications with user-friendly knowledge bases:** in order to move away from black-box applications, more attention needs to be paid to KBE knowledge base component development; means must be provided to substantiate knowledge used in KBE. More advanced knowledge management techniques and features may be used, such as knowledge life-cycle management and security provisions. In support of this, the ontological component [27] of KBE design must receive proper attention. Another route is to investigate direct interfacing and cooperation with KM applications.
3. **Enabling knowledge re-use:** adhering to KBE methodologies (including the inherent recording of captured knowledge in both informal and formal models) and moving away from black-box KBE applications (forcing the explicit consideration of knowledge explication) provides a large part of the research avenue for enabling knowledge re-use.
4. **Quantification of the advantages and costs of KBE:** this issue seems easy to accomplish, but IP and funding concerns may prohibit quantification of KBE efforts in research literature. Also, selection bias may prevent less successful KBE initiatives from reaching publication. Of

course, quantification cannot be enforced. However, the benefits of adhering to strict quantification of KBE efforts in research are significant. This will enable a bottom-line estimate of the viability and success factors of KBE applications moderated for a variety of contexts, leading to accelerated research and development. From a research perspective, simple hypotheses along the line of 'higher KBE development investments lead to higher KBE savings', of course moderated for confounding factors such as complexity and context, may be tested quantitatively.

5. **Critical review of KBE:** A critical assessment of the advantages and disadvantages of KBE implementation is so far lacking in literature. Such an assessment would have to compare KBE with other design methodologies and application alternatives and objectively compare advantages and disadvantages. For instance, the complexity of KBE implementation and the adaptability of developed applications may prove to be significant drawbacks to KBE. However, reaching an objective view on KBE may be difficult from established literature, as selection bias may prevent less successful KBE initiatives from reaching publication.

4 Conclusions

In their paper on achieving benefits from knowledge-based engineering, Sainter et al. noted [7] that 'the future of knowledge-based engineering is promising'. This conclusion still holds true roughly 10 years later. As this paper has made clear, the contextual foundations of KBE are reasonably well-defined. Also, KBE still maintains a solid competitive positioning by offering considerable advantages over both established practices and KBE alternatives. However, there are still notable drawbacks that need to be researched and solved. The field of knowledge-based engineering has its challenges cut out for investigation over the next decade.

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Collaboration for Knowledge-based Engineering Templates Update

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Abstract. These This paper addresses some issues concerning the update of knowledgebased engineering templates in the computer-aided design field. Our objective is to provide support tools to facilitate and to speed up the update and the update propagation of knowledge templates. The problems we tackle concern the searching of solutions for template issues and the minimisation of the time needed to propagate template modications to their instances. The proposed solutions are based on an issue-based information system. This system is used to ease the collaboratio between engineers in order to find and apply solutions about template issues, but also to provide a design rationale solution as templates are evolving complex knowledge elements. We also propose a smart grouping approach to reduce the number of check-out/check-in procedures in conjunction with the Product Data Management system in the scope of template updates propagation as it is a time consuming action. These both tools provide engineers with support that will enhance the template update process in time and in quality.

Keywords. KBE template, computer supported collaborative work, issue-based information system, template update

1 Introduction

These days, high-tech industries such as automotive or aerospace industries are designing products becoming more and more complex, and which integrate various domains of expertise. Furthermore, we can see a diversification of the product range that leads to new product development processes and tools such as Knowledge-Based Engineering (KBE). KBE aims at facilitating the re-use of knowledge between designs thanks to parameters, formulas, rules, automation and knowledge templates. Knowledge templates are intelligent documents or features that are designed to adapt themselves to specific contexts. They are efficient solutions to share, for example, intelligent CAD models between several

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assemblies like cars within a model range. However, the use of templates creates maintenance challenges. Templates are subject to modifications for bug fixes of for the addition of new features. The for consistency reasons, the modifications applied to templates have to be replicated where they are used, that is in other assemblies or templates. This brings about time consuming tasks that could be optimised and supported.
The work presented in this paper targets support tools for collaboration, in order to speed up update tasks related to KBE template update.

2 Addressed KBE template update problematics

2.1 Knowledge-based engineering templates

During the last decade knowledge-based engineering has become a standard in product design. Its aim is to capture and re-use the intent and product design knowledge through parameters, rules, formulas, automation, and also knowledge templates. KBE is used by many companies and has proven its advantages. Examples of enhancements resulting of the use of KBE are presented in [2, 3, 4].

KBE templates are knowledge-based applications allowing to store and to re-use the know-how and best practices of a company. Such applications can be intelligent parametric CAD models, software, or computer-aided engineering studies. They are designed in a generic way to be able to adapt themselves to a given context that will provide the inputs of the template. The process of putting a template in a specific context is called instantiation. The instantiation process is in charge of creating a copy of the template in the context, called “instance,” and setting its inputs (geometry, parameters…). The instance will adapt itself due to rules and formulas included in its definition. For instance, we can design a clamp template that aims at holding a metal sheet. From this template model we can produce different clamps of various height and length, which can be used in a machine shop assembly model. The height and the length would be configured according to the position of the clamping point and the table surface given as inputs during the instantiation process.

2.2 Template update

Templates, like other models, evolve and are modified during their life. Main reasons for updating templates are the addition of new functionalities or to fix bugs.

As templates are complex elements, updating them is a complicated and time consuming task. It implies finding a solution to the problem, then make the necessary modifications to the template, and finally, propagate the changes to the template instances. Finding a solution to repair or to enhance the template while taking into account the different aspects involved in its design is a complex task.

2.3 Updates propagation

After a template update, when the template has been redeployed after update, we want to update its instances. The objective is to use the same version everywhere. This way the instances will be consistent with the corresponding template definition in order to simplify the management. The problem we faced is to efficiently update the instances, but also related documents that may undergo some consequences of the changes in the template.

The complexity of this task comes from the high number of instances present when having several large assemblies like cars or aircrafts. Another constraint is related to the time spent for some tasks related to the update propagation. Before being able to modify models, we need to check them out from the Product Data Management (PDM) system over the network. When the modifications are applied, we can check them back in. The check-in/out time can last several minutes depending on the size of the assemblies. To reduce the time needed for this task, the documents have to be smartly retrieved from the PDM system in order to prevent redundant time consuming data transfers.

3 Related work

3.1 Decision support

Decision support and design rationale are research fields that have been investigated for decades. They aim at supporting decision making activities while keeping the path of the decisions, their argumentation and alternatives through the design process. We will present the most significant frameworks for our work.

One of them is the Issue-Based Information System (IBIS) [7]. An IBIS is a argumentation-based framework for problem solving, in which multiple stakeholders can participate. The solving process is based on elements that are issues, positions about the issues, and arguments pro or against the positions. The result of the argumentation is the choice of one or several positions that will become the solution of the related problem. IBIS gave several derivates such as the Questions, Options and Criteria (QOC) [9].

Distributed and Integrated Collaborative Engineering Design (DICE) [12] is a collaborative platform project that includes design rationale aspects with the Design Recommendation-Intent Model (DRIM) [11]. DRIM was also inspired from the IBIS framework. The model is composed of intents that refer to what we want to achieve, recommendations that satisfy the intent, justifications that explain why a recommendation satisfies the intent, and the context that is the information generated during the design process.

An ontology-based method for product decision support is presented by Arndt in [1]. He proposed a knowledge model that is an extension of the IBIS framework, which uses an ontology to represent knowledge. Some extensions were also proposed such as for technology selection. He also presented an application on decision support for CAD templates. He specialised the knowledge model to integrate the template link flow aspects, which are relations between templates and other documents. These relations can also be documented with the design justifications. The aim is to provide information to CAD template designers as well as to CAD template users and thus allows to reach faster a high degree of maturity for the products.

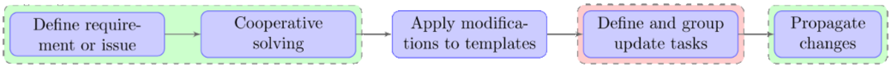

Figure 1. Proposed process for template update

3.2 Update support

Template maintenance has been the purpose of few research work. The problem of template management and distributing the latest versions of templates is addressed in [8]. The proposed solution involves ontologies that are used as a knowledge representation layer about templates and their interconnections. An ontology allows to represent concepts and relationships between these concepts [10]. Ontologies also enable the use of inference engines in order to find dependencies and to check their consistency. One ontology is created from each template by mapping them to the knowledge model. Each ontology describes the inputs, outputs, and links to CAD models of the corresponding template. The visualisation of these information is used to facilitate the propagation of changes to other templates. However his approach does not handle template instances and does not provide any design rationale solution.

4 Collaborative update approach

4.1 Template update process

We propose the process shown in figure 1 to update templates. It is composed of five major steps. The first step is to define the issue or the requirement about a template. Once the problem is defined, the resolution step involving all people concerned by the templates follows. The decision resulting from the previous step will then be applied to the template. In order to have up-to-date instances of the template as presented in section 2.3, the next step is to establish an update sequence and to define update tasks according to the dependencies between templates, instances and other models. Finally we can apply the update tasks to template instances.

This paper focuses on steps marked (a) and (b) in figure 1. Steps marked (a) concern the definition and solving of the template related issue and the propagation of the made modifications to the template instances. We address these points by providing an issue-based information system for cooperation as well as for storing the information related to the decision process in order to support engineers. The step (b) tackles the definition and scheduling of update tasks to be able to efficiently propagate the changes to the template instances. Our objective is to speed-up these time consuming tasks by providing support methodology and tools.

4.2 Issue-based system

To define an issue or a requirement concerning a template and to find answers to it, we propose to resort to an adapted Issue-Based Information System. Our model was inspired by the work presented in [1]. We decided to resort to an IBIS to store design proposals and choices, with their argumentation, during the template life cycle. Design rationale will help future decisions but also provide documentation on the templates functionalities.

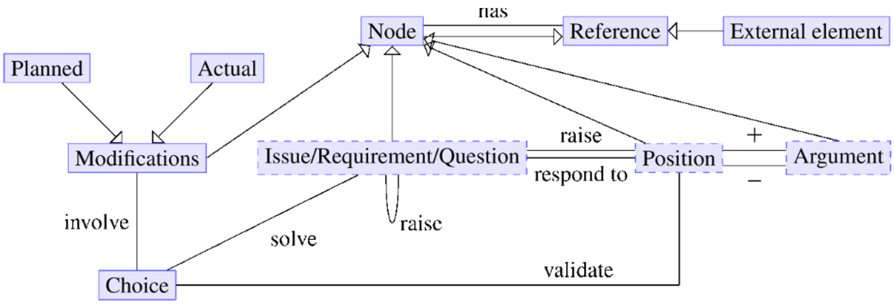

Figure 2. IBIS-based knowledge model

Figure 2 presents the main parts of our knowledge model. The core elements are those from the IBIS framework. They will help engineers to present the issues, give their positions on this issue and argue. At the moment, the storage is done in natural language but the structure of the IBIS is implemented as an OWL ontology in order to facilitate the integration with the ontology presented in [5]. This ontology is provides a formal representation of the templates and CAD models that will be instantiated with data from real models. This way, it is possible to reference some CAD elements or documents in a proposal or during the argumentation.

We extended the IBIS to focus on our problematic with the possibility to add information describing the modifications planned and applied to templates that are related to a design choice. The objective is to provide persons in charge of updating templates with relevant information about the necessary changes. Once the template update task is completed, they report the actual modifications in the IBIS. This information will be helpful for the update propagation phase.

4.3 Template update propagation

Once a template has been updated, we need to propagate the modifications to its instances. This task is time consuming and can lead to errors or to incomplete updates. To support engineers in their update task, that is finding template instances and documents involved in the update, we developed an algorithm that computes an update sequence from the dependencies between documents [5]. This update sequence gives the order in which the documents have to be updated to satisfy the dependencies, prevent redundant or incomplete updates. The algorithm assigns a rank to each document concerned by the propagation. The ranks are attributed according to the dependencies between documents. Starting from the initial rank, engineers will have to process all documents located at current rank before moving to the next one. Following the sequence will ensure that the update is comprehensive.

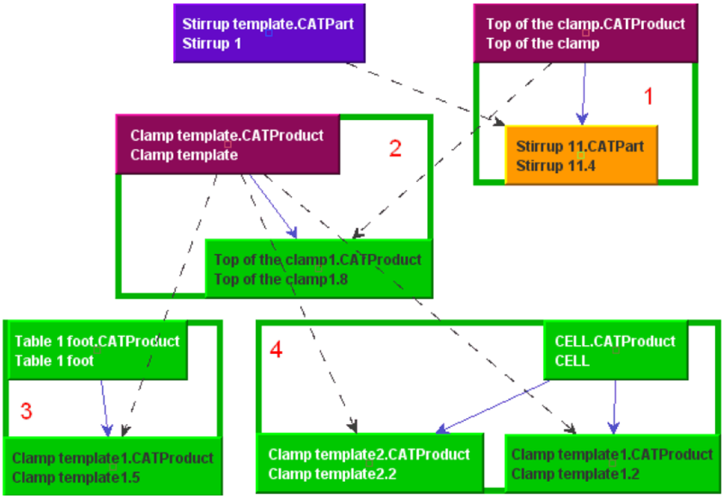

Figure 3. Update sequence with groups for smart PDM check out

To speed up the activity of template instances update, we are addressing two issues. The first concerns the update task itself. The IBIS, through added information after the template update, provides detailed data about the modifications done on the template. This facilitates the update task as the engineers will not have to analyse and compare the old and new template versions to decide how to tackle the update. The use of the IBIS creates a seamless communication between the template engineers and the template users.

The second issue concerns the time needed to retrieve (check-out) the models that are stored in a PDM system. Checking them out can take several minutes for large assemblies. Furthermore a model should not be checked-out several times for modification. Otherwise models simultaneously modified have to be merged, implying possible conflicts, and thus lead to additional work. The idea we had is to smartly organise the check-out/in to accelerate the global update propagation process. This can be achieved by grouping documents in such a way that grouped documents are loaded together. It will ensue a decrease of the data transfers as well as prevent conflicts, which will result in a reduction of the time needed for the global update propagation task.

To manage that, we worked on the computed update sequence as all documents that will be loaded are present in it. If we merely follow the update sequence, we will encounter some situations where some documents, especially containers, will be retrieved (*i.e.* checked-out and checked-in) several times. In order to clearly identify the elements that need to be checked-out together, we grouped them explicitly. To reduce the number of check-out activities, each assembly should only be retrieved once. This constitutes our main criterion for the grouping. By loading an assembly, we also import its content on which the modifications will be done. These groups can be considered as "meta-tasks" that gather several atomic tasks. Once all documents in the group are processed, the whole group can be checked-in back to the PDM system. Besides its contribution to the reduction of check-out/check-in procedures, this approach also offers the possibility to parallelise the template update tasks.

The figure 3 illustrates the resulting update sequence after the modification of the "Stirrup template." Each row represents a rank on which all elements could be processes at the same time. Green rectangles that are numbered from one to four represent the groups, also called "meta-tasks". Solid arrows are links from a product to each of the model it contains and dashed arrows link template documents to their instances. From this sequence, we can see that we can parallelize meta-tasks 1 and 2, and when 2 is accomplished, meta-tasks 3 and 4. With the provided sequence we avoid that meta-task 4 is split into two, which would result in a necessary merge in the "CELL" document.

5 Implementation

In our recent work we have proposed a collaborative architecture based on web services [6], which is composed of a blackboard containing domain ontologies. These ontologies allow a formal representation of concepts related to a specific domain and facilitate the reuse of domain knowledge. We integrated our IBIS ontology described above in the system's blackboard and provided needed Web Services to allow engineers to propose their issues, positions, arguments, etc. in a system independent way.

Concerning the template update part, we developed a tool to analyse Dassault CATIA V5 CAD system models to extract and store relevant information about the models and their relationships. These data are then used to compute an update sequence as described in section 4.3.

6 Conclusion and perspectives

Updating KBE templates is a complex task that raises several issues. In this paper we address two of them: finding solutions for template design issues, and speed up the updates propagation of template modifications.

To support the collaborative solution of template issues, we propose an issue-based information system adapted to the template update problem. It brings the support for collaborative solutions elaboration as well as for design rationale. It is a mean to communicate between several disciplines and to store decisions and argumentations. It also allows to re-use proposed solutions for future design evolutions and to support the template instances updates by documenting the modifications. The solution we propose complete the documentation of links for template use [1]. Both can be used together to enhance documentation around templates and facilitate their use. We also presented a solution to smartly check-out and check-in documents from a PDM system in the scope of template update propagation. This will prevent concurrent or blocking modifications, that would lead to conflicts, but also speed up the overall task, because just one check out can take several minutes for processing. This tool completes the template updates support system proposed in [5] by addressing the time consuming steps that are data transfer with PDM systems.

The main evolutions we can bring on our system involves the proposed IBIS. The next improvement would be to formalise the way we store users' contributions (issues, positions…) by defining specific concepts instead of using natural language. The second would be based on these formal definitions to allow the use of case-based reasoning to automatically extract and propose solutions based on the previous design experiences stored in the IBIS.

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Engineering Knowledge Modeling in Design

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Abstract. The paper concerns the modeling, acquisition, storage, management and re-using of the engineer's knowledge. The presented approach is based on the hierarchical structure of design knowledge. Each design domain involves theories, know-how and models which are coherent (on a suitable professional level) and have been developed over many years. With the help of this complex knowledge the core of the design process can be captured. On this basis programs and systems supporting the design process can be built which result mostly in partial models of the design product and the design process.

Keywords. Knowledge Based Engineering, Engineering Knowledge Management, Object-Oriented Design

1 Introduction

The paper concerns the modeling, acquisition, storage, management and re-using of the engineer's knowledge. All these issues are closely connected with the domain called Knowledge Management [16]. The term Knowledge Management usually depicts knowledge management in companies and organizations. The knowledge management has to provide effective solutions for a certain class of problems to the wider community of users. Therefore, the most important feature of the knowledge management is its practical utility and universality.

The knowledge embedded in the Knowledge Management Tools can be used productively by the designer himself. It represents a knowledge source which is understandable and intellectually processed by him. In this case the Knowledge Management Tool becomes the designer´s personal and active notepad which serves basically as a knowledge store in daily routine work [11, 16]. Although another purpose is also possible. KM may also support the development of the procedural applications or in general, Knowledge Based Engineering applications (in engineering design) [1, 11, 15].

One of the most important functions of the Knowledge Management Tools is to store the knowledge development that forms the basis for the development of procedural engineering applications. The Knowledge Management Tool stores the

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theoretical foundations of the system and its correlation with the procedural software development. The example in figure 1 [4, 12] shows the development of the design process of industrial staircase (LaScala system). The industrial stairs are described by various parameters and structures. The preliminary stage of the design process consists of calculations, analysis and the optimization of the basic characteristics of the industrial stairs. The application is developed in an object oriented environment. This approach allows the separation of different software components and flexible control of the software development in the case of knowledge development. It is relatively easy to catch the structure of the system and make its modifications. This structuring reflects the way the knowledge is captured and modeled during development. The example depicts a complex and coherent model of design aspects concerning industrial staircase. The deployed knowledge is based on literature and practice [4, 12] and allows to specify key features of stairs construction. Figure 1 also shows the evolution of the software system.

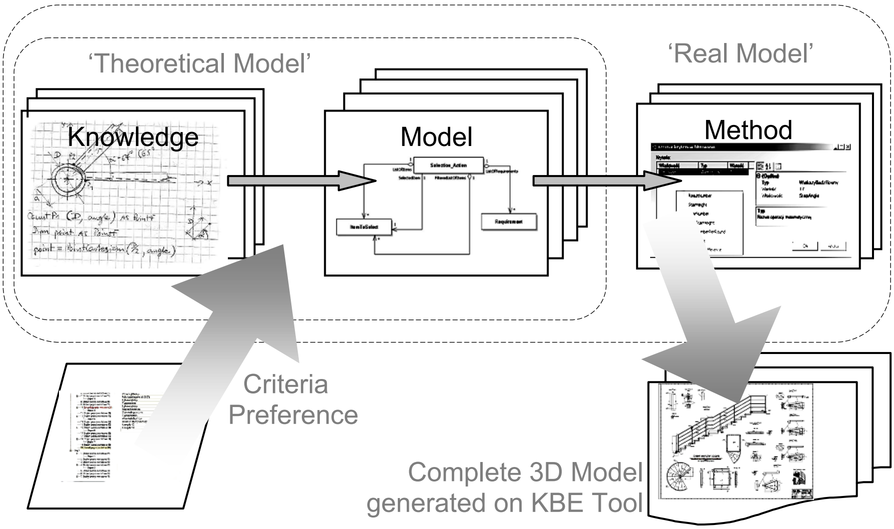

Figure 1. Knowledge development in the proposed KM Tool

If you observe the engineer, he applies various theories, methods, models and procedures when designing a product. Most of this complex knowledge results from many years of research, development and expertise. The knowledge is coherent and non-decomposable and often assembled dynamically. The above example of the industrial stairs indicates these features. The procedural/object-oriented approach gives successful results with the computer implementation of that complex knowledge. Moreover, the modeling of the theoretical knowledge development of such tasks can be realized with relatively little effort. Following [12], this kind of model has been named as "theoretical model" of the design process. [12] presents the production application supporting the design process of spiral stairs, where "theoretical model", mainly based on essential company know-how, encapsulates all initial calculations, decision processes and partial optimization models.

The Knowledge Management Tool can function as a diary or notepad, documenting the development of knowledge which is critical for such an application. The computer application designed on object-oriented patterns can be well integrated with the content of a Knowledge Management Tool.

When designing the industrial staircase, for example, many problems related to the final form giving of particular joints, arms, etc. have to be considered. These problems are distinct from its main structural scheme. Each of these components requires very detailed knowledge, which is essential to create their exact form and can determine the manufacturing process. This knowledge also evolves dynamically. It can be stored in the Knowledge Management Tool as well. [11, 15, 16] assumes that this part of the design process is performed after the "theoretical model" of the industrial stairs has been accomplished. This means that after creating the structural model of the stairs, the engineer designs the components of the structure on the basis of his knowledge. This knowledge is often articulated as rules which can be modeled in KBE tools [1] of the legacy CAD/CAE systems. In the work [4, 12] concerning the design of spiral staircase this model has benn named as "real model". It handles the details of the designed artifact. Some stages of the manufacturing process are also presented in [12].

2 Process of KBE applications development

Unlike CAD systems where design process for single item is modeled, the product from KBE applications concerns the whole class of products of a certain type. Therefore, it is possible to easily and quickly design one instance from the family of products. Furthermore, in KBE systems the various types of knowledge can be collected, not only geometric features. This knowledge can be saved and stored for the forthcoming, novice designers and if needed easily modified.

Nevertheless KBE is not the answer for all engineering problems. It should not be used when [8, 15]:

- design knowledge cannot be clearly exposed (when it is not a routine task) or cannot be fully gathered;
- design process evolves permanently;
- design process can be described in straightforward subroutine.

One can distinguish two approaches of the modelling of knowledge in the KBE systems. First one is a usage of knowledge module of the commercial CAD systems, e.g. Knowledgeware in Catia [1]. It goes bottom-up, from the particular to the general approach. Then the geometrical model of the product has to be created (in the geometric modules of the CAD system), before the aspects of knowledge can be implemented. Usually, the first stage is parametrization of the geometrical model. Then basic aspects of knowledge like formulas, relations, equations, checks etc. are applied. Finally, more complex forms of knowledge management (generative models, intelligent knowledge templates e.g. Power Copy, UDF templates in Catia) can be used. Main disadvantage of this way of knowledge modelling is that there is no possibility to model the design process and the product structure in the conceptual phase, before detailed design is performed and full geometrical model created. Building the whole set of part and assembly models with its knowledge for the very complicated structures appears to be quite difficult task. Another problem arise, when managing the large number of files with many variants of parts.

An alternative approach is to create an independent, dedicated KBE system. From the standpoint of the order of steps in design, it is an opposite, top-down approach. It assumes building the models of design process and product for the given class of constructions as a first step. The specific cases of products provided in these models can later be created and the documentation (e.g. geometrical) generated. Because the whole design process is modelled, the particular design steps can be eventually edited and modified later. It is also possible to examine the reasoning and design rationale of the designer.

3 Concept of expanding the scope of KBE applications

While it is relatively easy to build software application supporting routine, easy to automate, design tasks, there is always a problem to develop one, supporting conseptual side in the design process. And building the concept is a very important part of design. Although it is difficult to automate this phase by the computer some aspects of supporting the designer can be considered. In this paper the authors propose expanding the scope of classical KBE system by enhancing its functionality by support of the concept phase. The overall scheme of work in extended KBE [14] application contains:

- design concept building phase;
- configuration of decision parameters;
- generating detailed product model;
- automatic generation of documentation in the integrated CAD system.

The very important advantage of adding conceptual phase to the KBE system (so called extended KBE) is that it allows easy design of few variants concurrently in the very first phase of the process. Designer can detect same potential errors and exclude non-feasible conceptions at the very beginning. The design space is better penetrated. Additionally some analysis, simulation and optimization can be performed at this stage - in this case it corresponds to “theoretical model” mentioned before.

4 Supporting the process of building the extended KBE tool

In order to develop the KBE application for particular design process, the deep understanding of the design process and its product structure is indispensable. Therefore design knowledge acquisition stage requires special attention and insightful analysis. Trying to accelerate this activity seems to be aimless, however saving acquired knowledge would be useful.

Another task is to structure captured knowledge chunks, group them into categories and try to identify some connections between them. This leads to developing product and design process models. KBE application contains also other object structures like user interfaces and graphical views of the designed artefact that needs modelling too. Presently, there are no universal tools for developing dedicated KBE applications. Creating these models or more precisely translating structures of these models to representations in object-oriented programming language are the key activities that in authors opinion should be supported. This might lead to significant reduction of labour and time.

To fulfill this postulate the concept of creating the set of templates of different structures was developed. This set would be the basis for particular model development. The inspirations for this concept were several projects in which authors participated. The most significant and most successful one, was project named LaScala [12]. It concerned development and deployment of the dedicated KBE application for spiral staircase design process.

The templates should refer to models mentioned above. To create specific templates the generic structures are needed. As far as product model is concerned the meta-models are well known from previous works. The Core Product Model (CPM) developed in the National Institute of Standards and Technology (NIST) [3] aggregates three aspects of product definition: form, function and behaviour. Another generic product meta – model is the one developed during MOKA project [8]. It in turn sees the product in 5 views: Structure, Function, Behaviour, Representation and Technology. The authors lean towards the MOKA idea, as it appears more clear and better elaborated. The most important for product modelling is its structure. Therefore for now we mainly focus on the Structure View. These classes can serve as a first template. Another aspect which we consider is the technology. In the LaScala project we experienced the problem of modelling classes for generating manufacturing route cards, so naturally it was the issue of concern.

The main classes of the MOKA Views and specific classes of the Structure and Technology Views are presented in the Fig. 2.

It is the extension of the product model structure template and it is described in the very generic form. Especially Manufacturing Process is thought as abstract class which needs further specialisation. In the LaScala project class Operation was used to model different operations occurring in the route cards.

Templates are also required to build up the model of design process. In the case of design process there are some ideas of representing it developed by researchers [8]. Main concept of MOKA model assumes division of the design process to activities which can be compound or elementary. Compound activities contain sequence of activities (compound or elementary). This idea of the whole, which is composed of design activities was known before and a single activity was modelled as object that can transform consecutive product model design states. IDEF0 [5, 6] methodology defined design step in terms of the input, control, output and mechanism as ICOM block (Fig. 3a).

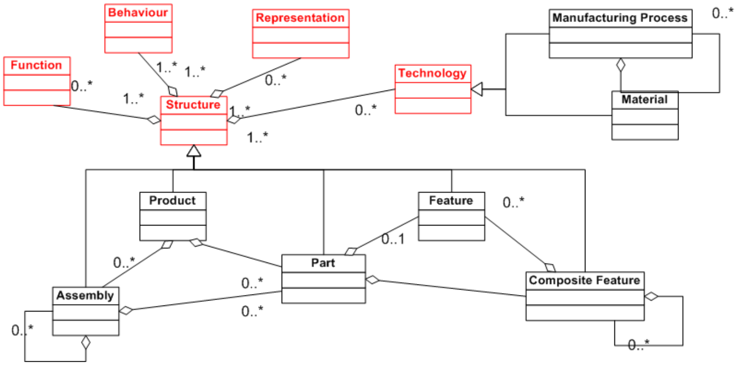

Figure 2. The MOKA like views. The structure and Technology views in detail

Sim and Duffy [7] specified it similarly, but the elements connected with generic design activity were identified on the knowledge level (something more then just data or information from IDEF0, [5, 6]). Fig. 3b shows the Design Activity and the elements related: the Input Knowledge, the Output Knowledge, the Design Goal. In MOKA, the activity is defined by following attributes: Description, Inputs, Outputs, Locals, Constraints and Method.

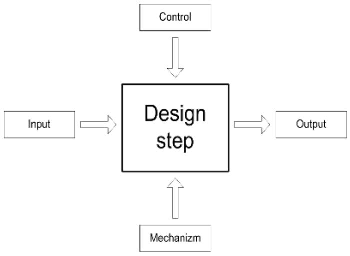

Figure 3a. ICOM block from the IDEF0 methodology

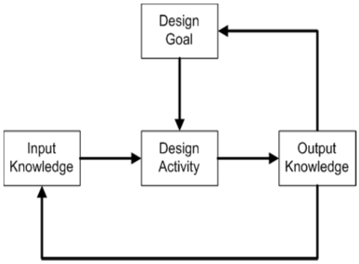

Figure 3b. Generic Design Activity defined on the knowledge level

First attribute is descriptive and defines the aim and the rationale for activity. Inputs and Outputs are links for instances (of objects) from product model which are used by the activity (as incoming data or outgoing results). Locals in turn are additional design process data which could not be defined in product model. Constraints impose boundaries on parameters. Method substantiates the action of the activity. Usually it is the main rule associated with it. Based on above description the generic template for overall design process could look like the diagram in Fig. 4. It appears that different design processes may also require different modelling. Thus, it is a difficult task, because almost every artefact can have its own, unique design process. Nevertheless the researchers were trying to describe the types of design processes [2, 9, 10, 11, 17].

So far, the overall idea of the design process is described, but the more specific templates are also required. The subject of our consideration is extended KBE application, so templates would include classes useful in the specific innovative, conceptual stage as well as ones for the part of modelling routine tasks. As far as this innovative stage is considered we can point out two styles of the designers' work. Corrective action is building variants step by step and modifying them repeatedly, which can be supported by dynamic results presentation in the different types of views (collections of elements, 2D, 3D). So the templates would be the classes of the different views corresponding to the classes of the product model. In the example the tree like view is composed of the tree nodes classes which can represent objects from product model.

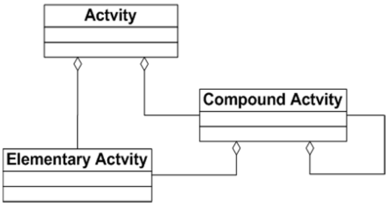

Figure 4. Generic template for the design process

As opposite, the generative approach assumes automatic creation of many conceptual solutions, from which the designer chooses the most appropriate one. The decision making can be supported by some filtration or optimization subtasks. The templates could model f. ex. the filtration task. In the case of routine design stage the templates should primarily relate to the types of chunks of knowledge. In the routine tasks they are mainly parameters and their relations in form of different kind of calculations and rules. As a basis we can use the approach proposed in the knowledge module of one of the CAD systems, CATIA v5. The possible forms of relations for parameters, which model calculations, are functions and equations. In case of more complicated tasks the template class for external computations should be created.

As far as rules are concerned the basis template would embrace conditional instruction and its dependencies. The proposed template classes for multiple depth levels of conditions are presented in the Fig. 5.

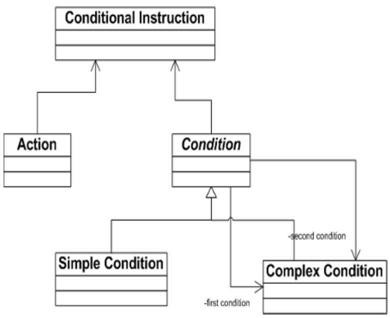

Figure 5. The Conditional Instruction template

Example stage in the extended KBE application, that has its template, is also the configuration of the decision parameters. This template could also contain classes for modelling the interaction with the user, for example to gather the values of the decision parameters in the form of wizard.

D. Ullman [17] brings the idea of creating other templates which can be useful in building KBE applications. Ullman writes about: selection, configuration, parametric design, original design and redesigning. Since parametric design has already been considered and original design and redesigning are too generic to KBE application tasks, we have focused on the selection and configuration. Selection boils down to picking the right solution from the set of available solutions on the basis of the set of requirements. Configuration refers to the selection, because it is the connection of multiple selection tasks, but with additional set of requirements related to the possible relations between selected individual solutions. The class diagram for the selection task template is presented in Fig. 6.

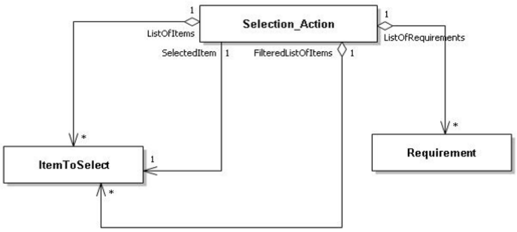

Figure 6. The template for the Selection task

5 Templates use case

In the previous chapters, the conception as well as some generic structures of particular templates, were presented. In order to better illustrate the main idea of the templates, we will show an example. During the academic course of Object-oriented programming the KBE application concerning the designing of the shaft was developed. Authors of the article together with the group of students elaborated generic structures for modelling domain knowledge of the product and its design process. Based on the concepts from MOKA meta-models, which were the kind of templates the global models were created. It contained classes for the different activities of the shaft designing as well as the ones for modelling the shaft itself (parts, features,...). Another tasks involved modelling of the particular design activities like setting shaft step function, designing bearing, setting surface roughness, etc.

Figure 7 presents the excerpt of the shaft design activities model. Its classes are developed based on the templates shown in the figures 4 and 5. The DesignShaftStep activity is composed of another three activities: AddShaftStep, ChooseMainFunction and DesignFunctionSolution.

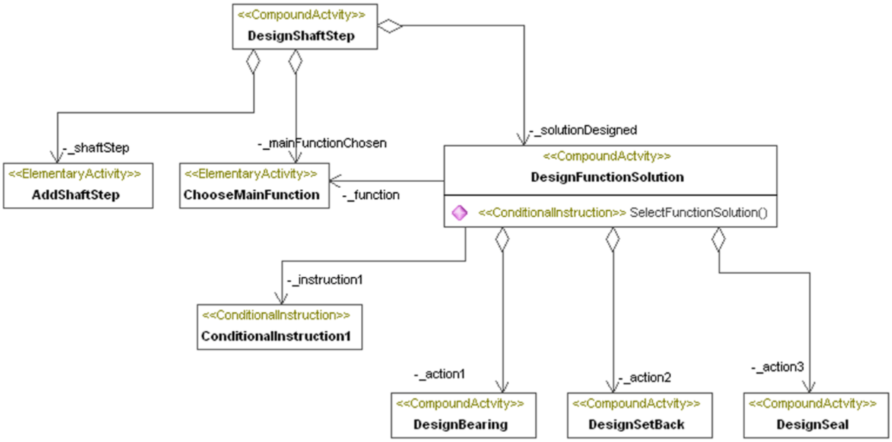

Figure 7. The excerpt of the design process model of the shaft

The compound activity DesignFunctionSolution, based on the output from the ChooseMainFunction activity, decides about next activity execution. The design knowledge which models this decision is shown in the figure as a Conditional instruction meta class: ConditionalInstruction1. It translates into If...Then block in the final application code. Other meta classes shown in the picture (from the design process template) models actual classes in the application.

6 Conclusions

The presented approach is based on the hierarchical structure of design knowledge. Each design domain involves theories, know-how and models that are coherent (on a suitable professional level) and have been developed over many years. With the help of this complex knowledge the core of the design process can be captured. On its basis programs and systems supporting the design process can be built which result mostly in partial models of the design product. The partial product models can also be visualized with the help of CAD/CAE systems or by using individually developed tools. Applying KBE tools at the stage of a "real model" (or the detailed model) accelerates the whole design process. To divide the computer tools of the design process into procedural/object-oriented tools and KBE tools [3, 15] makes the building and developing of a complex software for the support of engineering activities more efficient and more understandable.

The distinction between a "theoretical model" and a "real model" as mentioned above is subjective. It is just another component of the design process modeling. For a specific design task usually there are different solutions possible, which becomes obvious with the industrial stairs example. If the main issue had been the strength of components, the division into "theoretical" and "real models" would have changed the process structure completely.

The above problem also has its knowledge context. Knowledge concerning problems which are represented as theoretical models is in general very extensive.

It is rich in literature, models, stages of development etc. But it is difficult to apply only single components. In such cases the Knowledge Management Tools play the role of a repository where knowledge sources, comments and single practical knowledge elements are loaded, stored and used in the folowing design processes.

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Ontology-Based Intelligent Personal Assistant

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Abstract. The paper presents the system for knowledge acquisition and its management in designinng process. The main aim of the system is to aid designinng process by means of Generative Models creation, which constitute a kind of KBE (Knowledge–Based Engineering) application. The system uses ontology which has been worked out especially for that purpose. The system has been verified while creating Generative Models using CATIA system in designing subassemblies of drive system of a car as well as some objects using fast assembly systems.

Keywords. Ontology, Intelligent Personal Assistant, knowledge-based engineering

1 Introduction

The need to record designing knowledge has been present for a long time and there have been attempts to fulfill it in various ways. However, the development of CAx systems and in particular the growth of importance of Generative Models [9], [10], [11] in desinging process made the up till now ways of knowledge record neither sufficient nor effective. Therefore, greater attention is paid to the acqusition of designing knolwdge, mainly oriented to knowledge record needed for knowledge templates in CATIA, Inventor, UGS NX systems. One of the methods of securing designer's knowledge is to use computer applications which facilitate creation of notes by a designer in the designing process. These applications are known as Intelligent Personal Assistants (IPA) [8].

Intelligent Personal Assistant (IPA) enable a designer to recollect methods and actions taken while working on a similar project some years ago. Time needed for routine calculations, information search, rellevant bibliography will be much shorter due to the ready made recipe , the essence included in knowledge base. Simultaneously, the saved time can be devoted to concept tasks in desinging process. Detailed knowledge base makes a good base for very fast constructing of Generative Models [9], [10], [11]. The knowledge recorded in such a knowledge base emphasizes these parts of designing process which can be automated.

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2 Requirements for designer's IPA

Designers in the process of designing recorded and gathered records which in their opinion were representative and characteristic for their designs. These records were collected so that they could be used in other designs. They were collected in personal files in a form of calculations, conceptual drawings, standards and extracts from books. Computer application of designer's IPA is used for recording designer's knowledge and it substitutes the up to now forms of knowledge record used by designers and thus it has to enable collection of this knowledge and ordering it by means of formalizing its record on the one hand, and on the other hand providing private space which allows unrestricted access to an individual designer.

So far that knowledge has enabled automation of designing process to a certain degree by means of repetitive usage of confirmed codes of practice and now it is used for redoing usage of these practices. Nowadays, in CAD systems knowledge used in routine tasks can be integrated directly in CAD model, automating designing and modeling in CAD system for a limited range of routine tasks. Such CAD model which is additionally enhanced with designer's knowledge is sometimes called as Generative Model [9], [10], [11]. Purposefully, the recorded knowledge and in particular its form of record should allow easy integration with CAD system. Ensuring private space for each designer should not limit possibilities of using and processing knowledge in a team work which means its verification, acceptance and usage by other designers. In classical usage designers had problems with ordering their private records and assets, it was difficult or recreate and recollect the codes of practice. Therefore, it has been assumed that the form of record will play an important role and in particular its interface which should be oriented to recording the way of behavior based on simple graphic interface of a user.

3 Ontology of designer's knowledge

The ontology concept appears at the methodological approach [12], [16] to the creation of knowledge base. In knowledge engineering, one of the first definitions of ontology was given in a descriptive way [4]. Here ontology was determined as description of basic terms and relations, including a glossary of a given branch and rules of connecting terms and relations for defining this glossary. Current ontology definitions in knowledge engineering applications can be divided into two groups: the first one characterizes the term by defining the process of ontology creation, the latter consists of more general descriptions of a term referring to the description of phenomena and a given branch. Definition characterizing the process of ontology creation is specially connected with knowledge engineering as it refers also to relations between ontology and knowledge base.

According to this definition [3] knowledge representation is determined in knowledge base, whereas in ontology the very knowledge branch is defined as well as relations between elements of that branch. Therefore, there is no doubt that ontology includes glossary and the corresponding definitions. More detailed requirements for ontology creation are different and depend most frequently on the way it is formatted. The terms definitions can be determined in a formal way or in natural language. Natural language is used for creating and agreeing on ontology between experts, whereas formal languages are expedient and target system of recording in case of ontology being machine processed. The latter way, very language formality dependent, is usually more difficult but necessary in knowledge base usages.

Other definition [15] gives the broadest scope of ontology not only for engineering knowledge usages: Ontology can have different forms but it must have a glossary and specification of the meanings as well as mutual relations between terms. The whole forms constraints of possible interpretations of terms

For knowledge representation languages the problem of ontology is considered in a special way for each usage (KL-ONE, CLIPS, KIF, XML, OWL,). Among these languages OWL (Web Ontology Language) [6] and UML (Unified Modeling Language) [5] are commonly used. OWL is an application of XML (eXtensible Markup Language) language specified for ontology record while UML as one of very few by definition incorporated graphic representation of ontology.

3.1 IPA ontology specification

The structure of a part of created ontology is based on MOKA (Methodology and software tools Oriented to Knowledge-based engineering Applications) [10], [12] ontology, from which a concept of informal model and ICARE forms have been used. Informal model from this ontology is for ordering the knowledge space which is responsible for communication with a user. The main objective of this communication is acquiring and sharing knowledge.

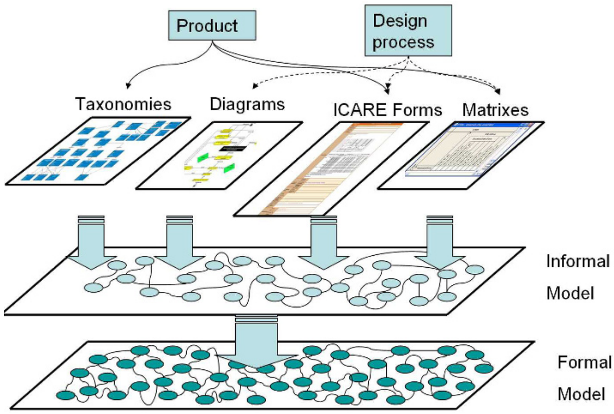

Figure 1. A Framework of knowledge base ontology

The acquisition of knowledge is carried at two levels of detail: i.e. conceptual and detailed ones. ICARE (Illustration, Constraints, Activities, Rules, Entities) forms are used for detailed knowledge acquisition and they have two kinds of field. One can be directly filled in by a user, whereas the latter one are fields filled in automatically with knowledge by the system which is fed into by means of other forms of dialogue with a user e.g. diagrams where some relations from diagrams appear in the forms Figure 2.

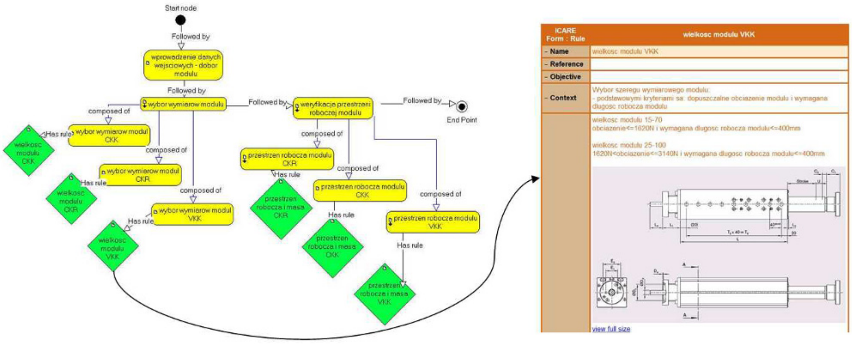

Figure 2. Exemplary Activity diagram with associated Rule ICARE form

Knowledge acquisition at the concept level is done mainly by diagrams and in particular by their two basic types i.e. activity and structure diagrams. Activity diagrams are responsible for procedure knowledge record regarding first of all procedures of designing process, whereas structure diagrams are to record product structure as well as its representation. Each form constitutes a detailed description of diagram elements. Basic elements which occur in the activity diagram are activities and rules which manage these activities and thus they are described in details by Activity and Rules forms. By contrast, structure diagrams consist of structure entities and constraints imposed by these entities and they are described comprehensively in Entities and Constraints forms.

The second main part of ontology is formed by formal model, which is an extension of MOKA ontology and is used for designing various forms of design representation. In the present version of ontology specific representation with the use of CATIA system i.e. Generative Models have been included. Generative Models are built for the benefit of automation of designing process in advanced CAD systems such as CATIA. They are a kind of interactive CAD model for repetitive parts of construction. Their interactivity can be seen by adapting to other parts of design. Formal model contain the structure of Generative Model together with designing actions included in the model. Both the structure and the actions of Generative Model are a part of informal model but they are adopted to the from of record which is characteristic for a given CAD system (CATIA).

4 Implementation of Intelligent Personal Assistant

The system of Intelligent Personal Assistant was created on the basis of applications for knowledge acquisition and record by means of ontologies. Suitability of ontology for the record of designing knowledge has been tested on Protégé OWL [13] systems as well as PCPACK5 [2], [7]. The recording has been done in both systems but during verification the suitability of each of them was different, which resulted from possibilities of both systems.

In Protégé OWL system, XML Schema language is used for ontology record, and thus inner form of ontology record is directly accessible and can be easily processed which has big influence on the possibilities of further processing of ontology itself as well as knowledge base recorded by it. Interface based on structuralized forms is used for designing and recording ontology and knowledge. Although there is a possibility of graphic visualization of ontology and knowledge base in form of knowledge maps, there is no option of active editing these maps. The very graphic handling of knowledge maps is quite difficult and one needs some experience.

PCPACK system for knowledge record uses very effective and at the same time simple graphic interface similar to known UML language, they are two types of diagrams activities and class ones. Apart from that it is possible to create trees and diagrams in graphic form as well as other forms of record such as matrixes and forms. Therefore designing and recording knowledge becomes more effective while using this interface. Diagrams are particularly useful for conceptual knowledge record, whereas forms turn to be functional at recording detailed information. Interactive connection of particular forms of record results in the fact that they are used as specialized views to the same complex knowledge base. The knowledge recorded in PCPACK program can be easily published in the form of www page but the problems are encountered while trying to process the base for other purposed than publication. The reason is the lack of access to the internal format of knowledge record.

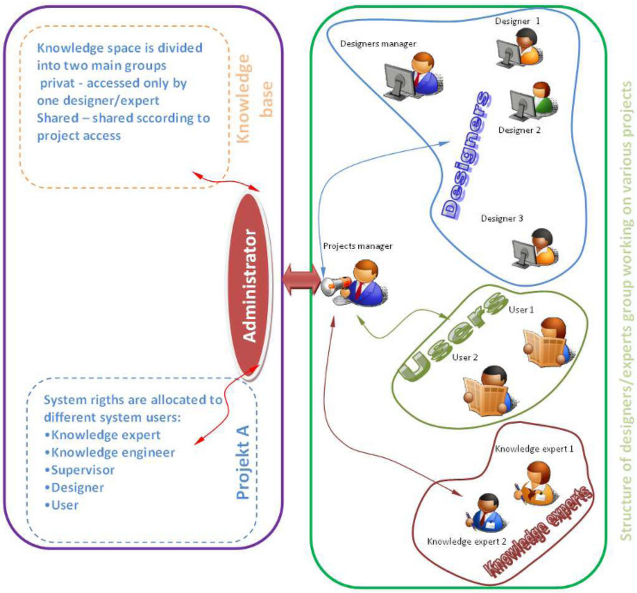

Figure 3. Model of group work

Designing process usually involves a team of designers who have their tasks (Figure 3). Tasks assignment is carried by a leader or head who is responsible for it. Therefore, he should have a good knowledge of designers' abilities so that the assignment is accurate. Sometimes some members of a group work remotely and then we have intensive and selective exchange of designing knowledge.

The structure of physical dependencies and authorities can be reflected in the system of Intelligent Personal Assistant in a model of group work. The picture above shows such an example.

Users are authorized only to browse assets which have been allowed by an administrator. Different people can become users who should get to know a part of knowledge on a given product.

They are experts who are very knowledgeable in a given discipline and they are authorized to read the whole knowledge which is made accessible to them by administrator in form of knowledge base and www pages. Knowledge experts aid engineers in the whole designing process and are the source of rationale knowledge which is not recorded anywhere and results form their long work experience.

Knowledge base operating on the server allows not only work on mutual projects but also creation of personal knowledge base for designers. Each designer can edit his own base created by administrator. In order to made it accessible for others he can publish it as the whole or part or apply for allocation of his base to another user at given authorization procedure. While creating WWW page it is possible to give permission selectively by means of indication to suitable elements in the publication process.

4.1 Hardware implementation

By definition the application was meant to enable knowledge acquisition and processing for Generative Models creation. Since the cooperation with internal experts was assumed from whom knowledge would be acquired and next the knowledge would be recorded in mutual and coherent base, than remote and save access to application to implemented base in the system was understood which would include:

- Operational system Enterprise Windows Server 2008
- Software PCPACK5 1.4.6B.

They have been installed on two-processor-Server with the main board Intel 1500 processors Intel Quad, 4GB RAM memory, two hard disks each 750 GB configured as RAID 1.

From four analyzed scenarios of accessing knowledge base two were chosen. The server which is outside Intranet has been chosen and thus independence form local network administrator has been increased as well as it gives possibility to individual protection and configuration of server. The users will be able to use directory contents or Terminal Services which enables greater functionality of the system.

The first way of access predicts the usage of terminal service from Windows Server, thanks to which the users who have access to the domain automatically have it to the contents of the domain. It allows maximal use of server contents with minimal processing on client's computer. This solution has an advantage of great independence of server and at the same time it demands high protection from outer attacks, therefore only computers with server VPN (Virtual Private Network) link have access granted.

The second way of access forms a modified version of the previous one. The server is outside Department intranet and communication is carried via VPN connections for both external and Intranet computers. One advantage of this solution is greater neutrality of the server and independence from local administrator or possible failures of the system. Nevertheless, it increases the threat of hackers' attacks and decreases data safety. The access can be realized by means of VPN net links. VPN technology used in nets ensures safety of transferred data so that they cannot be intercepted by unauthorized persons.

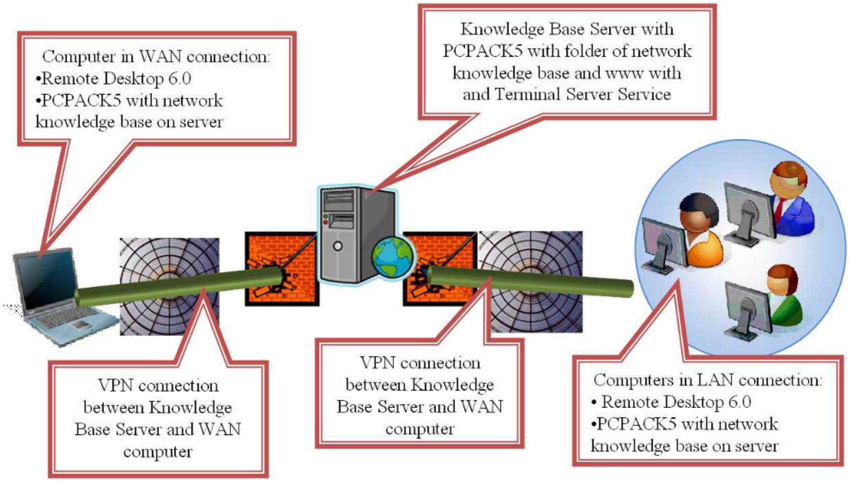

Figure 4. Model of team work using a Server outside Intranet

5 Conclusions

The system for knowledge acquisition and management in designing based on the ontology elaborated specially for that purpose with PCPACK5 software, has been used in aiding designing in a few projects and in particular for the creation of Generative Models in the process of designing. Generative Models were aimed to accelerate the very process of designing and were worked out in CATIA system for objects from fast assembly systems (Bosch-Rexroth, ITEM) and of elements of a car drive system.

The system based on ontology proved well in generative modeling with the use of Knowledgeware tools included in CATIA. As verification stage some tests of automatic processing of knowledge base in agent system [1] aiding designing have been carried. However, it turned out to be more effective to use analogous system with Protégé OWL software. Possibilities of free access to formal record of the ontology were the decisive factor influencing easiness of transformations of knowledge base records.

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Multiagent System for Aiding Designing Process

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Abstract. The paper presents knowledge-based engineering system which is based on multiagent system. Apart from this system, a complete process of knowledge processing has been presented – from the identification and knowledge acqusition and its usage in multiagent system, up to application of the results of multiagent system operation directly in CAD systems. The offered concept of knowledge processing comprises computer aiding tools, ontology, record formats and knowledge processing at particular stages.

Keywords. Multi-agent system, CAD, ontology, knowledge-based engineering

1 Introduction

The usage of CAD systems in designing in various branches is becoming indispensible. Currently, a lot of attention is given to formal usage of knowledge in designing processes. Nevertheless, Knowledge-Based Engineering (KBE) is rarely integrated with CAD systems. In the process of knowledge processing, beginning from its acquisition, collecting and analyzing, formal usage in KBE systems and finally using knowledge in CAD systems separate tools are often used, and incoherent formats of knowledge record which results in impediment and lengthening of designing process. Neither full separation nor complete integration of stages of knowledge processing give a good approach. Autonomy of these stages with the use of specialized aiding tools, with simultaneous assurance of knowledge processing integrity and easily processed formats of knowledge record [15] were the main assumption of creation of multi-agent system for aiding of designing processes.

2 The concept of knowledge processing system for aidning designing process

The concept of knowledge processing system for aiding designing process covers three main stages:

- Knowledge acquisition

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- Reasoning with the use of knowledge
- Geometric modeling

Consecutive stages with suggested aiding tools and record formats have been shown on Figure 1.

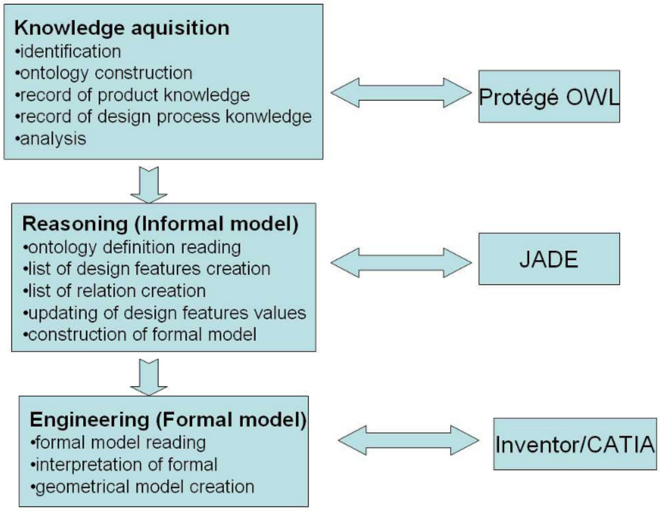

Figure 1. Knowldge processing in the creation of multiagent system in designing

Knowldge in acqusition process is recorded in a form of classes and their instances as well as proper relations connecting the classes and links between their intances. The very structure of classes and relations between them is preliminary recorded in a form of ontology and covers general designing issues. Detailed acqired knowledge is recorded in a form of class instances and relations (Figure 2). Protégé OWL system [13] has been used for knowldge acqusition.

Multi-agent system uses knowledge recorded in Protégé OWL directly, which is transferred in XML format however, the knowledge structure is defined by means of pre-elaborated ontology [11]. The knowledge which is transferred to multi-agent system is called informal model. As a result of multi-agent system we obtain a set of designing features of a designed object with values of these features recorded in universal format XML, which is managed by a proper ontology.

Taking into consideration the specialty of record of a given CAD tool, a set of designing features manages generation of geometric model in this system. Knowledge transferred to CAD system is called formal model.

3 Multiagent system in design supporting

By [2] agent it is understood ‘a program that performs a series of automated tasks according to a set schedule or at the request of a user. An agent consists of three components: the trigger (when it acts), the search (what documents it acts on), and the action (what it does)'. Program agent is characterized by the following features [6]:

- autonomy (an ability to take decisions on one's own);
- communicative (an ability to communicate with other agents and users);
- perception (an ability to perceive environment changes).

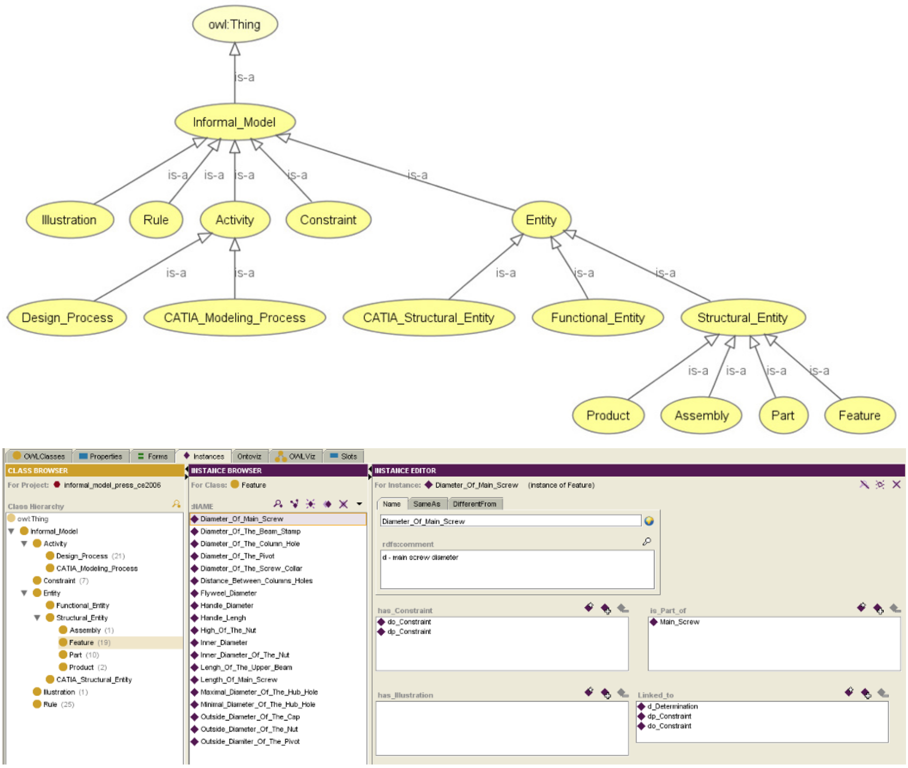

Figure 2. Graphic and tabular way of representation of classesand their instances (Protégé OWL)

The most important feature as far as design aiding is concerned is autonomy. Program agent gets information from the received messages from other agents, from users as well as from information on environment that it operates in (by means of perception systems). The received information form a basis for data processing which is optimized to certain goals. The goals are usually defined while initiating the agent. Data processing can be simple and focus on obeying simple rules or it can be more advanced and use expert systems. One advantage of using expert systems is a possibility to employ engineering knowledge.

By connecting few agents together so called multi-agent system is made. What is important is the fact that within such a system agents cooperate in order to realize a given task. In the issues concerning machinery design, technical objects are divided due to their complexity. Therefore the following elements are distinguished: part, subassembly, assembly, subsystem, system, device, device group and technical megacomplex. In CAD systems this differentiation is usually represented by part model and parts assembly, and finally assembly of assemblies.

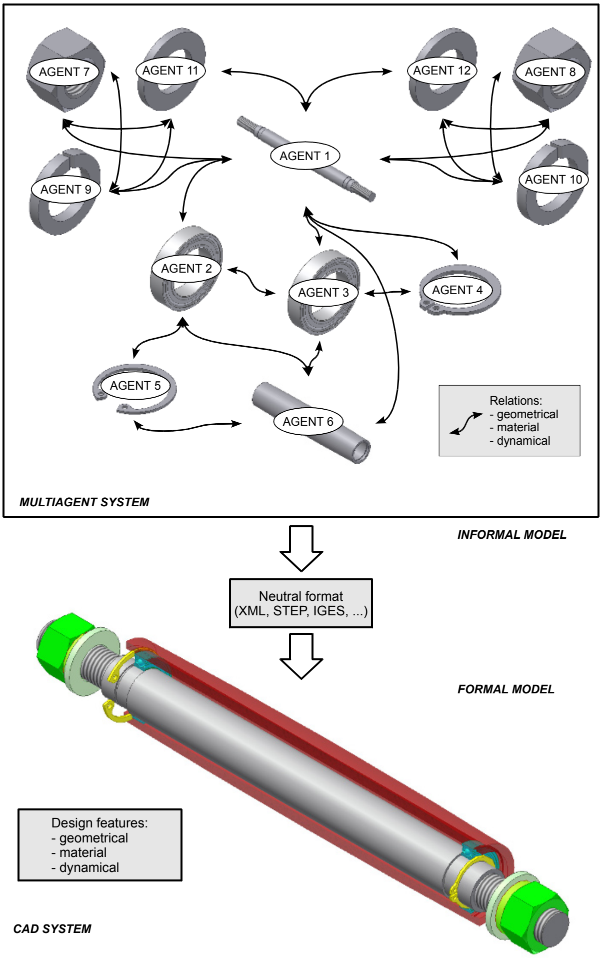

Figure 3. Network of agents representing the actual object model as a set of parts. The transition from informal model to formal model.

In the case of using agents is assumed that a single part will represent at least one agent. Agents will be connected together creating a logical structure of model with network structure (Figure 3). Connections between agents are conditioned by the necessity to exchange messages in given situations and in a given time. Net structure of connections should be treated as design relations, whereas information included in sent messages as information on design features.

Moreover, it is assumed that few agents can be represented by one agent, in which case single agent will represent agents' subnetwork. From user's point of view thanks to group agents a model of real object can be considered at different levels of details.

Real object model, which is represented by agent system, forms informal model, based on knowledge recorded in knowledge bases which are accessible for agents. As a result of agent system operation, formal model of technical object is obtained, which can form a basis for further processing [4]. On the basis of formal model e.g. 3D model of an part is created. In practice, a format describing information which is the fundamental for 3D creation with the use of available tools for geometric modeling is needed [7]. A few neutral formats are available which enable data exchange between different CAD/CAM systems or PLM. As example IGES (ANSI-1996) and STEP (ISO 10303) formats can be mentioned. For the multi-agent system XML format is used.

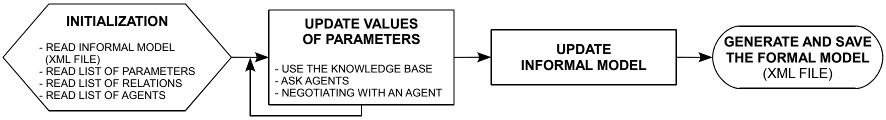

Figure 4. General architecture of multi-agent system

Figure 4 shows general architecture of our multi-agent system. All the agents have the same construction. Differences between them occur after having read a given informal model written as XML file as well as a list of geometric, materials and dynamic parameters connected with this model together with a list of relations between parameters. These relations can be between the local parameters as well as local parameters and the parameters allocated to other agent. What is more, each agent has an assigned list of agents which are necessary in updating process of parameters value. Next step is to update value of parameters by means of available knowledge or a question to a selected agent (in case of correlated parameters e.g. diameter of an opening and pivot). When all the values of the parameters are set , agent updates informal model and based on that creates formal one. After that such a model is recorded in an archive in a form of XML file. Furthermore, each agent should be able to read definition of the same ontology which in turn enables exchange of messages between them.

4 Examples of usage

JADE (Java Agent DEvelopment Framework) [3] environment has been selected for creation of multi-agent system, which is a platform fully congruent with the specification elaborated by FIPA foundation [1].

The essence of agent operation is determination of unknown values of design features (first of all geometric design features) by means of relations which occur between known values of design features set by a constructor or acquired values (e.g. from knowledge base or from other agent) of selected construction features (usually material like and dynamic design features). Selection of values of design features is divided into two stages: updating and/or negotiation, the difference between these two is that during accordance phase, agents determine mutual value for a given design feature using e.g. aggregation method for that purpose.

For the exchange of messages between agents JADE uses special ACL (Agent Communication Language) language. In order to guarantee coherence of transmission of messages, simple ontology has been worked out consisting of vocabulary and concepts. An extract of the elaborated glossary is the following:

```
DESIGN_FEAT = "Design feature";
DESIGN_FEAT_ID = "idDesignFeat";
DESIGN_FEAT_VALUE = "value";
DESIGN_FEAT_UNIT = "unit of measurement";
DESIGN_FEAT_DESC = "describe";
DESIGN_FEAT_INFSOURCEID = "idInfSource";
DESIGN_FEAT_COUPLED = "Coupled design feature ";
DESIGN_FEAT_COUPLED_ID = "idCoupledDesignFeat";
DESIGN_FEAT_COUPLED_INFSOURCEID = "idCoupledInfSource";
```

Vocabulary was the basis for elaboration of three concepts. One of them is presented below:

```
concept(DESIGN_FEAT){
        DESIGN_FEAT_ID, REQUIRED_PARAMETER;
        DESIGN_FEAT_VALUE, REQUIRED_PARAMETER;
        DESIGN_FEAT_UNIT, OPTIONAL_PARAMETER;
        DESIGN_FEAT_DESC, OPTIONAL_PARAMETER;
        DESIGN_FEAT_INFSOURCEID, OPTIONAL_PARAMETER;
        DESIGN_FEAT_COUPLED, OPTIONAL_PARAMETER;
        DESIGN_FEAT_COUPLED_ID OPTIONAL_PARAMETER;
        DESIGN_FEAT_COUPLED_INFSOURCEID, OPTIONAL_PARAMETER; }
```

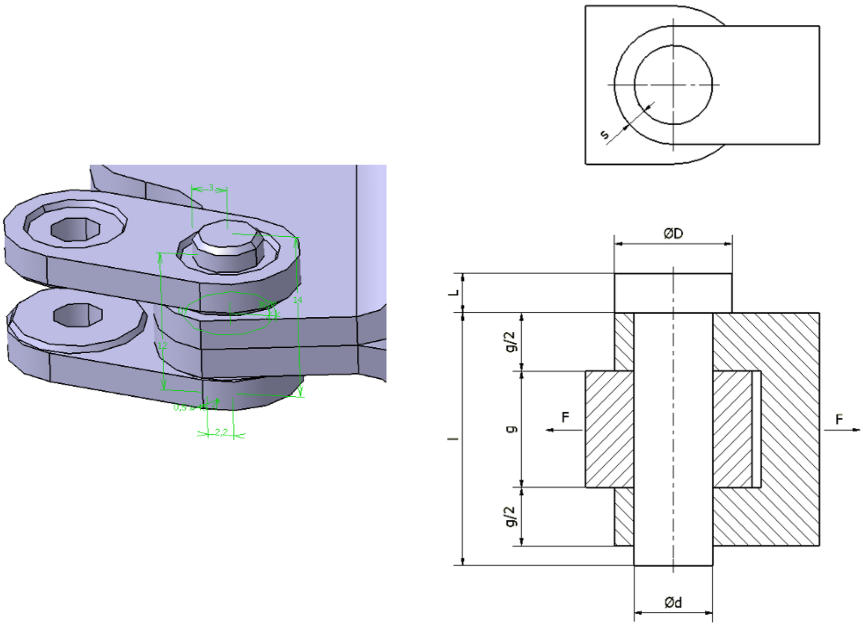

Figure 5. Drawing of the knuckle joint assembly

As an example verifying the operation of the elaborated multi-agent system, selection of geometric values of knuckle joint shown on Figure 5 has been chosen. The knuckle joint assembly consists of three elements i.e. knuckle pin, single eye end and double eye end [5]. The names of the elaborated agents correspond to the names of these elements – aKnucklePin, aSingleEyeEnd, aDoubleEyeEnd. Each agent was allocated other set of design features and relations which formed its calculation model.

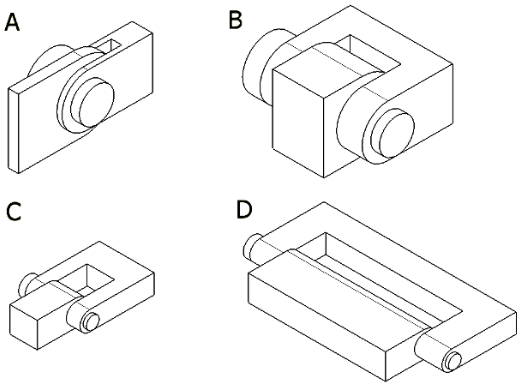

Figure 6. Examples of knuckle joint asseblies for diffenrent values of design features (description see the text)

One of the phases of verification consisted in the change of selected designing features. Figure 6 shows the obtained results. Case A is base result for values force F=10[kN] and ultimate tensile strength R_m=500[MPa] assigned to all the elements. In other cases the following changes have been introduced:

B – for the material single eye end (aSingleEyeEnd) the value of ultimate tensile strength has been determined as R_m=100[MPa]

C – for knuckle rod diameter (aKnucklePin) value ϕd=5[mm] has been determined

D – for the material single eye end (aSingleEyeEnd) the value of ultimate tensile strength has been determined as R_m=100[MPa], and for knuckle rod (aKnucklePin) diameter value ϕd=5[mm] has been determined

The obtained results have been expected. The increase in the value of ultimate tensile strength of the single eye end (case B), resulted in the decrease of its width (g), and as consequence the decrease in the width of double eye end as well as lengthening of knuckle rod. Introduction of constant value of knuckle rod diameter (case C), with the value of ultimate tensile strength identical to all elements, caused the increase in the width of single eye end and double eye end. However, the decrease of the value of ultimate tensile strength of the single eye end and introduction of constant value of knuckle rod diameter (case D), resulted in significant increase of the width of single eye end, whereas after the process of agreeing also the increase of the width of double eye end with the lengthening of knuckle rod pivot (l).

5 Conclusions

The concept of knowledge processing system for aiding designing process assumes full automation of knowledge processing with autonomy of particular stages and separate aiding tools. Coherence of processed knowledge is assured by the use of XML language as a format for recording and transferring of knowledge between knowledge acquisition process, reasoning with knowledge and geometric modeling in CAD system. Common ontology covering these stages allows easy adjustment to changing CAD systems. In further works it is necessary to make ontology more detailed and test the system in more complex designing examples.

6 Acknowledgement

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Part V
Lean Product Development

A Formal Model of a Complex Estimation Method in Lean Product Development Process

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Abstract. The advantages of complex estimation of a product development process are presented. The formal model of a lean product development process that bases upon the graph theory is presented. The product development process many-criterion optimization is performed by the shortest path method. The software implementation of the model is discussed.

Keywords. Integrated product development, Process optimization, Formal process model

1 Introduction

Using the lean product development requires the solution of many tasks. The main task is the optimization of the design and production properly. To use the benefits of concurrent process organization [1] we must choose the best consequence of jobs from all of the possible combinations. For this purpose the business-process modelling software is used widely. These models are designed to analyze the processes from different sides using several methods, which can be conventionally divided into two groups.

The first group of methods uses dynamic models. These models are very complex. It takes much time and work to design them. The analysis bases on probability that is estimated by human. Besides, the probability is used to estimate the uncertainty and the fuzziness which is not always correct [2].

The second group uses static models and the most common method here is Activity Based Costing (ABC). There are some weaknesses in this method. Firstly it is focused only on costing. It tells us nothing about any other aspect of the process. Secondly it uses different assumptions that make this method not very precise. But it works very well when calculating the prime cost. But if we need to perform the

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complex analysis of a business-process, besides the cost, we must analyze other criteria [4].
Authors have performed modelling and complex analysis of different variants of design and engineering processes. It can be determined and proved how to lower the prime cost of some of them using the ABC methodology. And in order to increase the quality of the process we can propose different actions: job replacement, job order modification. Authors suppose that some of these actions can make the process “better” or “worse”. Here the decision can be made intuitively, or by a group of experts. Each expert might have his own opinion on how this little action can influence on the whole process. For example, the design process improvement gives very little to the final product without respective improvement of design and production departments’ interaction. In this case improvement of one part of the process is the waste of time and funds.
The most tasks, that human challenge, can be solved in different methods. This refers to design and production, illness treatment or governing a state. In most cases these methods are well-known but human needs to choose one of them. And if these methods are modelled the cost or how much time it takes to execute them may be estimated. And the most low-costing or the fastest way may be chosen. But in practice lot of other criteria must be taken into consideration. Some of them are safety, ecological compatibility, novelty, quality, accuracy, appearance, productivity and so on.

There are a lot of criteria and we cannot consider each of them. The importance of each criterion varies depending on the process. For example in chemical industry the production process safety and ecological compatibility are of high importance. And the office employees’ safety is not of such concern.

Therefore we consider that it is necessary to create a formalism that would help us to solve tasks below:

- set the estimation criteria and the parameters of that criteria, that would be the rate of job’s compliance to that criteria;
- set the importance of each criteria in order to range them;
- estimate the business-process as the jobs’ queue;
- compare different processes on the set of criteria to choose the best one;

2 Formal Model

To solve this task let’s consider formal model of technical objects description proposed in [3] and a process model discussed in [5]. This work describes the process as a graph, the nodes of a graph being jobs (or functions) and the edges of a graph being the connections between the jobs.

If this model is inverted, the jobs would be described by the edges and the nodes of a graph would present the results of those jobs (Figure 1). The weight of the edge represents the estimation of a job on some criterion. If it is necessary to add another criterion another edge to connect two nodes must be added.

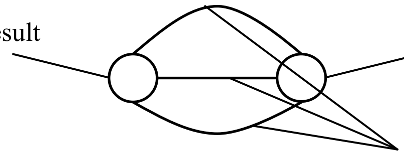

Figure 1. Job estimation.

The model of a process can be described as a graph:

$$\mathbf{G} = (\mathbf{R}, \mathbf{J}) \quad (1)$$

J being is the set of jobs and **R** is the set of results. To represent the set of results the formal model, described in [5] will be used:

$$\mathbf{R = (Gr, Tb, Tx)} \quad (2)$$

Gr, Tb and Tx being graphical, table and text documents respectively, describing the result of some job. The results are counted from 0 (the start point) to n (the number of steps). The jobs are represented by the graph edges, each job is a set of variables, and each variable is job estimation on some criterion:

$$J_i = \{c_1, c_2, \ldots c_k\}, \quad (3)$$

In general these variables are non-numerical, they possess the value of a linguistic expression (poor, average, good, excellent, etc.). But each non-numerical variable can be described to a set of numerical variables:

$$\mathbf{c_i} = \{p^1_{ci}, p^2_{ci}, \ldots, p^k_{ci}\}, \quad (4)$$

For example, ecological compatibility can be determined as a set of variables, each variable being an amount of waste emission. Let's call these variables parameters:
p^1— carbon dioxide emission
p^2— chlorine emission
…
If another criterion is needed, another set of parameters must be added. In that way each job can be estimated on plenty of criteria. And here is the decision point, which criterion is more important from the point of analysis. Then the criteria must be ranged by the importance.

This formalism helps to express numerically such terms as "poor" or "good" by comparing the job under investigation with some etalon job. Moreover, if two similar jobs are compared, it may be determined which of them is preferable.
When estimating the whole process it must be noticed that consequential jobs influence each other. Moreover, the local improvement may give nothing to the

whole process. For example if quality of blueprints is poor we cannot expect that the final product would be of high quality, in spite of high quality of the production process. Hence, when analyzing the process, the criteria cannot simply be added to each other, as it is made in Activity Based Costing methodology. Therefore at first each job must be estimated on several criteria and only then the whole process can be estimated.

3 Software Implementation

Considering the process model as the formalism described above all the variants of the process can be represented in one graph. If all the jobs are estimated, the task of finding the best process turns into the shortest path problem. And the decision of this problem is well known.

The focus should be set on process modelling. The main trend is using the existing software: AllFusion Process Modeller. It is powerful in modelling and has a wide range of functions. For process modelling purposes the IDEF3 diagram is used, so draw different variants of a process with junctions could be drawn. Some of PDM/PLM software has process modelling functions too. One of the possible implementations is to use its functions. This will help to integrate in product lifecycle processes.

Let's consider AllFusion Process Modeller. The authors intend to use its User Defined Properties (UDP) function to implement estimation mechanism. Then a subroutine is needed that would analyze the process. It will interact with Process Modeller using API. Other way is to use the xml-file, exported from the Process Modeller. After the subroutine is executed, there will be the information about all the advantages and weaknesses of all the variants.

When modelling the process the limited range of jobs is used. It is modified from one object domain to another. When using PDM/PLM software to model process in different domains this limited range of jobs should be used that may have been estimated beforehand, so the new process model would be estimated in-design time. As a result the knowledge about the process in some object domain will be saved.

PDM/PLM software has one more advantage. On its base it is easy to implement the results' representation (2). By combining these two aspects, the process and the result, it can be seen, that an integrated product design environment has been built. Using the PLM software the process can be modelled, analyzed and implemented. And then data flow, controlled by the PLM system, makes the design group work according to the process.

4 Conclusion

The model of integrated process and product design environment is proposed. The process is represented as the consequence of jobs. The result of these jobs is the product data represented as graphical, table and text documents. To understand how the process may be made better the jobs are estimated and the process is analyzed. The analysis includes the creation of different variants of a process model. Then it turns into the shortest path problem.

The implementation of the proposed is possible in two aspects: as the analyzing subroutine in process modelling software and the integrated product and process design environment, based upon PDM/PLM software.

The application of the proposed model is possible in design and engineering domains, especially if it is necessary to adapt the manufacturing to new conditions. This includes the wide range of activities: product modification, licensed production, franchising. But authors do not limit the application of the model in other domains.

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Identification and Modelling of Product Development Process Activities: Time and Cost Analysis in SME´s

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Abstract. The intense competition in global market along with constant changes in customer demands have forced companies to re-think some of their business processes in order to survive and stay competitive. Product development is one of the key business processes for any competitive or global company. The implementation of a product development process must fit in its technical, cultural, and most importantly financial needs. SME´s, usually, don't have a clearly understanding about their product development process (PDP) in terms of resources and costs required. This paper presents ongoing research focused on the application of a PDP in SME´s. Three stages are considered for this: PDP analysis and definitions, Activity Based Cost (ABC) parameters identification and finally an analysis of the PDP costs. IDEF0 was used as a tool for supporting the PDP analysis, ABC parameter definitions and modelling. Each PDP activity was defined in terms of its cost. A Brazilian water filter elements manufacturer has been chosen to test the initial ideas of this research. The research shows that the proposed approach can be helpful to understand the importance of the resource costs (human and equipment) within the PDP.

Keywords. Product development process, ABC system, costs

1 Introduction

Companies business main processes are composed by different, internal and eventually external sub-processes, such as purchasing, manufacturing, delivering, assembling, etc.. Usually, processes that contribute to the product value addition should be considered the more important ones, mainly because of their time-to-market and costs issues on the final product [5].

Product development is one of the key business processes for any competitive and global company. The organization and formalization of this process can provide final product development reductions and savings in time and costs [19,

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25]. Having a product development process (PDP) defined within a formal model, by itself, cannot assure total competitive advantage to companies, but the lack of it might be for sure disadvantageous. This process encompasses understanding the costumer's needs (customer´s values), defining the design concept and manufacturing the product (product costs), selling and finally discarding the product. Clark and Fujimoto [7] state that the correct application of product development process (PDP) has become a powerful tool to improve companies competitiveness, mainly related with satisfying their customers' expectations in a long term strategy.

Also, considering the needs for efficient and agile product development within a supply chain context, companies have demanded from their partners (some of them SME´s) the application of a structured PDP, resulting in an efficient and agile time-to-market product development. Thus, SME´s are challenged to understand, measure and define their PDP in terms of activities, recourses and costs [13,27].

The academia has presented and discussed different product development methodologies and models during the last years [1,22,29,26,18]. Several companies have put efforts in this area as a part of their competition strategy, focusing on new products as a way of increase market sharing [15,23]. The application of these models in the company´s environment is not a straightforward process, since each company PDP is strongly influenced by the type of product produced and also from cultural and organizational aspects [4, 30]. Morgan and Liker [30] consider also that the PDP is composed by three sub-systems: processes, people and tools and technology. These aspects and considerations can be more critical in SME´s, as these kinds of companies usually don´t have a very formal organization structure, resulting in an informal PDP [21]. On the other hand, processes such as PDP are crucial to the company strategy and surviving, mainly if the aspects of technology and innovation are considered. Thus, the definition of this process can be helpful to a company understand the required activities, resources and costs involved in the product development process.

This paper presents an initial study related to the analysis, modelling and formalization of a product development process in a SME, by identifying its main activities, their resources and costs, based on an external reference model for PDP. The idea is to explore a method to analyse the actual cost of the PDP for these kinds of companies. For testing the ideas a Brazilian water filtration elements manufacturer was used as a case study.

2 Product Development Process: Modelling and Costs

Putting a new product in the market is not an easy task for most companies, being usually a result of a long time process involving several activities and functional sectors of the company. Some authors, such as Clark and Fujimoto [7] and Kotler [15] state that the PDP management is a kind of business strategy and it should be placed in line to the company overall strategy.

Usually, in the PDP initial phases are defined the main specifications and design solutions of a product, where materials, technology and manufacturing processes are defined. Dixon [10] defines PDP as the transformation process of customer needs into a product or services, by a set of activities involving most of a company sectors.

The PDP, when compared to other company business process, has a wide range of specificity, such as high level of uncertainties and risks in the beginning of the process, managing and generating of a large amount of information and knowledge, different sources of information, and several requirements and restrictions considering all phases of the product lifecycle. All these characteristics make this process very complex and unique, demanding appropriate management models and practices to coordinate it. Some authors [1,3,29,20] define, or classify, the PDP in different phases, in order to better understand the characteristics of each one. This allows that any changes made in the PDP can be focused on each phase specific. However, this classification is not same for all kind of products or companies, requiring, eventually, adjustments [18].

Rozenfeld [24] proposes a Unified Model of PDP, where different stages, phases, and activities are formalized. This model, which gathers concepts, structures, tools, methodologies and other aspects, from different PDP models presented by previous literature, provides a generic basis for the PDP. It is a didactic and structured model, which can be used, as an external reference model, for companies that evaluate or compare their own PDP. This model has been selected by this research as a reference model for the PDP analysis. It is composed by three macro-phases: pre-development, development and pos-development, each one composed by different phases, which are, in turn, decomposed in several activities. The phases are: Product Strategic Planning, Project Planning, Informational Design, Conceptual Design, Detailed Design, Production Planning, Product Launching, Product/Process Monitoring and Product Discontinuance. Each phase is composed by different activities. In addition to these activities and phases, the PDP is also a decision making process, resulting in a strong dependence among its activities. Therefore, to evaluate its PDP, a company must comprehend each one of functions associated to this process, identifying main inputs, outputs, controls and actors.

In order to analyze and model a process is necessary to have some information about it, such as process goal, physical and logic inputs and outputs, controllers, rules, etc.. It is also necessary the use a defined notation that provides a clear process representation, in a common and understandable language for all involved. Two aspects must be stressed when modelling processes: functions (or activities) and the relationships between these functions.

To model the activities and information of a PDP, this work has defined the IDEF0 notation [14], which is a well structured notation to model activities and information. The IDEF0 allows building different visions of the PDP, in different levels of abstractions. Thus, the models build can represent from a macro vision of the process to a detailed and specific vision of the process using the very same notation. These models will provide an understanding about the working and integration of different activities realized by the different sectors of the company, not only in terms of inputs/outputs, but mainly in terms of resources and costs.

The product costs are directly linked to the performance of product development process, as they result from decisions taken during this process [16, 28]. The product development team needs to consider the product specifications and time to market limitations, considering the final product functions and characteristics that can add actual value to this product [2]. Usually, the pressure for costs reductions occurs during the industrial process phases. However, it is during the PDP where risks related to the final product costs and time-to-market can appear [5]. One of the decisive factors for competitive products is the product design. Investigations confirmed that product development sets around 90 % of the product cost during the product design stage [1,29,6]. Consequently the final product cost is mainly influenced by the costs of related development activities associated to its PDP (**Figure 1**). In order to understand these cost pieces, the PDP activities must be identified, value mapped and modelled, in terms of resources and time consumed.

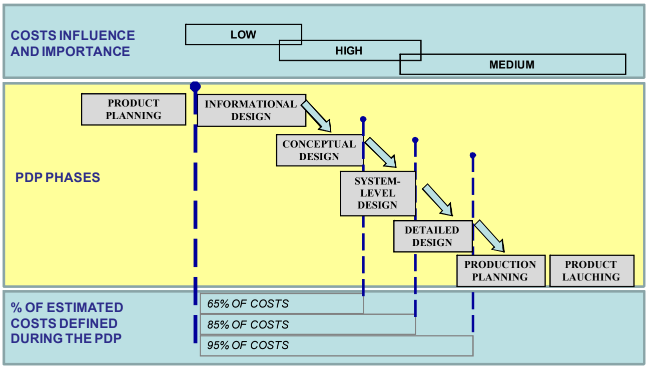


Figure 1. Product estimated costs influence and distribution during PDP phases

Thus, product costs can be resulted of either, physical aspects of its production (material, manufacturing, assembling, etc.), and costs involved in each activity of its development process (**Figure 2**).

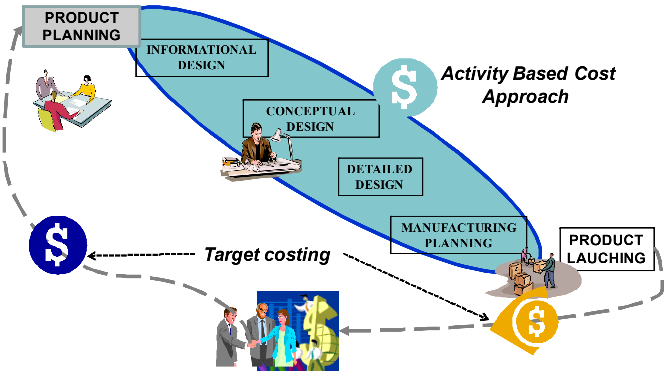


Figure 2. Approaches for PDP cost analyses

The first perception has been discussed traditionally in terms of target costing, value engineering technique and other approaches [17, 11, 30, 31]. These are usually associated to the material and manufacturing product costs. For example, Target Costing, which can be considered a market-driven strategy and process, establishes product's possible selling price that can be achieved in the marketplace. Thus, as others customer requirements, the target cost is treated as an independent variable that must be satisfied rather than the result of design decisions [12].

The second perception is usually approached in terms of ABC system [3]. Borden [3] stresses the importance of using the Activity Based Cost (ABC) system, where the costs associated to all processes related to the product life cycle affect the final product cost. Therefore, the costs must be estimated or measured for the whole life cycle, and not only to the manufacturing process. The use of ABC system can provide better and more precise understanding about the final product costs, identifying the value added by each activity. This research has been focused on the later perception, i.e. the understanding of the PDP activities and how they influence on the PDP costs.

3 Research Methodology

This work was based on an exploratory research focused on a case study. The main goal is explore a method for analysing and identifying the costs and minimising the wastes during the PDP.

Based on a PDP reference model well defined in terms of phases, sub-phases and activities an analysis was realized in company product development process. This was made, in a first moment, checking the existence, or not, of each PDP reference model activity against the company process, by interviews and analysis of documents. After the identification of each activity its actors, resources, time required and costs were analysed. For modelling the activities IDEF0 was used. These provided the basic elements for the ABC analyses of the PDP. In a second phase of this research, a analysis of the wastes involved in each PDP activity will be developed, considering the group of wastes presented by [30]. However this is not approached at this paper (**Figure 3**).

For testing the analysis realized, a SME, manufacturer of filtration elements, mainly for water filtering, was selected. Its product is used in commercial and residential water filter systems, which can be produced by the company or by others company that buy only the filter element. Thus, the development of a new product can be started by the company or by one of their customers.

The company does not have a formal and structured product development processes, although new product are developed every semester, either by costumer requests, or providing new solutions to the market. Also, new products are developed based on redesign, as the product concept doesn´t change.

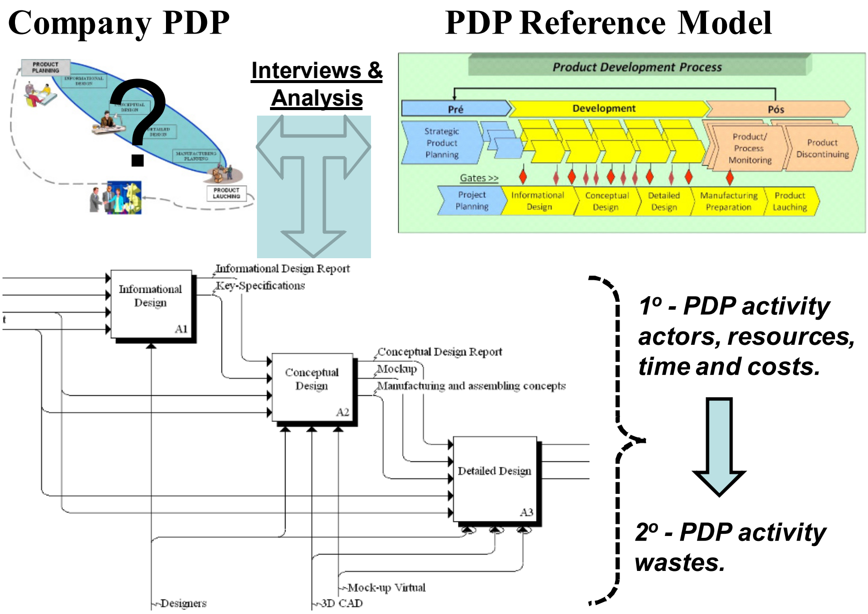


Figure 3. PDP IDEF0 modelling process

The work was done in the form of case study. It was analyzed the workflow of the process, main phases, activities, inputs/outputs and resources/tools, allowing a close relationship of the researcher with the reality to be investigated. The pieces of information identified in the company were compared with the academic reference PDP model. The analysis of this information was realized considering the structure and alignment of the model in terms of phases, steps and activities [8]. This process was conducted by semi-structured interview with the company´s director, manager, and engineers related to the PDP. The focus of this phase was to identify (delimitate) the existence of each company PDP activities in relation to the PDP reference model.

Work has been previously made identifying and modelling the PDP activities in a chain of automotive companies and comparing them to two PDP reference model, an academic and an industrial [9]. Although automotive companies are usually more formal and structured in terms of PDP, the work realized has provided a good experience and sensibility regarding to this subject.

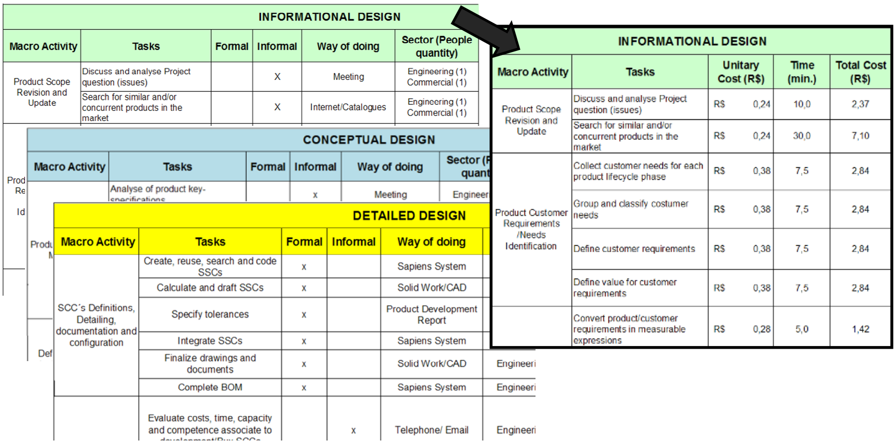
Within the ABC system, each activity must be set in terms of parameters, such as the resources, cost drivers, time spent, etc.. Thus, considering the activities previously identified, firstly qualitative aspects were analyzed and afterwards, quantitative aspects were studied. Some of these aspects are: formal/informal activity; means and resources required to develop the activity; number of people involved; time required; individual cost and activity costs. The IDEF0 was used to support the capture of these aspects associated to each PDP activity, and the model was focused on the design process main phases, i.e. informational design, conceptual design and detailed design.

4 Identifying PDP Activities and ABC Parameters

4.1 Design activities identification

A semi-structured questionnaire was applied to the people involved in the product design phases, i.e. engineering, marketing, commercial, etc.. Each design activity defined in the PDP reference model was analyzed in terms of its presence, or not, in the company PDP, who and how it is done, resources utilized, time consumed, etc..

The team responsible for the product development is small since the knowledge associated to the each new product development is relatively known. Therefore, phases such as conceptual design are very short. On the other hand, the company is also compromised in developing new application products for the filter elements, adding more value to the final product. **Figure 4** shows an example of a list of activities and tasks analysed to the design phase of the PDP.



INFORMATIONAL DESIGN				
Macro Activity	Tasks	Unitary Cost (R$)	Time (min.)	Total Cost (R$)
Product Scope Revision and Update	Discuss and analyse Project question (issues)	R$ 0,24	10,0	2,37
	Search for similar and/or concurrent products in the market	R$ 0,24	30,0	7,10
Product Customer Requirements /Needs Identification	Collect customer needs for each product lifecycle phase	R$ 0,38	7,5	2,84
	Group and classify costumer needs	R$ 0,38	7,5	2,84
	Define customer requirements	R$ 0,38	7,5	2,84
	Define value for customer requirements	R$ 0,38	7,5	2,84
	Convert product/customer requirements in measurable expressions	R$ 0,28	5,0	1,42

Figure 4. PDP design phase activities parameters and cost identification

Initially, the activities and tasks were analyzed in terms of how they are made (formal/informal; resources). For the case shown on **Figure 4** most of the activities are realized in an informal way and usually by the same engineer, which makes difficult to evaluate the real cost and value of the activity. Based on each design activity/task information, the ABC parameters associated to the main resources (human), time and costs were identified. The resources associated to equipments, telephone/internet, etc. were not considered, at this moment.

Figure 4 depicts also an example of time consuming and costs information for the tasks involved on informational design phase. This information was not precise assigned as most of these activities happened in an informal way. The company does not have a formal documentation to register these values of time consumed on each activity.

4.2 PDP Design Activities Analysis

Based on the information collected a comparison among the design activities involved in the company´s PDP was realised. **Figure 5** shows a comparison between these three main design phases for the case study. The time consumed and costs are highly significant for the detailed design. In the case studied, as previously mentioned, the product has the concept already defined, requiring some understanding from the customer point of view (Informational Design) and most of the effort in detailing the geometry, manufacturing plans, suppliers' definitions and packing the product (Detailed Design).

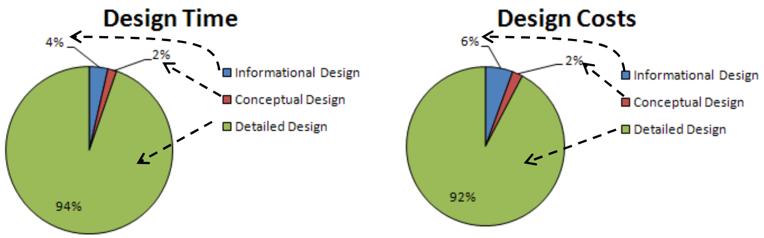


Figure 5. Time and costs distribution for main design phases

Figure 6 shows a distribution of the costs within each main design phase. In the first phase, i.e. Informational Design, there is an effort for understanding the main costumer needs and converting them in product specification.

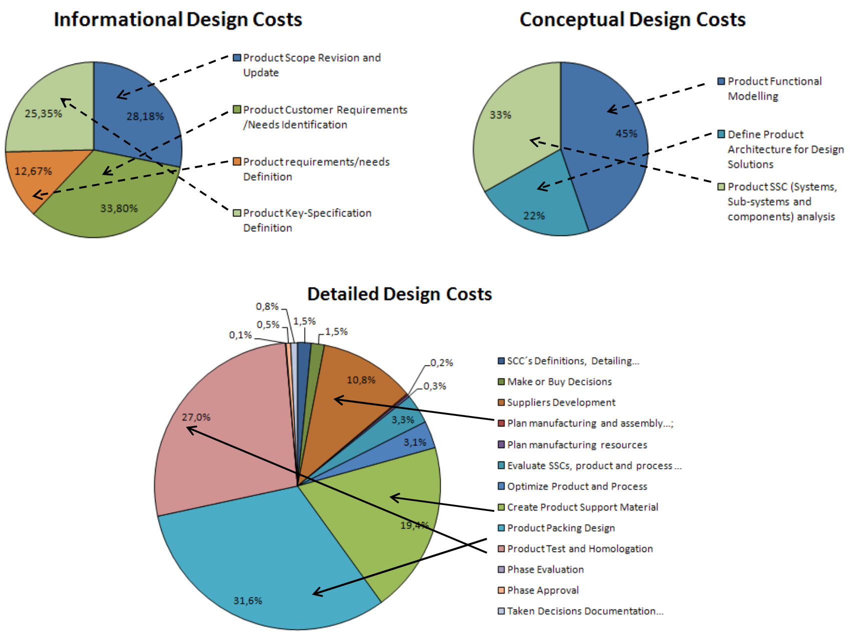


Figure 6. Costs for each main design phases within the PDP – Case study

The activities are well distributed at this phase. This phase happens in an informal and short time. Usually, the results of this appear in the detailed design where pieces of information are missing (wastes). Also, the time appointed in the case study is significantly shorter than the time required completing this phase. This is a result of the time needed to wait for information.

The second phase is almost inexistent. The perception of the product function is only understood in terms of its main function (water filter). These activities have appeared in this case as a result of the PDP reference model used during the interviews. It can be said the company does not have an understanding of its product in terms of product main functions, architecture and systems.

Finally, in the third phase, i.e. Detailed Design is where most of PDP activities appear. Four main activities can be identifies at this phase: suppliers' development, product support material creation, product packing design and product test and homologation. The product SCC (System, sub-systems and components) definition activity, which is the base of this phase, does not receive much attention as the product concept is defined.

5 Conclusions

The paper has presented a study conduct in analysing the product development process activities in a SME. An academic PDP reference model has been used to support the identification of the main PDP activities and IDEF0 was used to model these activities parameters, such as time consuming, costs and resources. Three main design phases involved in the PDP, i.e. informational, conceptual and detailed design, were analysed mainly from the duration time and costs.

Using a PDP reference model was helpful for analysing the company informal PDP, providing a well structured definition and IDEF0 model, which was used for a more detailed analyses.

The results presented in this first study were expected since the product analysed has a defined concept, requiring major effort in its detailed design phase. On the other hand, these results have shown also that the time required for complete each design phase is larger than the sum of its design activities. This confirms the following investigation regarding to wastes, e.g. waiting time, associated to the PDP.

The next research stage is to continue the PDP analysis of each PDP design activity from the value adding perspective, mainly in those activities where more time/cost are spent. The idea is to understand how these activities actually add value to the final product. There is a need to consider additional ABC parameters, mainly associated to the physical facilities used to support the PDP.

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The Conceptual LeanPPD Model

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Abstract. This paper is presenting the conceptual Lean Product and Process Development (LeanPPD) model which is a project funded by the EU-PF7. The project is addressing the needs of European manufacturing companies of a new model that goes beyond lean manufacturing, to ensure the transformation of the enterprise into lean environment. This is a respond to the market demand of value creation, incorporating sustainability and customisation as well as ensuring business growth through the development of high quality products in a cost effective manner at the shortest time. The authors believe that significant change in enterprise performance can be achieved through the adoption of lean thinking throughout the product life cycle. The paper presents the LeanPPD enablers which represent the building block of the model.

Keywords: LeanPPD, Lean Thinking, KBE, SBCE, value creation

1 Introduction

The increased international competition in the current open global market is putting pressure on companies to improve the performance of their product development. This is to sustain and improve market share through the production of a high quality product in a cost effective manner in shorter time. This is because organisational survival and long-term growth depends on the introduction and development of new products. The European manufacturing companies are in need of a new model that goes beyond lean manufacturing to ensure the transformation of the enterprise into lean environment. This is a respond to customers and market demands of value creation, incorporating sustainability and customisation. The authors believe that significant change in enterprise performance can come from the adoption of lean thinking through out the entire product life cycle. In this research; sponsored by the EU-PF7, we refer to it as Lean Product and Process

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Development (LeanPPD). Lean concepts were derived initially from the Toyota Production System, which in simple terms is defined as: producing what is needed, when it is needed, in the time that is needed, with the minimum amount of resource and space. The whole objective of lean is the elimination of waste. This is good to achieve an isolated success within a manufacturing company but is not sufficient. What is needed is a new paradigm that will take the Lean manufacturing and lean thinking concepts from waste elimination into value creation. In order to make a significant change in enterprise performance and saving ultimate system costs, there is a need for the entire enterprise to undergo a lean transformation. Lean design is going to be an important part of this lean transformation, as up to 80% of the manufacturing cost is determined in the design stage. It is important to note that a complex design product cannot easily be “leaned out” in production stage. Hence the production of affordable and sustainable products would require an effective lean design and engineering.

This paper is presenting the conceptual LeanPPD model through its enablers; which represent the building block of the model. These enablers are: lean assessment tools, the product development value mapping tool, the set-based lean design tool (SBLDT) and set-based concurrent engineering, the knowledge-based Engineering and the knowledge-based environment.

2 The Related Lean Product Development Literature

Lean principles proposed by Womack based on Toyota Production System (TPS) to improve the productivity of the shopfloor by eliminating wastes may be described as: specify value, identify the value stream and eliminate waste, make the value flow, let the customer pull the (value) process, and pursue perfection. These principles have been applied in the shopfloor what is commonly referred to Lean Manufacturing. In order to make a significant change in enterprise performance and saving ultimate system costs there is a need to have the entire enterprise undergo a lean transformation.

Karlsson and Ahlstrom carried out research based on observing several industries to come up with recommendations about the path to Lean Product Development. The research did not define the meaning of lean and the general recommendations were more related to CE applications such as supplier involvement, cross-functional teams, simultaneous engineering and integration of activities. There were two major lean thinking projects in USA and UK. The Lean Aerospace Initiative coordinated by MIT (USA-LAI 2010) and the UK Lean Aerospace Initiative (UK-LAI 2007). It is clearly noted they are specifically oriented to the aerospace industry and only to those companies in USA and UK as well as the information are available only to the projects’ members. The efforts started by understanding the Toyota Production System (TPS) through publishing the book “The Machine that Changed the World”. The book gave a name to TPS as Lean Manufacturing. Most of the efforts were put in understanding lean applications on the shopfloor and developing both practical models and lean techniques to help the implementation. This effort then evolved to the lean transformation of the enterprise. This is now called the Lean Enterprise that covers the adoption of lean thinking to the management of the enterprise as well as it supply chain. Some part of the UK Lean Aerospace Initiative started in April 1998 (ended in 2001) was addressing the issues of adopting Lean thinking in new production introduction. Haque and James-Moore used experiences of lean implementation in manufacturing processes, and process improvement initiatives in Lean Product Introduction (LPI) such as CE to make a comparison in order to make an argument about LPI. In addition, an extensive literature review was carried out to identify possible techniques or tools (based on both lean manufacturing and CE best practice) to support LPI. This led to a level of understanding to propose general characteristics of a LPI System.

Several books have been published with titles related to Lean Design or Lean product development; some are based on the research carried out in USA which observed and analysed the Toyota product development system (Kennedy, Morgan and Liker, and Ward). The general findings of these books are the following:

- System Designer Entrepreneurial Leadership: A technical leadership paradigm that efficiently brokers the right knowledge into the right product.
- Set-based Concurrent Engineering: An exploration paradigm that generates extensive knowledge from many perspectives to maximise product alternatives with minimal risk.
- Responsibility-based Planning & Control: A management paradigm that provides efficiency, flexibility, and knowledge as the backbone for project execution.
- Expert Engineering Workforce: A paradigm that assumes engineers have both the technical capability and access to the right knowledge to make the proper decisions to optimise the current product, while building the knowledge for future products.

According to the National Centre for Manufacturing (http://lpdi.ncms.org/), Toyota product development projects can take half the time of US equivalents, with four times their productivity (150 product engineers utilised by Toyota per car programme versus 600 for twice as long at Chrysler). Mr. Kosaku Yamada, Chief Engineer of Toyota's Lexus line said "***The real difference between Toyota and other vehicle manufacturers is not the Toyota Production System; it is the Toyota Development System***"

Mascitelli (2007) based his book on his long experiences as consultant in product design in many companies. His approach is to provide a toolbox of methods that enable manufacturing cost reduction to become a foundational part of product design and development. Fiore (2005) attempted to merge lean manufacturing with six sigma to develop a template of three main foundation pillars:1) the lean design, 2) the manufacturing process and 3) control pillars. Huthwaite (2004) put his experiences as consultant in Design for Manufacturing and Assembly (DFMA), process control and cycle cost into a new approach to provide designers with recommendations on how to avoid wastes and to create values in their design.

In the USA, several researchers (such as Durward Sobek II and James Morgan) made an effort to study the Toyota product development system, and the findings indicate that Toyota product development projects can take half the time of US equivalents, with four times their productivity. Toyota product development system is based on what is called a ‘set-based concurrent engineering’ (SBCE) that is different from so many other manufacturing companies. SBCE focuses on collaboration between different development departments and aims at shorter development times with an increased quality level by improving collaboration and by paralleling parts of the development process. Design participants practice SBCE by reasoning, developing, and communicating about sets of solutions in parallel and relatively independently. As the design progresses, they gradually narrow their respective sets of solutions based on additional information from development, testing, the customer, and other participants’ sets. As they narrow, they commit to staying within the set(s), barring extreme circumstances, so that others can rely on their communication. SBCE processes starts with large design alternatives covering broad design spaces and then gradually narrowing the set of possibilities to converge to a possible design by eliminating the weakest alternatives rather than choosing one “best” alternative. It is a counter-intuitive approach and looks paradoxical to people trained in the traditional point based approaches. Various sets of alternatives are taken ahead for all parts of the product and the weakest ones are eliminated as one move in the product development life cycle. SBCE assumes that reasoning and communicating about sets of ideas leads to more robust, optimised systems and greater overall efficiency than working with one idea at a time, even though the individual steps may look inefficient. This approach may require more time early to define the solutions, but later stages can then move more quickly toward convergence, and ultimately production, relative to more point-based processes.

3 The New Paradigm of the Lean Product and Process Development

The fundamental issue in the new LeanPPD paradigm is the move from waste elimination to value creation. This is being realised through the development of an integrated set of tools and models that the current literature is missing. Performance measurement that considers human resources, technology factors and processes of an enterprise are going to be used to measure the readiness and level of adoption of lean thinking principles in current industrial practice of product design and development processes. This will lead to an understanding of how product and process development is structured and what is needed to streamline the process to maximise value creation. Hence, the project is addressing the mapping of product development process to measure the values from the customers’ point of view and estimate the-cycle costs, including the manufacturing and in service components. The LeanPPD model being developed in this project will enable manufacturing companies to balance the need to react to value creation opportunities against the efficiencies to deliver them effectively. This will be achieved, as any engineering decisions taken will be based on proven knowledge and experience, to reduce risk and maximise utilisation of resources of both the enterprise and its supply chain.

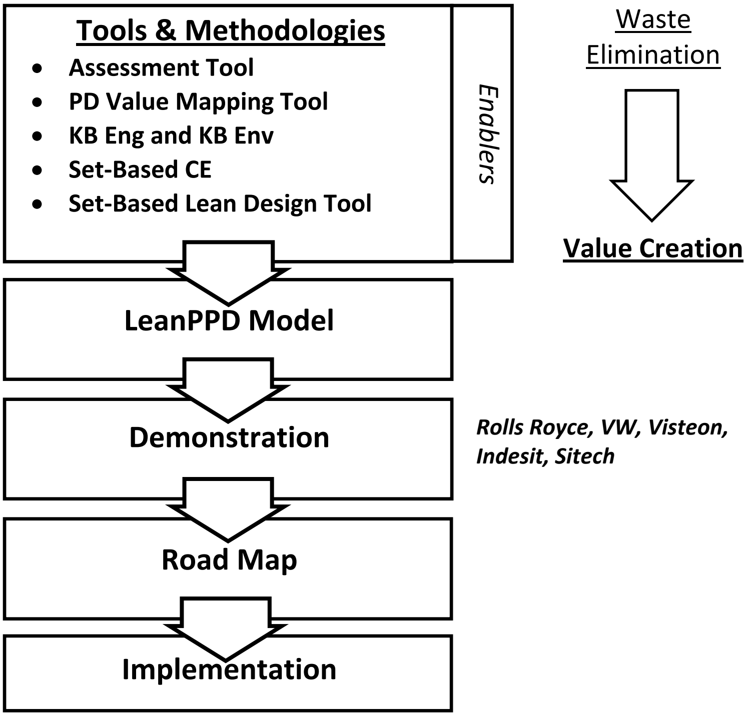

Figure 1. The LeanPPD Paradigm

The aim of the LeanPPD project is to develop a new model and its associate tools based on lean thinking that will consider entire product life cycle. Providing knowledge based user centric design and development environment to support value creation to the customers in term of innovation and customisation, quality as well as sustainable and affordable products. This is the new **LeanPPD paradigm** which is the result of the application of lean thinking in product design and development. Figure 1 illustrates the LeanPPD paradigm which consists of several enables namely: lean assessment tool, product development value mapping tool, the knowledge-based engineering and environment as well as set-based CE and set-based lean design tool. These enables are the building block of the LeanPPD model that will be demonstrated using several business cases from three different sectors; aerospace, automotive and home appliances. A route map for the incorporation of the model into organisations at different levels of development will lead to the full implementation of the LeanPPD model. The following section is presenting the conceptual LeanPPD model and explains the rational and the role of its elements.

4 The Conceptual LeanPPD Model

The conceptual LeanPPD model is illustrated in figure 2. The main features of the model that are in the progress of definition and development are; value creation, knowledge-based environment and the Set-Based CE (SBCE). In applying lean concepts, a major objective is to identify value and non-value added activities. In product development, any activity that would result in customer requirements being met could be considered as value adding activity. Notions of 'value' are relatively straightforward to apply in a manufacturing context but need to be further developed to be truly applicable in the product design and development arena. For example, iterations in manufacturing are usually seen as non-value adding, but iterations that are used to explore a design space are an essential part of delivering an optimal product solution to the customer. The model is developing tools and approaches to identify opportunities for value creation from a customer viewpoint, as well as a tool to help in representing them in the design of the product and product development process. A novel (Set-based design lean tool (SBLDT) is being developed to generate a set of lean designs based on definition of design and manufacturing features that are affected by lean principles. These lean features would be identified, extracted and inspired from lean tools, e.g. Poka-Yoke, Single Minute Exchange Die (SMED) and Quick Change Over (QCO).

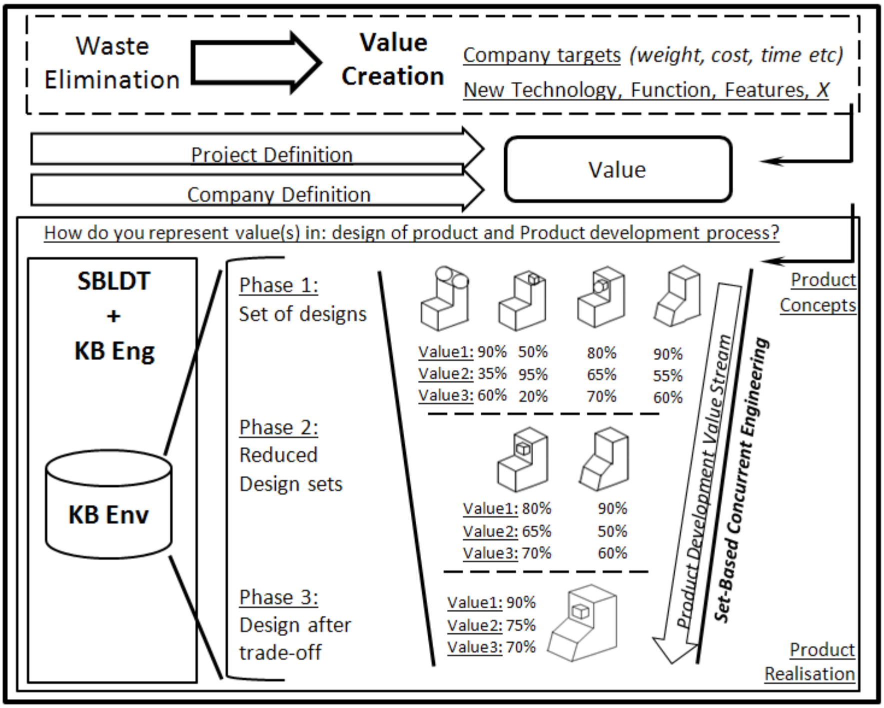

Figure 2. The Conceptual LeanPPD Model

The project is adopting the hypothesis that lean product development is product development in a knowledge-based environment. Hence, one of the main features of the conceptual LeanPPD model is knowledge provision. A knowledge-based engineering architecture will be designed to support the development of two knowledge-based systems, these are Knowledge-based engineering (KB Eng) and Knowledge-based environment (KB Env). The KB Eng will capture several domain knowledge (e.g. injection moulding and stamping to support a range of product life cycle engineering applications such as costing and DFMA. The KB Env will capture the previous projects to be one of the main sources of knowledge to define a set of conceptual designs of a new product. The authors believe the knowledge environment will enable manufacturing companies to balance the need to react to value creation opportunities against the efficiency to deliver them effectively. This will be achieved, as any engineering decisions taken will be based on proven knowledge and experience to reduce risks and maximise utilisation of resources of both the enterprise and its supply chain. The project is developing a new lean knowledge life cycle to support the systematic methods for knowledge capture, re-use and creation to enable a knowledge-based environment for LeanPPD.

SBCE principles are going to be used in order to trade-off among the different concept designs based on the value of the lean features that will be measured in terms of function, cost, ease of manufacture, and quality as well as the smooth transformation to a lean manufacturing system for the physical realisation of the product. This will results in the definition of one final lean design

5 Conclusion

The related literature of lean product development research has indicated that the research community has made a small progress in addressing lean aspects of product and process development. In addition, the previous research into lean has not addressed the applications of knowledge-based engineering, nor provides solutions on the evolving issue of product development value mapping to highlight value creation throughout the development process. Therefore, a significant lack of techniques could be used to provide a route by which lean thinking could be incorporated into existing product design and development in different sectors. The proposed conceptual LeanPPD model intends to resolve these gaps by merging the latest in knowledge-based system architecture with value-based model for LeanPPD.

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From Lean Product Development to Lean Innovation: Finding Better Ways of Satisfying Customer Value

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Abstract. The application of Lean principles in Product Development (LPD) is perceived by many as the key to maintaining competitiveness in a globalized business environment. LPD advocates claim that "a strong product development system is a crucial core competence and fundamental to the success of any consumer-driven company" [1].However, imitating the work processes and practice of competitors and other companies, essentially Toyota in this case, can at best only bring you so far. This article considers the role of Lean as part of a company's overall innovation strategy. It is suggested that Lean principles should not be limited to product development, but concern all aspects of a company's innovation efforts. Furthermore, most studies on LPD tend to place too much focus on the importance of product development with respect to maintaining profitability. The term 'Lean Innovation' reflects a more balanced view, taking into account research, ideation, services, marketing, distribution, and other innovation aspects, which are all critical competitive factors.

Keywords. Lean Product Development (LPD), Innovation, Design management, Engineering design, Customer value.

1 Introduction

Western businesses are experiencing the effects of globalization as new competitors operating from low-cost countries gear up, entering established markets with aggressively priced alternatives. Moreover, the recent economic downturn has impaired markets, which were more or less saturated in the first place. Examples include the automotive industry, textile industries, electronics, and other areas where customers can choose to delay their purchase or settle with pre-owned or low-cost alternatives. How can then businesses operating in high-cost countries stay competitive under such hostile conditions?

The application of Lean principles in product development is perceived by many as the key to maintaining competitiveness in a globalized business environment. LPD advocates, such as Morgan & Liker [1], claim that product development capabilities are a fundamental key to the success of any consumer-driven company. However, imitating the work processes and practice of competitors, essentially Toyota in the case of LPD, can at best only bring you so far. Furthermore, markets defined by companies competing on the same metrics are what Chan and Mauborgne [2] characterize as 'red oceans'. A trend where

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'everyone' seeks to become LPD champion offers little competitive advantage to those businesses already operating in overcrowded markets. Exploring new, untapped market space, 'blue oceans', that offer prospects for profits and growth, calls for innovation efforts beyond product development. Therefore, companies should extend the application of Lean principles into all innovation initiatives, seeking to develop new unique market positions. The notion of 'Lean Innovation' reflects a more balanced concept – one that takes into account research, ideation, services, marketing, distribution, and other aspects, which are all critical competitive factors.

This paper provides and introduction to the principles behind LPD and shows how the concept can be a valuable part of company strategy. An overemphasis of product development initiatives as key drivers in an innovation strategy, however, involves risk of overlooking alternative and better ways of satisfying customers. While 'innovation' is a popular buzzword among business leaders, consultants, and academics, its meanings must be fully understood before its relevance in relation to product development and the notion of Lean can be considered. The meaning of innovation in a business context is therefore presented in Chapter 3. The discussion of Chapter 4 suggests that the 'Lean hype' overemphasizes the importance of product development in relation to other innovation activities by building on what has been presented in the preceding chapters. An example of how companies can improve their 'outsight', as part of a Lean innovation strategy is finally presented, and findings are summarized in the conclusion.

2 From Lean Manufacturing to Lean Product Development

New products and improved production methods made the Japanese industry recover quickly after World War II. Many of these manufacturing principles were already well known in US and Europe, but Japanese companies were able to refine the production concepts to surpass their Western competitors. What we know as Lean Manufacturing today is based on the production system (TPS) of one of the most successful of these companies: Toyota Motor Company. TPS is a well-proven production strategy that originally focused on waste reduction. TPS is probably best known within the automotive industry and represents *the* benchmark for competitive manufacturing across the world. The term Lean Production was introduced in the early 1990s by researches at MIT, and the concept was then extended to the Lean Automotive Factory and later to the Lean Factory in the mid 1990s, changing its focus from waste reduction to cost, quality, and delivery. The next expansion of the concept includes the Lean Enterprise in the late 1990s, before taking the Lean notion into other areas such as product development, accounting, management, research, innovation, etc. in the early 2000s, with the focus drifted to customer value.

It is well known that Lean Manufacturing no longer represents such an exclusive competitive advantage. Lean principles applied in other areas such as product development, may still to some extent influence the rules of competition. Notwithstanding, LPD efforts focus traditionally on reducing lead time and production cost (including development cost), and less on the third dimension of competitive product development: creating outstanding customer value through innovation. For example, Morgan and Liker [1] stated in 2006 that current automotive markets were identified by consumers selecting vehicles "not only on the basis of cost and quality but also on style and features. As a result, most consumer-driven companies must work to meet customer demands by accelerating product development and bringing to market the products that customers want when they want them". This calls for a demand to shorten the time required for product development while delivering high value, not only low price, to customers. Morgan and Liker used the automotive business as example, but globalization makes the concept valid for most companies targeting consumer markets.

LPD aims at delivering customer value with the least amount of waste. Although the concept is derived from production, the basic definitions used to separate waste from value do not apply to product development. Product development is a much more complex 'process' since it – rather than physical parts or objects – concerns the generation and use of information that collectively is applied for reducing the risk of manufacturing a product. Unlike physical objects, information can reside simultaneously in multiple locations and be stored in a number of forms (thoughts, sketches, writing, CAD, prototypes, etc.). In product development waste is typically associated with doing activities with the wrong input rather than doing unnecessary activities as in manufacturing. Moreover, waste removed at micro process level may create waste at system level [3]. The lack of common tools and techniques, along with the complexity of implementing an LPD strategy, means that the concept does provide potential for competitive advantage.

Womack and Jones [4] generalized the characteristics of Lean into five main principles: 1) Definition of customer value; 2) Identification of value stream; 3) Establishing and streamlining flow; 4) Creating pull, following the value chain back to the material supplier, and; 5) Continuous improvements and striving for perfection. They emphasized that activities within a company must be aimed at supporting efforts connected to delivering customer-defined value (1^{st} Lean principle). A value stream is a chain of activities tied to delivering value, and according to Ward [5] businesses must concentrate on sustaining both the operational value stream and the development value stream. "The operational value streams run from suppliers through factories into product features, and out to customers" [5]. It includes converting raw material to products in the hands of customers, and value-creating activities change materials into products that customers pay for. "The development value stream produces operational value streams" [5]. It involves activities from recognizing an opportunity through launch, and includes the generation and use of information that constitute a "recipe for producing a product" [6].

Creating a robust knowledge flow across different development projects is according to Kennedy and Harmon [7] the most important element of an LPD-concept. They introduced the term knowledge value stream, representing the process of generating, capturing, generalizing, standardizing, and (re)using knowledge and information in and between development projects within the enterprise.

3 The True Meaning of Innovation

The word 'innovation' originates from the 16th century Latin verb 'innovare', which translates into 'in to make new' (in- novare). The word may refer to the process of innovating or to the outcome of this activity, which may involve a new method, idea, product, etc. To innovate is therefore to "make changes in something established, especially by introducing new methods, ideas, or products" [8].

Carlson and Wilmot [9] illustrate the lifecycle of a product or service in the form of an S-curve (Figure 1) 'A' indicates the inception of a new idea or concept, which through development becomes a new product or service, working its way up the customer and company value axis. 'B' marks the point of market introduction. The product or process is offered to customers until it reaches maturity, point 'C', where it is either commoditized or obsolete. Ensuring continued profits beyond this point calls for development of new products or services that offer greater value to customers.

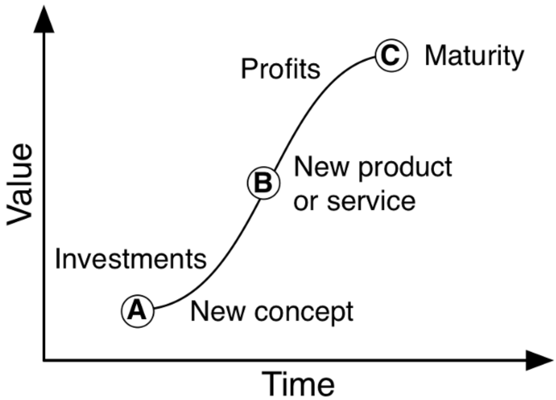

Figure 1. The product or service life-cycle, as reproduced from Carlson [9]

Referring to Carlson and Wilmot [9] *"Innovation is the process of creating and delivering* new *customer value in the marketplace"*. Considering this statement in light of Figure 1, innovation is the process of getting from 'A' to 'B'. According to Huthwaite [10], generating new ideas is easy whereas shaping those ideas into inventions requires more skill. Converting an invention into a successful innovation is even more difficult. This viewpoint clearly identifies innovation as an activity that requires far more effort than just coming up with an idea or an invention. An alternative view from Carlson and Wilmot [9] sees innovation as "the process that transforms an idea into commercial value". While this definition distinguishes idea generation and invention from a separate 'innovation activity', others see innovation as the entire process of idea generation, invention, and product and process development. For example, Hildre [11] states that innovation is the creation and implementation of new or improved products, processes, supply chains, alliances, etc.

The origin of the word 'innovation', 'innovare', does not distinguish between phases of an innovation process, nor does it require a valuable outcome. It simply states that to innovate is to ‘make something into new’. But ‘something’ has to exist as a starting point for the innovation. Both views may be applicable, depending on what we see as the starting point, this being an idea, a need, or a customer want. The following discussion is based on Hildre’s [11] definition, since an innovation process cannot depend on ideas coming about by chance, although it should be able to extract value from them when they do.

Hildre, Andreassen, and Hein [12] [13] use an S-curve similar to that in Figure 1 to explain technology development (Figure 2). Leaps represent the introduction of disruptive or radical innovations. That is, “*innovations that have a disruptive effect on* both *customers and producers*” [14]. Radical innovations break the rules of established markets by satisfying new customer needs or existing needs in significantly better ways. For example, the introduction of the electronic pocket calculator effectively disrupted the demand for sliding rules. Similar leaps can occur in service markets as companies find new or better ways to satisfy customers. Online banking is an example of how customers more conveniently can monitor account balance and make transactions at any time of day without having to visit their local branch. Furthermore, the banks achieve significant savings as they let customers perform a greater share of what used to be their work.

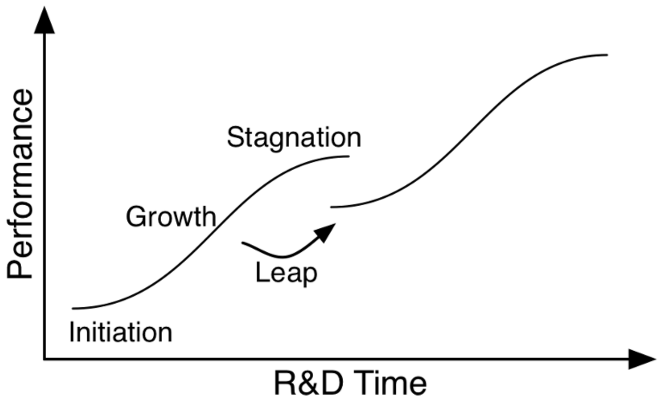

Figure 2. Technology development, as reproduced from Hildre [12]

According to Doblin Group [15], “most companies equate innovation with the development of new products. But creating new products is only one of ten types of innovation, and on its own, it provides the least return”. Doblin’s framework includes ten types of innovation, summarized in **Table 1**. While other sources may suggest different ways of categorizing innovations, the key takeaway is the existence of different types of innovation.

A strategy canvas, as introduced by Chan and Mauborgne [2], is a valuable tool for capturing the state of play within a known market space. The most important competitive factors are identified, and company performance relative to the competition is illustrated by a value curve. Using a strategy canvas makes it easier to visualize the overall picture and answer questions like: “what is really the importance of product performance with respect to our competitiveness?”

Table 1 The ten types of innovation, as presented by Doblin Group [15]

Innovation category	Innovation type
Finance	1 Business model
	2 Networks and alliances
Process	3 Enabling process
	4 Core processes
Offerings	5 Product performance
	6 Product system
	7 Service
Delivery	8 Channel
	9 Brand
	10 Customer experience

4 The Real New Frontier: Lean Innovation

Morgan and Liker [1] have stated that "given the dramatic changes in the automotive product development environment, it is obvious that a strong product development system is a crucial core competence and fundamental to the success of any consumer-driven company… In fact, it can be argued that product development will become the dominant industry competence within the next decade".

What Morgan and Liker describe is a red ocean type of market, which according to Chan and Mauborgne [2] is characterized as existing markets where industry boundaries are defined and accepted, and the competitive rules of the game are known. "Here, companies try to outperform their rivals to grab a greater share of existing demand. As the market space gets crowded, prospects for profits and growth are reduced" [2]. Blue oceans, on the other hand, represent untapped market space, usually created by expanding existing industry boundaries.

It is felt that Morgan and Liker [1] overemphasize the importance of product development. The same comments apply to Ward [5] who fails to see the development and operational value streams in relation to innovation areas aside from product performance, "Development has value only if it enables operations to deliver better products to the external customer" [5].

Doblin Group underpins that a company can innovate in ten different areas, and that product development typically is the least profitable one. Considering that "Innovation *is the process of creating and delivering new customer value in the marketplace"* [9], main profits for an automotive company may not necessarily have to come from manufacturing and selling vehicles. Exploring other ways to satisfy customer value may even increase the likelihood of coming up with new product opportunities. Apple realized this with the introduction of the iPod. The iPod is not sold as an independent product, but rather as part of a bundle that includes iTunes, a media player closely integrated with Apple's online music store. Attempts to integrate iPod and iTunes into a complete package are apparent from looking at Apple's web site, where they are marketed under a common title: 'iPod + iTunes' [16]. Realizing how innovation involves more than just product performance, Apple continues to dominate the personal audio market by combining product and services into a broader customer experience.

The strategy canvas described in Section 3 is an excellent tool for benchmarking competitors, but it offers few pointers in terms of what exact measures can be implemented to create blue oceans. Introducing Doblin's ten innovation types as benchmarking categories in the strategy canvas helps solve this problem. The outcome is a universal metrics that can be used for any industry. Figure 3 shows a 'before and after' strategy canvas, which was developed as part of a joint project between the Norwegian boat manufacturer Hydrolift, and NTNU (Norwegian University of Science and Technology). The general state of the boat market was benchmarked against leading companies within each innovation category. It is worth noting that none of the reference companies, the 'innovation benchmarks', operate in industries with any relation to the boat market (e.g. automotive, computing, hotel business, agriculture, etc.). Looking at their existing practice would therefore provide new insights as to how Hydrolift could benefit from leading edge practices. The strategy canvas becomes what Huthwaite [10] would refer to as an 'outsight tool'. That is, it supports "going beyond our experience and knowledge to explore new ideas from different industries that have already solved the problems we are just now facing" [10].

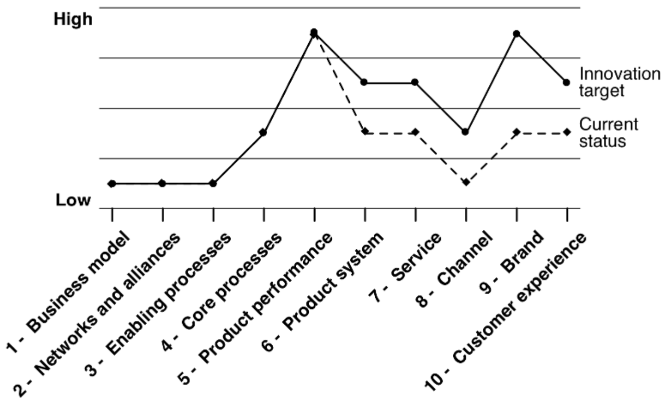

Figure 3. Strategy canvas from the Hydrolift project

5 Conclusions - What is the Value of Lean Product Development?

Companies that rely on LPD as the only means of achieving competitive advantages are failing to realize the myriad of other ways to satisfy customer value. However, since more 'products more often' is anything but what is needed for staying competitive, what is the value of Lean Product Development? Morgan and Liker [1] argue that consumers want the latest style and features. However, the iPod example of Section 4 demonstrates how Apple has remained the market leader by introducing only a few incremental innovations to a system of services and products, and brand that was extremely well-designed in the first place. Apple understood the true meaning of customer value, and how to deliver that value through innovations in a number of categories (ref. **Table 1**).

Lean Product Development is only part of the equation. The term 'Lean Innovation' provides a more complete picture of how Lean principles should be applied in maximizing customer value. Some might argue that innovation strategy is management's responsibility. While this may be correct in some cases, product development teams still have to approach their task in light of how the customer perceives the end product as part of a greater experience. This includes business model, service, brand, and other aspects. The iPod's success is an exellent example of what can be achieved when a company coordinates innovation efforts to create a complete user experience.

Maintaining a more-products-more-often type strategy will in many cases result in markets and ultimately junkyards overfilled with obsolete technology. Such a philosophy has nothing to do with satisfying customer-defined value!

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Identifying Lean Thinking Measurement Needs and Trends in Product Development: Evidence from the Life Sciences Sector in Switzerland

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Abstract. Measuring the implementation of Lean principles constitutes a major challenge for many organizations. Several frameworks and tools have been developed and proposed, but no one has shown full success to specifically focus on measuring lean in the product development process. In order to fulfill this opportunity, one of the results of the LeanPPD FP7 project funded by the European Commission, is to develop a self-assessment tool to enable companies to assess their maturity and readiness for Lean implementation and guide them through the implementation process with both qualitative and quantitative measures. In parallel to the tool development, an exploratory research was carried out to understand the current practices and tools firms use to measure their lean implementation and to identify their needs. Therefore, this paper aims to diffuse the findings of how companies are measuring the progress of Lean thinking implementation into their product development. The data was gathered from five highly innovative companies from the Life Sciences sector located in Switzerland.

Keywords. Lean principles, Product development process, Life sciences industry, Lean implementation measurement, Balanced scorecard.

1 Introduction

In order to bring more insight on the needs of highly innovative companies for the development of a framework and tool to self-assess the implementation of lean principles into their product development process, an explorative research has been carried out in five highly competitive international companies located in Switzerland. This work is part of the LeanPPD FP7 project whose challenge is to deliver new tools to establish a lean product & process development by implementing lean thinking principles.

Various studies have been published on Lean Product Development (LPD) and components characterizing a Lean product development have been described.

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However LPD has not yet reached the same success and top performance level as it is the case for Lean manufacturing. Numerous efforts have been spent to identify the best practices of Lean product development systems. However the important question of how companies successfully introduce and enable their self-assessment on their Lean product development journey remains largely under-investigated.

As a result, the work provided in this paper aims at examining the State of the Art concerning lean thinking implementation and measurement in the product development process. Specifically, it is investigated which Key Performance Indicators (KPIs) may be useful for a successful measurement of Lean principles in product development, and which tools companies are currently using – if they do use any – to assess their Lean performances and implementation progress. Especially, the potential of implementing the Balanced Scorecard concept which would be specifically designed as one of the tools of the LeanPPD project.

2 Latest Findings in Lean Product Development

2.1 Definition and Challenges of a Lean Product Development Process

Since Womack and Jones described their five Lean principles [1], they have been successfully applied to manufacturing and many references are available with the validation of such outcomes. However, there results are not the same for product development.

The five principles described by Womack and Jones [1] – i.e. *Specify Value*, *Identify the Value Stream and Eliminate Waste*, *Make the Value Flow*, *Let the Customer Pull the Process*, and *Pursue Perfection* – provide a simple structure for building a detailed route map for any organization wanting to apply Lean Thinking to a business process. However, these principles are not completely applicable to PD without adaptation. LPD aims at helping companies to develop a flowing PD value stream with minimal waste, defined and pulled by the customer.

Managers tried to apply Lean thinking to product development with the same core principles (uninterrupted flow, eliminate all non value-adding processes) but results were not as good as in manufacturing [2]. One reason for this may be principally because Lean implementation in PD requires whole organization-wide changes to systems, practices and behaviors that are not easy to accomplish.

Despite the basic principles remain the same, lean manufacturing and lean product development require different methodological approaches.

2.2 Lean Product Development Characteristics

Whereas Lean Manufacturing is a subject that is well defined, has been successfully implemented, and results have been shown, for LPD requirements are different. Several publications on the topic exist, but it there is no unique, or at least general, explanation of Lean principles specific to the Product Development process or clear and structured implementation method.

It should be noted that rarely the writings of the different authors on LPD are based on empirical data. They used to make observations and conclude with theoretical ideas on LPD characteristics which are rarely verified experimentally. Moreover, they all tend to remain vague on how to concretely implement the principles they claim to be the basis of a successful LPD process.

In addition, even if there may be some overlap between the principles described by the different authors, the focus and the number of components varies from one author to another. Among the wide range of definitions, the set of principles proposed by Morgan and Liker [3] appears to be one of the most complete.

In their book: "The Toyota Product Development System: Integrating People, Process, and Technology", Morgan and Liker listed 13 principles that must be applied to the product development system in order to achieve a Lean PD.

According to the authors, in a Lean Product Development system model, there are 3 subsystems which are interrelated and interdependent affecting the organization's ability to achieve its external purpose: Skilled People, Tools & Technology, and Process [4]. Each subsystem is then comprised of different principles.

The Process Subsystem – It includes all the tasks necessary to bring a product from concept to production.

Principle 1: *Establish Customer-Defined Value to Separate Value-Added Activity from Waste*;
Principle 2: *Front-Load the Product Development Process While There Is Maximum Design Space to Explore Alternative Solutions Thoroughly*;
Principle 3: *Create a Leveled Product Development Process Flow*;
Principle 4: *Utilize Rigorous Standardization to Reduce Variation, and Create Flexibility and Predictable Outcomes*;

The People Subsystem **–** It covers recruiting, selecting and training engineers, as well as leadership style, organizational structure and learning patterns.

Principle 5: *Develop a Chief Engineer System to Integrate Development from Start to Finish*;
Principle 6: *Organize to Balance Functional Expertise and Cross-Functional Integration*;
Principle 7: *Develop Towering Technical Competence in all Engineers*;
Principle 8: *Fully integrate Suppliers into the Product Development System*;
Principle 9: *Build in Learning and Continuous Improvement*;
Principle 10: *Build a Culture to Support Excellence and Relentless Improvement*;

The Tools and Technology Subsystem

Principle 11: *Adapt Technology to Fit Your People and Processes*;
Principle 12: *Align your Organization through Simple, Visual Communication*
Principle 13: *Use Powerful Tools for Standardization and Organizational Learning*;

As this model can be considered as one of the most complete and diffused ones, it has been taken into consideration as the first input for the LeanPPD project and the development of the questionnaire designed for this research.

2.3 The Balanced Scorecard as a Framework for LPD Implementation

The Balanced Scorecard (BSC) is a management tool used for measuring the performance improvement of an organization. It is a framework focusing on combining financial as well as non-financial measures of performance in one single scorecard.

In its original form, the BSC includes performance measures for four perspectives and requires developing appropriate objectives, target values and initiatives needed to achieve target for all 4 perspectives:

- Customer perspective - (factors that really matters for customers)
- Internal Business Perspective - (processes that have the greatest impact on customer satisfaction)
- Innovation & Learning Perspective - (ability to innovate & improve)
- Financial Perspective

Companies tend to focus on the BSC because it has an easy-to-understand design, a more formalized process of performance management and a linking strategy with measures and outcomes [4].

Starting from the State of the Art about Lean Thinking, Liker's thirteen principles, and the BSC as the framework of reference, the goal will be to build an effective and powerful tool that will help companies assess their level of Lean implementation in the PD process and guide them from this point to the complete and finalized implementation, independently of the company's progression in the lean journey – i.e. starting the transition or almost done.

Some modifications and adaptation will be required in order to make the BSC designed for lean implementation in the PD process. The main modification will be in its perspectives: Indeed, when thinking in terms of the Liker's thirteen principles, they do not fit into the traditional perspectives. New ones must be created in order to take the value and waste aspect in the PD process.

Based on previous work, the LeanPPD consortium agreed on the following perspectives: *Skilled People – Tools & Technology – New Product Development Process – Cost & Time*.

This framework will come with a list of measures and a complete list of Key Performance Indicators (PKI) to be adapted to the companies' different needs.

In addition, many softwares exist to implement scorecards, performance dashboards, and strategy maps; however none are especially designed for Lean implementation and measurement. This is one of the challenges of the LeanPPD project.

In order to better understand and define the needs of companies for a set of tools to prepare them for the organizational change inherent to lean thinking implementation, to guide them through the implementation process and keep track of their progress until success achievement, an exploratory survey has been undertaken and is described hereafter.

3 Exploratory Research on Lean Measurement & Implementation in Product Development

The four main objectives of this study were to investigate the following points:

1. *To what extent are the 13 Lean principles proposed by Morgan & Liker applied to the Product Development process?*
2. *To assess the measurement of Lean in a different sector rather than the ones usually investigated, in this case Life Sciences.*
3. *To determine if and with which tools (softwares) do companies measure their level of Lean principles implementation.*
4. *To identify which are the most relevant KPIs companies think they should measure to track the lean principles implementation in their product development process*

A detailed questionnaire has been designed and submitted to a small sample of companies in the Life Sciences sector in the French speaking part of Switzerland. Among the twelve companies contacted, five returned the questionnaire and in one case, a face to face interview has been carried out to bring more details to the analysis. The five companies are competing in specific sectors of the Life Sciences industry: Medical Devices, Food, Pharmacology, Chemistry, and Biotechnology.

3.1 Lean in Product Development

In this section, interviewees were asked to assess to what extent the concept of "Lean" is defined and applied in their Product Development department. More precisely, some examples of the questions were: "*If companies have implemented a PD process mapping tool*"; "*How clear the definitions of PD waste and value are*"; "*What are the potential PD wastes identified*"; "*How clear the Lean concept is*"; and "*The level of implementation of Liker's 13 principles*".

Results from this first part of the survey show that process mapping tools are commonly used in the five companies. However, despite the PD process is mapped, the general tendency is that companies have difficulties in clearly defining which activities in PD add value to the product, and what are the PD wastes, even if in the latter case, things seem to be a bit clearer.

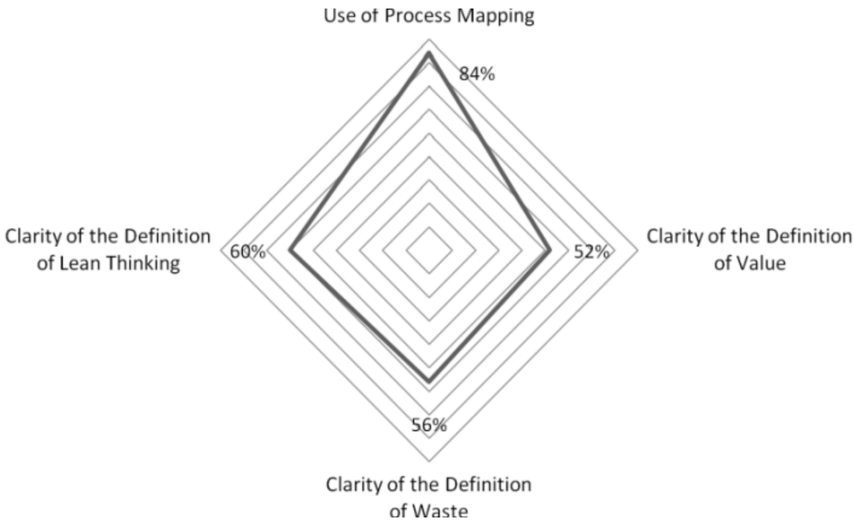

Figure 1. Weighted result of how clear the concepts of waste, value, and Lean are for the companies, together with the use of process mapping.

The next question investigated to which extent Morgan & Liker's 13 Lean principles are implemented in the five companies' product development process.

Results showed that there is not any common tendency among the companies while implementing one or the other. This would indicate that this process in fact depends on the specific needs of each of the single company. Therefore, a methodology to implement Lean in the PD should thus be customized according to their specific needs.

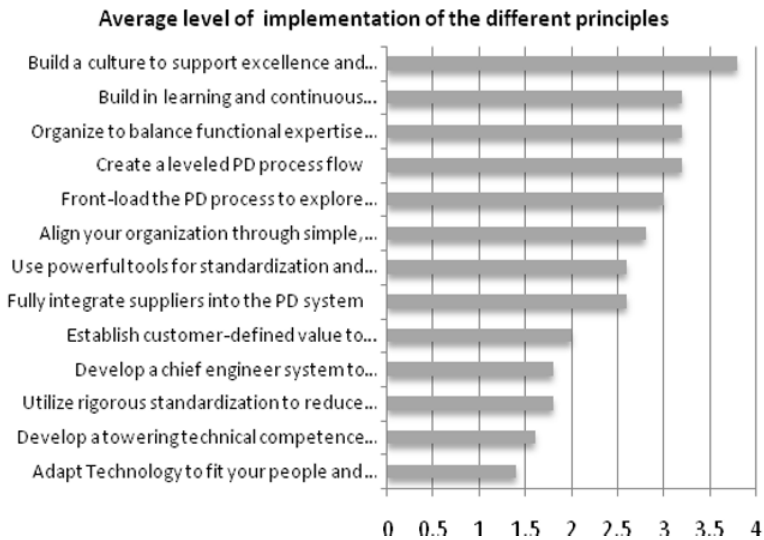

Figure 2. Average level of implementation of Liker's principles in the different companies

In figure 2, the average degree of implementation is shown indicating the tendency that companies have to implement Lean principles. Although principles are heterogeneously implemented, fig. 3 shows that companies give preference to continuous improvement related principles, as well as creating a leveled workflow and organizing cross-functional teams. Other principles are more heterogeneously applied.

3.2 Lean Self Assessment

Results from this section showed that the BSC is a widely used tool to manage general performance, indicating that companies are using this tool and would probably feel comfortable to use it in a Lean context.

Concerning the question if companies use or have used specific methodologies ***to implement*** Lean thinking in their PD process and if they ***measure*** the progress of the implementation process, the results are:

- Not implemented "Lean" in PD (3 cases)
- Hired an external consultant (1 case)
- Used the SAPTM NPDI solution (1 case)
- Do not measure the progress of implementation because they have not implemented Lean principles strictly speaking (3 cases)
- Do not measure the progress but would be interested to do it (1 case)
- Use the LESATTM method (1 case).

3.3 Lean Key Performance Indicators

To assess the importance of KPI's to track the implementation process thanks to the modified BSC, results show that companies have not established a list of KPI dedicated to Lean performance measurement (even if they may use KPI to measure PD performances). When questioned, the KPIs they value the most for this purpose are:

- Quantitative**:**
  - Time reduction;
  - Product launched on time;
  - Number of returning designs;
  - Percentage of design re-use;
  - New product cost reduction:
  - Percentage of training participation.

- Qualitative:
  - Use of Value Stream Mapping;

- Participation of customers in PD;
- Integration of partners & suppliers;
- Spread of Lean culture;
- Employee motivation.

3.4 Tools to measure Lean Implementation Status

The last section of the questionnaire concerned the evaluation of different softwares to implement Balances Scorecard (BSC). Among a list of softwares provided, four companies mentioned they have not heard before and only in one case three software were known. However, none of these softwares were used in the interviewed companies. In one case, a software tool that creates dashboards and reports, the "Tableau Software", is used to manage PD performance, but not to measure lean implementation.

Other results showed that the attributes companies value the most on IT tools to measure their progress on lean implementation are: A reporting system, visibility, compatibility, time consideration, data integration, access control, availability of training material in different languages, a library of KPI, support.

4 Acknowledgements

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5 Conclusions

Companies' awareness for better PD performances achievement through application of Lean thinking is clearly established. However companies tend to implement Lean principles heterogeneously and by various means. There is a clear feeling that there is a lack of a standard and successful method to guide companies through the organizational change which is required with Lean implementation.

The five surveyed companies are all managing in one way or another to improve their PD performances by applying Lean principles. However the implementation is neither applied to the whole PD process (or simply not applied in PD) nor completely applied (i.e. implementation of all principles), while it has been shown that to achieve success both should actions should be undertaken.

In addition, companies do not really assess their level of implementation of Lean thinking into their PD, indicating a lack of a solid framework to guide firms through this organizational change.

The results have also highlighted the fact that the principles that are mainly implemented are the ones concerning the continuous improvement process, cross-functional teams, workload leveling, and concurrent engineering. More technical principles, like adapting the technology, process standardization, developing technical specialist, etc., have less success in these companies.

This may be due to strategic choices, resources limits or simply because of a lack of a common and standard method to perform Lean implementation in PD.

Results also showed that BSC is a commonly used tool in these companies. Its use as a Lean performance management tool may thus have a good acceptance through these companies. Except the LESAT method in one case, the companies do not measure their progress of Lean implementation, for two reasons: first because they may not have implemented Lean in Product Development (PD) yet, while being interested, second because they do not know how to do it. Both cases indicate the need of a framework to implement Lean thinking and measure the implementation progress.

The State of the Art concerning how companies measure their level of Lean implementation progress is established by showing that no measurement system exists to fully track the Lean product development implementation. Some methods are indeed used to help companies through the implementation process, sometimes external consultant, sometimes other methods (programs, softwares, etc.).

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Applying the Core Elements of a Lean Enterprise to Product Development

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Abstract. In the last 20 years lean thinking has found more and more applications in areas beyond manufacturing. Altough the benefits of lean thinking in product development have also been widely recognised, a more fundamental set of principles is required that has been derived from established lean enterprise values. In this paper the authors discuss the complex nature of the development or product creation process and derive these principles accordingly.

Keywords. Lean Mangement, Lean Enterprise, Lean Product Development Process, Product Creation Process, Core Elements, Company Values, Continuous Improvement Process, Porsche

1 Introduction

In the last 20 years lean thinking has found more and more applications in areas beyond manufacturing such as administration or sales. It has also been recognised that lean thinking can provide significant benefits in the product development process [1]. Various methods and tools have since been developed to improve quality [2], reduce cost and throughput time [3] throughout the product development process. Other work focuses on improving the product itself for lean manufacturing, service or other life cycle phases [4, 5].

The understanding of lean thinking within product development was deepened through researchers and professionals working on the field in recent years. However, previous work on the topic of lean product development mainly focussed on tools or specific methods to improve development processes. Although principles have been defined for product development [1], they have been based on specific tools or mechanisms. A more fundamental set of principles is required that has been derived from established lean enterprise values. Lean principles in

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development need to be further understood, as they set the basis for the appropriate selection of methods and tools.

In this paper the authors discuss a lean enterprise framework and how within this framework lean principles are related to a set of values for the entire lean enterprise. Based on these values the paper continues to derive fundamental principles for lean development.

The concepts discussed are a result of Porsche Consulting's experience in implementing and improving lean product development systems at over 50 clients. Based on this experience the authors discuss key aspects for applying the derived principles in practice.

2 A Lean Enterprise Framework

Lean thinking has developed over the last two decades as improvement initiatives moved outside of out of manufacturing. The resultant principles for the individual areas need to be orientated to a set of values valid for the entire organisation. These values should be supported by appropriate principles, methods and tools, which are often very specific to the functional or business areas they are applied to. The relationship between these elements can be placed within what the authors refer to as the lean enterprise framework. The pyramid in Figure 1 illustrates how values, principles, methods and tools relate to each other.

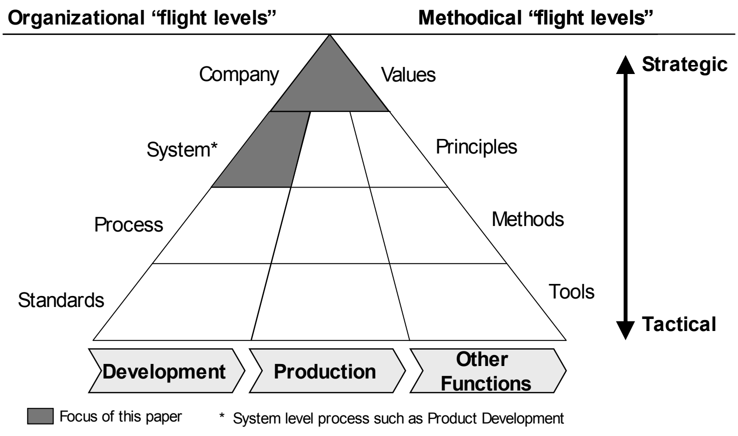

Figure 1. Lean Enterprise Framework

The farther away from the primary values the elements in the pyramid are, the more specific, or granular and therefore tactical they become.

Lean Enterprise values should bind the business together and enable it to move in one direction. As they represent the primary values of an organization they too define what the culture is desired to be. They are also a set of criteria to constantly evaluate whether the activities undertaken in the organization are lean. The

conclusion that can be drawn from this is that lean is firstly an encompassing management philosophy rather than simply a tool set.
The values of a lean enterprise defined by Porsche Consulting are discussed in the next section.

3 The Four Core Elements of a Lean Enterprise

Porsche Consulting has defined four core elements for the lean enterprise [6]; Focus on Value, Transparency, Synchronisation and Perfection. The first of the elements is the Focus on Value. Value is the portion of any activity that brings the benefit to the customer. This means that the customer, whether internal or external needs to be identified so that the value they perceive can de defined. This should be described in objective terms and represent the long term benefit. The second and third elements, Transparency & Synchronisation can be considered together and describe how the organization should work and communicate together. Transparency means striving to make the activities and the results transparent to all stakeholders. Expressing targets, results and deviations quantifiably, in a way that is swiftly comprehendible to all is integral to transparency. Synchronisation means linking and synchronising activities and aligning supply and demand along the value chain with customer demand. Linking activities in such a way requires clear definition of responsibilities. Perfection means the strive for perfection and never being satisfied with the status quo. Being able to determine what the status quo is and if improvements have, in fact, been made requires the use of standards throughout the business.

4 Deriving Lean Principles for Development

The ‘Product Creation Process (PCP)’ or Product Development Process, describes all the activities of an organization that are required to create new products up to the start of production [7]. The title ‘Product Creation Process’ is descriptive of the wide range of activities within this process as opposed to the narrower range of activities traditionally associated with product development such as design and testing. There are many generally accepted definitions similar to the one above, which take this wide range into account [8, 9].

Product development is fundamentally different to other processes within the organization such as the production process or administrative and sales processes. In production process, the tangible is being examined. The process can be readily viewed and measured. In general, the process contains a sequence of discreet steps and produces many finished products. In sales and administrative processes the physical products are replaced by abstract or virtual ones. In each process there remains a sequence of discreet steps and many finished products are produced (e.g. orders, invoices, applications processed).

The PCP, however, is generally one large dynamic system with very highly interrelated and interdependent elements producing very few finished products (e.g. designs ready for production). The information within the system matures as it moves from being an idea or concept to being of sufficient quality so that the end product specified can be manufactured. The information gains in maturity as it is exchanged, processed and specialised knowledge is applied. The highly interrelated nature of the PCP means that the information produced from one discreet step is not just the input for the next step but forms the constraints for many other parallel processing steps. This is a dynamic process in which the overall maturity of the end product is the sum of the overall maturity of the information within the system. The criteria to determine if the maturity of the various pieces of information is consistent with the targets set i.e. meets the quality requirements, for a specific point in time are also based on knowledge [8]. Therefore, the PCP must be treated as one system and this level of complexity requires an approach different to that of other business areas.

The fundamental problem in considering the PCP is how to approach understanding the entire process itself. This can be done by defining a set of principles derived from company values (see chapter 2), which can be used as a guideline. These can then be used as a reference to quantify the current state, define an idealised state and define improvement goals. A conclusion from this is that because the PCP is fundamentally different to the other types of processes, applying principles, methods and tools developed for other business areas to development is not appropriate. Drawing parallels from the principles or methods from other business areas may help to illustrate but should not be used as the base to define a set of principles for the PCP.

One difficulty that will be encountered in defining principles for the PCP is that the Lean journey usually begins in the Production area, the Porsche Turnaround being a good example of this [6]. As the highest amount of added value for the customer is generated in production, this is natural. However, this means that principles for production will, most likely, exist before a set of values that are consistent with a Lean enterprise. The following chapters discuss the principles as defined by Porsche Consulting derived directly from the core elements.

4.1 Principle for Focus on Customer Value

Principle: For the PCP to work in a value orientated way, customer requirements must be systematically identified and converted into measureable targets.

There are two customers that need to be considered, the external and the internal.

Considering the case of the external customer first, their requirements need to be systematically identified in terms of Quality, Cost, and Delivery Service (QCD) [10]. Quality can be defined as fit for purpose [11] and this applies to functionality or features. This means that the product should provide and fulfil the functions that the customer requires, no more, no less. The cost is the price that the customer is willing to pay for the amount of functionality and features provided within that market. As the market is the driving factor, the point at which it requires new products is defined by market cycles.

In much the same way the case of the internal customer can be considered in terms of QCD. As discussed above it is information that moves through the PCP and is exchanged between employees. Therefore it is the 'fitness for purpose' of the information to the internal customer which needs to be considered in terms of quality.

Once customer requirements have been determined they need to be converted into measureable targets. In the case of the external customer these need to be derived top-down as opposed to bottom up, or in a 'solution neutral' fashion. For example, for a sports car one may determine the need for a top speed increase because competitor's top speeds are increasing and it is important for customers that their cars are as fast. How this requirement is fulfilled, by say aerodynamic improvements, different gear ratios or more horsepower is irrelevant when specifying the need or function. Bottom up would be specifying a top speed increase because the engine group happen to be working on options for a more powerful engine. In practice a reasonable number of high-level 'product attributes' should be derived which can be tracked during the development process [13].

For internal customers, assessing the quality and maturity of the information during the development process is difficult. Standards are required to determine if the information is actually as mature as it is supposed to be at a particular point in the development process. Standards are based on knowledge that has been gained and recorded. The standards need to be put within a framework that can ensure that the maturity of the various pieces of information constituting the overall product are synchronised along the PCP (see 4.3). In practice, the product attributes and the standards used to assess informational maturity can be used to set up a balanced set of Key Performance Indicators (KPIs).

4.2 Principle for Transparency

Principle: Transparency is the key to creating a common understanding of the process itself and the status of the products being developed within it.

As has been discussed above the PCP system is very complex. The size of the system increases with the complexity of the products and the number of products being developed simultaneously. The challenge is to make the system comprehendible to those working within it. To create a common understanding requires that the information being conveyed about process or status is readily understandable by all and is objective.

A process contains three main elements, the process description, the execution organisation and the status reporting system; a transparent process description that contributes to creating a common understanding will have the following qualities; it can be viewed in its entirety on piece of paper, it will have summarizing elements that show the main phases of the process, it will show the main deliverables and delivery points. The organization should be defined after the process has been described. It is logical that roles and responsibilities can only be described after there is a common understanding of the process. The roles need to be clearly defined and not overlapping. Both the organizational structure and the role descriptions should then be made available in a clear format.

To manage risk during the development process it is necessary for deviations to the planned maturity to be immediately apparent. Creating transparency on status reporting requires that the value add for the customer of that reporting be defined.

There is no value add in generating or reading reports, the added value occurs when the information that is contained within them is understood by those receiving the report and this causes the appropriate reaction. As mentioned above, a reasonable set of KPIs supports this but also an objective culture where the conclusions drawn are themselves objective. The information relevant to the receiver needs to be collated in a clear and readily viewable format. This then allows focus to be put on the deviations or problems.

In essence, not having the appropriate transparency causes waste. For instance, if the process description is not transparent, it is unlikely that the process will be followed. The resulting loss in efficiency is waste. If standards are not clearly defined and made available the knowledge contained within them is wasted [8].

4.3 Principle for Synchronisation

Principle: For the efficient operation of the PCP, the activities and the maturity level of information must be synchronized

As the various pieces of information move through the system, many teams or individuals will depend on the outcomes of other processing steps as part of the input for their own step. In turn, their outcome will be the input for several more. To avoid waste, it is essential to synchronize the level of maturity of information between sub-processes while having the maximum amount of teams working in parallel.

Introducing a takt (or cadence) is an effective way of supporting the synchronisation of the level of maturity of information. This introduces regular points at which the exchange and handing on of information occurs between individuals and teams. The standards mentioned previously to objectively determine maturity and therefore quality, can be orientated to theses points. Placing the points within the overall framework of the process description will help to maintain a uniform overall level of maturity. For example, if one group or team works ahead of the rest it will have to make assumptions it would have gotten to continue working. If, at a later time when the other teams have completed their tasks, these assumptions prove to be incorrect, re-work occurs. If a team falls behind, the whole project will have to make assumptions and this may cause re-work for the whole project. The authors' view is that missing synchronisation is the primary cause of waste in the PCP.

The effective exchange of information between individuals or teams enables a true parallel working modus. In practice, different teams will need to work more intensively than others at different points in time during the process. There will also be an inherent sequence to the overall process. The effective exchange of information along the whole process regardless of work intensity or sequence needs to be ensured. Therefore all teams must be represented along the process and there must be a parallel start and end for all groups. To achieve this, multi-disciplinary teams representing each interest with sufficient depth and diversity of expertise should be established that stay together for the duration of the project [12].

4.4 Principle for Perfection

Principle: A stable and well defined PCP is the base for a structured continuous improvement process

The principles provide a good reference for Continuous Improvement (CI). Basic improvement theory dictates that the principles be referenced regularly to ensure that after each activity an actual improvement has been made that contributes to the overall improvement direction. This requires that CI be conducted systematically by means of a Continuous Improvement Process (CIP).

In essence, defining a process description, the roles and organisation and status reporting system, is defining part of the necessary standards for the PCP itself. It is necessary for these standards to be implemented and the process to be running stably so that the standards can be used as a base for CI activities. Without this stable and measureable base it will be impossible to determine if the CI activities have contributed to improvements in the principles or not.

To effectively conduct CI in development, holistic or system level thinking is necessary. Improving stable and transparent processes systematically will lead to iterative improvements in the process. However there needs to be an overall vision of what the future process should look like so that the performance of the PCP can move beyond the iterative improvements. Only through a transparent overview of the process that allows the process as one system to be understood and discussed effectively, can this vision be determined. The vision should address key questions such as, for example; where are the optimal points for peak resource use in the process, in which phases of the process should set-based concurrent engineering be practised, where should major milestones be positioned in relation to the start of production?

5. Putting the Principles into Practice

All of the principles are of equal importance, however, in practice priorities need to be set and a starting point needs to be found. Due to the complex nature of the PCP, starting with transparency makes most sense. A basic overview of the process is thereby created that then allows synchronisation to be applied. The challenge is that in order to change the system, large change activities need to be undertaken at overall system level and they can take a considerable amount of time and resources. This presents a number of problems. Firstly, isolated ‘bottom up’ changes rarely have any significant effect on overall performance. Secondly, in large development organizations, the effects of system level changes are too distant from most employees in the system for them to see change and react to this. Thirdly, it is necessary to establish visible success quickly in order to keep motivation high. Experience has shown that a parallel approach works best. At employee level, ‘lighthouse’ workshops should be conducted to establish success and culture quickly and prove to the employees that the methods and tools work. At system level, the work can begin to create a process description, define the roles and organisation and define the status reporting system. At Porsche Consulting this overall approach is contained within the PCP-Systematic.

6 Conclusion

Due to the fact that the PCP is one large dynamic system with very highly interrelated and interdependent elements, the way it is treated should reflect this. If such a system is to be understood and improved, it needs to be treated as a large abstract system. Principles defined for the PCP should reflect the nature of the PCP and be the guide when changing and also provide the goals for change. Deriving the principles directly from lean enterprise thinking rather than from other business areas ensures that the principles are applicable to the PCP. This provides a better understanding of how appropriate tools and methods should be selected.

Through a holistic understanding of the PCP, a lean vision for the process can be determined and performance improvements can be achieved beyond those of iterative improvements.

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Part VI
Mass Customization

Collaborative Design of Modularized Set-Meal Using the Mass Customization Concept

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Abstract. A chain restaurant's meal creation is a complicated process including tasks, such as the concept proposing, ingredient specifications, evaluation, and presentation design. These tasks are often cooperatively accomplished by staffs in the headquarter and its branches. However, the decisions of meal creation need to refer to the related data (such as customer preferences and feedbacks) that are often not organized, controlled and shared properly using the current product information management (PIM) solutions. The paper overcomes the current PIM deficiency by reengineering the set meal design process and its integrated information management. Using the modularized bill-of-materials (BOM) data management concept, we develop a decision support system for set meal design, called Collaborative Meal Planning (CMP) system, to enhance the efficiency of the meal planning and design process. Finally, the design interactions between headquarter and branches are studied to show the benefits in applying CMP. In the first phase of the study, the current data exchange model is derived. In the second phase, the to-be CMP-based meal design process is developed. In order to evaluating the performance of the proposed models, the case of a Japanese high-end chain restaurant is used to demonstrate the to-be CMP model at works with superior results.

Keywords. Mass customization; modular design; collaborative meal planning (CMP); mass customization

1 Introduction

The Group of Shintori is established in 1996 in Taipei. Through 14 years of development, Shintori Group now has two brands of restaurants, which are Shintori and People restaurants. They have 3 branches in Taipei, including Shintori No.3, Shintori No.4 and People No.5. There are 4 stores in Shaihai, China. The different strategies are implemented when position each branch to the market.

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Therefore, each branch has different decoration and food designs. The style of Shintori belongs to post-modern decoration. Rather than Shintori style, People restaurants possess the decorative style of minimalism. Shintori chain provides Japanese cuisine while People chain provides creative Chinese cuisine [1].
Managing the product data is a complicated challenge for restaurants, which need to change their monthly designs of set meals to stay competitive in the high-end sector. The current processes of meal design involve making meal list, appearance revising, photographs, meal testing, cost analysis, price setting, and integrated data management. Therefore, each stage will need all information to be recorded and, possibly, shared by other staffs. The related information includes the materials (BOM) list, the meal category rules, material costs, dish menu, recipes, and meal sampling results.

2 Literature Review

The process of set meal design can be treated as other consumer product design. Some academic research has classified the design efficiency and efficacy issues under the topics of modularity design and collaborative product design. In this section, we review the related research in the area.

2.1 Modular design

Huang and Kusiak [2] indicated that product design uses the modularization approach can reduce the time and cost of product development. Salvador et al. [3] also depict that product design based on modularity concept can simplify design activities. Using the modules that have been created to support product development can eliminate the designs of detailed modules. Nobelius and Sundgren [4] have focused on sharing common components and production processes for family of products.

2.2 Collaborative product design

Globalization and rapid adaptation of Internet and Web-based technologies have completely revolutionized the product developing process [5]. A collaborative environment, integrating diverse information systems, can enable the creation of a virtual enterprise to effectively and efficiently share their data and knowledge while working together. Knowledge-intensive collaboration design has shared the information in the entire design process via the web interfaces [6]. The design models and tools that base on the heterogeneous knowledge base can assist designers to evaluate their design program with different perspectives.

3 The As-Is Model for Set Meal Design

This section introduces the meal design as-is model using the INCOME behavior modeling tool. INCOME is a software used to construct business behavior, organization and information (object) models. It can also simulate the process for the process performance evaluation. With the clear views of as-is model, we can, then, improve the process by proposing a creative to-be behavior process to enable the modularized set meal design.

3.1 Behavior model for current set meal design

Figure 1 and Tables 1 and 2 depict the as-is meal design process (behavior) model, the drill down sub-processes, the consisting activities, and the related data entities to be managed and integrated by the CMP system (in the to-be model).

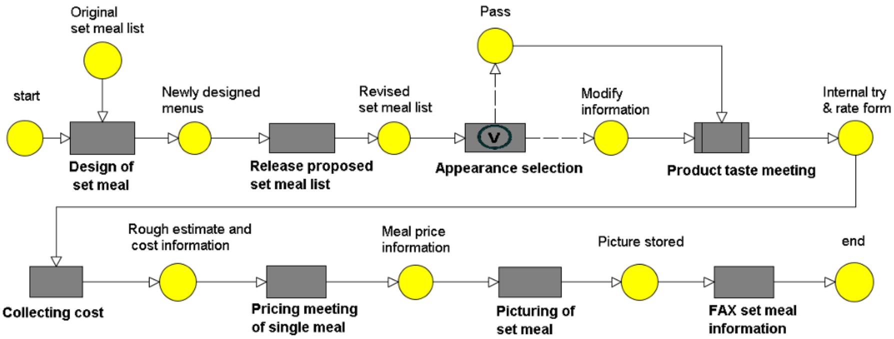

Figure 1. The current process model in set meal design process

Table 1. The as-is behavior model activity details

Activity	**Description**
Design of set meal	1. Chef has to re-design the menu of set meals monthly. 2. Chef can collect the recipes being used in the past as a reference for new one.
Release proposed set meal list	Chef releases the list of newly-designed set meals.
Appearance selection	Headquarter decides the appearance of the newly-designed set meals.
Product taste meeting	Chief chef, consultants, branch managers and staffs attend meal testing and refine the newly-designed set meals.
Collecting cost	Chief chef inquires material cost estimation from suppliers and delivers the information to headquarter.
Pricing meeting of single meal	Headquarter arranges price setting of each set meals according to material cost information.
Picture of set meal	Branches photograph of each set meals.
FAX set meal information	Branches fax products information to headquarter and those documents are archived into file collection.

Table 2. The As-is behavior main objects details

Object	**Description**
Original set meal list	Historical products information archived in file collection.
Newly designed menus	Newly-designed meal information.
Revised set meal list	Set meals list.
Pass	Results of appearance revising.
Modify information	Suggestion of appearance revising results.
Internal try & rate form	Meal testing results.
Rough estimate and cost information	Cost information of newly-designed products.
Meal price information	Price information of newly-designed products.
Picture stored	Photographs of newly-deigned products.

3.2 Some problems occurred in current practice

(1) *Inefficient data exchange and incomplete information in design document*

The updated design data of each cuisine cannot be shared with other branches. The headquarter also does not possess the development information of every branch. Branches may design their set meals on thier own without the resourse (e.g., materials) consideration of the headquarter. In summary, there is no common development platform. Recipes are usually kept by the restaurant chefs without properly knowledge management and sharing controlled by the headquarter.

(2) *Customer feedback and preferences*

In the process of meal design, we have not integrated the customers' satisfaction and preference survey data. In other words, there is no customer participation in this meal development process.

(3) *Inaccurate cost information*

In the current practice, the cost of material supplies are managed by individual chefs without consistently stored and monitored by the headquarter information system. Thus, the accuracy of the overall restaurant operating cost cannot be guaranteed without an integrated information system.

4 Collaborative Meal Planning Model

4.1 The modularized meal design behavior model

The improved (to-be) behavior model are depicted in Figure 2 and described in Table 3 and Table 4 respectively.

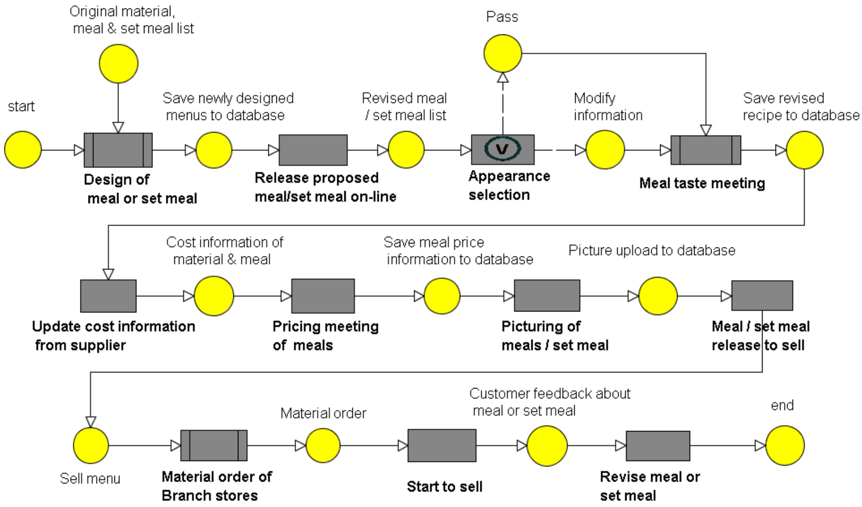

Figure 2. The to-be model in the CMP process

Table 3. The to-be behavior model activity details

Activity	Description
Design of meal or set meal	Chief chef surveys material information and currently products information from CMP system.
Release proposed meal/set meal on-line	Chief chef releases newly-designed products information through CMP system.
Appearance selection	Headquarter decides the appearance of newly-designed set meals.
Meal taste meeting	Integrate VIP customers' responses into meal testing results
Update cost information from supplier	Branches gather material cost information from CMP system.
Pricing meeting of meals	Branches upload photographs of products into CMP system.

Table 3. (continued)

Picturing meals/set meal	To shoot the set meal, and the image will use in menu. And the images are record in CMP system.
Meals/set meal release to sell	Branches release product information into CMP system.
Materials order of branch stores	Branches gather material demand regularly and send orders to headquarter through CMP system.
Start to sell	Meal selling in each restaurant.
Revise meal/set meal	Keep meals refining and adjusting based on customers' consuming suggestion.

Table 4. The to-be behavior main objects details

Object	Description
Original material, meal and set meal	Related information including meals, set meals and materials are recorded in CMP system.
Save newly designed menu to database	Newly-designed meal information is recorded in CMP system.
Revised meal/set meal	Revised meals and set meals.
Pass	Results of appearance revising.
Modify information	Suggestion of appearance revising results.
Save revised recipe to database	Revised recipes based on sample testing results.
Cost information of material and meal	Material costs obtained from CMP system.
Save meal price information to database	Meal prices information archived in CMP system.
Picture upload to database	Meal photographs archived in CMP system.
Sell menu	Dish menu information.
Material order	Material orders based on each branch's demand.
Customers feedback about meal/set meal	Customers' feedback and suggestion.

The design platform applies the concept of modularized design based on the bill-of-materials (BOM) data. The example BOM of a Japanese pudding (dessert) is shown on Table 5. The materials level expanded diagram of the dessert is shown in Figure 3. Further, the module examples of a set meal design are demonstrated in Figure 4.

Table 5. Example modularized BOM green tea pudding dessert

Material ID	Material name	Amount	Level
M1001	green tea powder	15 g	4
M2001	sugar	150 g	4
M2002	white sugar	4.5 kg	4
M2003	brown sugar	100 g	3
M2004	salt	8 g	4
M5001	milk	600 cc	4
M5020	cream	800 cc	3
M7003	yolk (egg)	250 g	3
M3005	red kidney beans	6 kg	4
M3006	frijoles	300 cc	2
M9001	water	6 kg	4
P3001	hot green tea pudding	1 unit	1

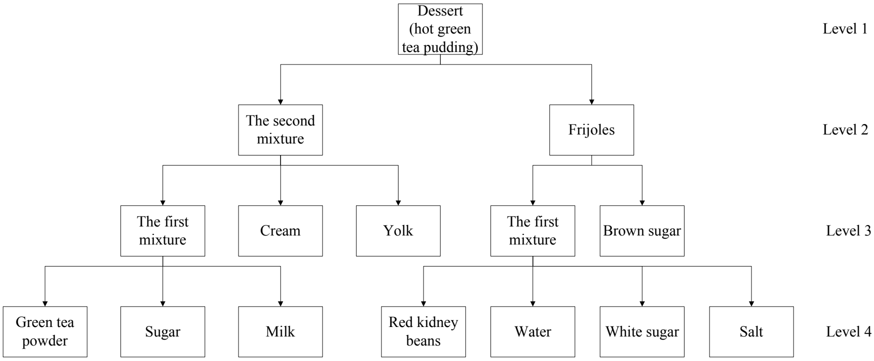

Figure 3. The materials level expanded diagram of pudding dessert

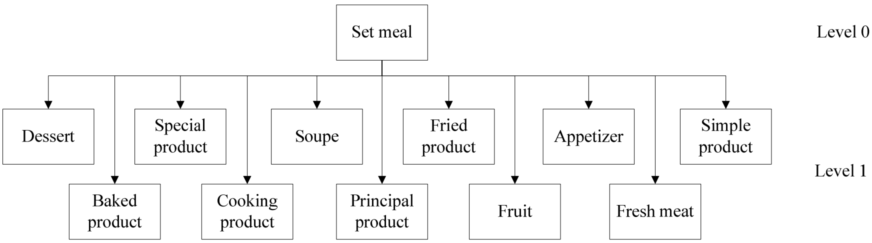

Figure 4. The expanded diagram of the module examples in a set meal design

In the Figure 5, when the headquarter decides to add a new set meal (product) on the menu, all branches need to propose their weekly demand forecasts on the system. Thus, the CMP system can consolidate and calculate the demanding materials automatically. The CMP system, with integrated data, can avoid calculation errors in material preparation. The consolidated material order lists can be sent directly to the suppliers with accuracy. The suppliers, in term, can predict their supply capacities. If suppliers accept the orders, then suppliers must log into the CMP system to make the order confirmation and fulfillment.

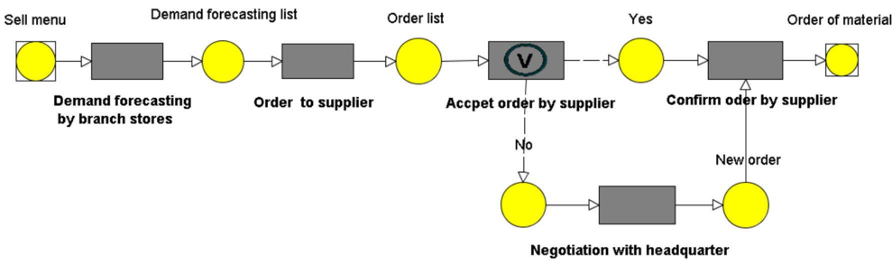

Figure 5. The to-be model in integrating material orders from branch stores to the final suppliers

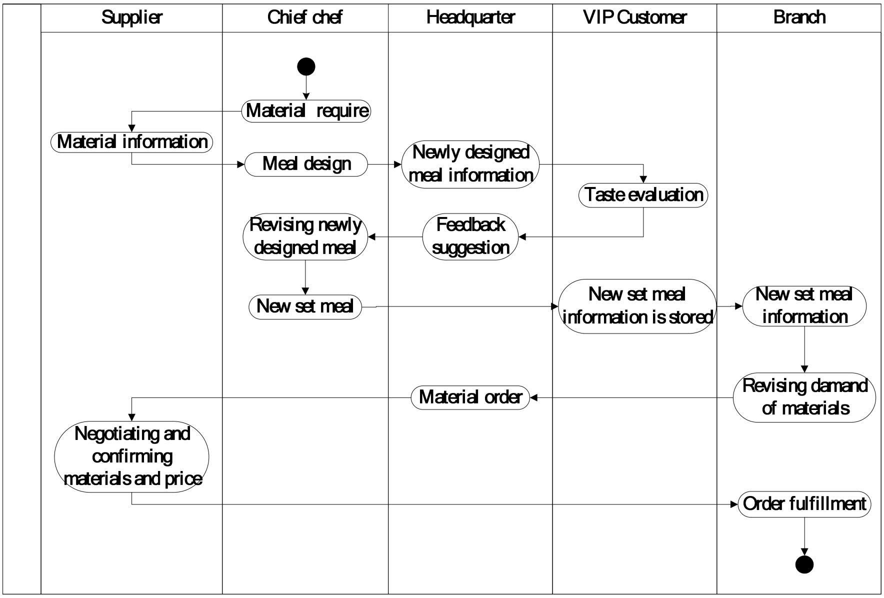

Figure 6. Connection of all participants during the design and production phases of the modularized and collaborative meal planning

The Figure 6 shows the collaborative relationship in the to-be model. We let the VIP customers participate in the taste meeting; this could improve speed of customer acceptance. And due to the supplier will continued update original or new material information in a period of time, the chief chef could get required data on time through CMP system. In the order phase, the supplier could update which material is available to supply. That headquarter could adjust the demand required ahead of order released time.

4.2 Elements of modular design improvement

(1) *Information sharing*

Using the collaborative meal planning (CMP) system to support development set meal, we have established a method for standardized data storage. Headquarter control the meal information from each branch easier. Meal designing processes become more time-saving and efficient via CMP system, since chief chef can easily get historical information of meals from database. Headquarter command the cost and inventory information of material from suppliers.

(2) *Consolidated demand information of materials*

Based on the modularized bill-of-materials (BOM) of set meals, the meals information is stored in CMP system. Each branch can forecast the demand of meal sales according managers' experience and send material orders to headquarter based on material aggregate demand data from CMP system. CMP count the materials aggregate demand, and send materials order to headquarter.

(3) *Mass Customization*

Each branch can better arrange dish menu based on the modularized design of meals to meet customers' preferences. Moreover, restaurant can better manage and understand customers' demand via CMP system to design customized meals and special meals for each customer groups.

5 Conclusion

In this research, the set-meal design process is reengineered based on the concept and platform of the collaborative meal planning (CMP). The CMP data model is defined based on the modularized bill-of-materials of set meals. The proposed solution can assist the chain restaurant headquarter, branches and their partners (i.e., suppliers and customers) in creating new set-meal designs with efficiency and efficacy.

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Sales Service Improvement for an Industrial Transformer Manufacturer

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Abstract: This paper defines and integrates after-sales service processes for an industrial manufacturer of power transformers. High priced and highly customized electricity transformers are sold to power generating companies that hold high service expectations througout the product life cycle. The e-integration of business processes for prior sales, ongoing sales, and after sales services are critically important for the transformer manufactuer to overcome well know problems with traditional paper based systems. This research analyses the business processes for transformer sales services and then integrates the best practices into a sales service platform. The study studies the current practices (as-is models) of customer services offered by the company. After identifying problems such as service delays, cost inefficiencies, and inappropriate responses to customers requests and complaints, the improved (to-be) process models are built, analyzed, and structured using the enterprise systems tool INCOME4. The Internet based system incorporating the to-be service processes is implemented to improve customer response as well as enhance the efficiency and effectiveness of after sales services.

Keywords: Business Processes Reengineering (BPR), After Sales Services, Power Transformers

1 Introduction

A transformer transmits electrical power and transforms voltages before and after power transmission. Power transformers have many component modules, different specifications, complex manufacturing processes, and are high value assets for power generating plants. Since power plants are customers of transformer

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manufacturers, they expect high quality products with good sales service throughout the product life cycle. If a transformer breaks down without warning, the electrical equipment linked to the transformer must be shut down, electrical power generation ceases, and significant income is lost by the power company. Therefore, the transformer end users necessarily require instant service from maintenance suppliers. Ongoing asset maintenace and repair is also required to reduce the risk of sudden transormer failure (Trappey and Ni, 2009). The purchase of a transformer is a large asset investment with a product life that spans several decades. Ongoing maintenance and after sales services help position the seller's market position and competitiveness.

After sales services are divided into periodic maintenance, preventive maintenance, and break down repair services. These services are also listed by the CRC for Integrated Engineering Assets Management (CIEAM) as primary tasks (CIEAM, 2010). For the first task, a manufacturer provides a maintenance schedule to ensure proper operation and function. When a transformer malfunctions (discovered either through routine maintenance or part failure) repair services are immediately scheduled to restore full operations. For traditional transformer manufacturers, the service processes are managed as paper records. Customers and manufacturers communicate the maintenance requests and repair schedules by phone, fax, or e-mail. The service maintenace supply chain lacks an integrated Internet platform to coordinate communication and data analysis processes. Using a paper driven system, the transformer manufacturer is less capable of tracking customer needs and is less able to deliver fast, cost effective, high quality service. Since transformer repairs often require the replacement of parts, components, and fluids, manufacturers are required to maintain and plan inventories using repair frequency and cost data. The management and forecasting of spare parts and materials is considered an essential function of the product life cycle services platform.

2 Literature Review

In order to respond to customer requests quickly and increase customer satisfaction, companies use business processes reengineering to evaluate current practices and improve service performance. Researchers recognize that technological progress and innovative ideas are the main drivers of economic growth (Hunt, 2000). Firms gain advantages by sharing resources and improving capabilities in novel ways. New technologies that share information and integrate enterprise systems improve cooperative efforts across the supply chain (Narus and Anderson, 1996). Given increased global competition, the implementation of information technological is considered a market necessity (Ives and Learmonth, 1984). The research of Zhang and Cao (2002) shows that firm which change from hierarchical organizational structures to matrix structures are also implementing process oriented measurement goals. Business process re-engineering emphasizes process simplicity and as noted by Hammer (1990), radical process simplification is an important way to reduce process times and costs.

Levitt (1972) argues that every business is in the business of service. Berry and Parasuraman (1991) and Bitner (1997) support this view and note that manufacturing companies and businesses in general should be service oriented. The service strategies offered by manufacturing sectors are critical factors for business success (Mathieu, 2001). Manufacturing after sales services impact revenues and competitive advantage. Gaiardelli (2007) stresses the importance of management's participation in after sale services. The current trend is for manufacturers of heavy equipment that traditionally rely on close and personal sales ties, work toward building integrated sales maintenance information platforms to better record, communicate and plan customer service delivery. For products that include self diagnosis sensory technology, after sales services can be further automated (Zackariasson and Wilson, 2004).

3 The As-Is Model for After Sales Services

The business process models for after sale services were defined using INCOME4, a system analysis tool with features that enable the evaluation of process efficiency and effectiveness. Using INCOME4, the processes are divided into behavior models that describe the process and sequence of actions, organization models which document the costs and responsibilities of departments and staff, and the object models that represent data entities and relationships.

3.1 Behavior Models

Figures 1 and Tables 1 and 2, depict the as-is behavior models, the drill down sub-processes, the process activities, and the data entities.

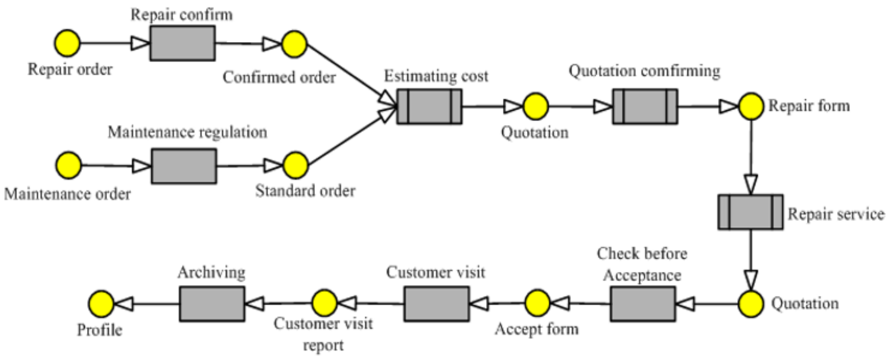

Figure 1. INCOME4 as-is behavior model for after sales services

Table 1. The as-is behavior model activity details

Activity	Description
Confirm Repair	3. Technology department receives the repair order from customers. 4. The technical staff confirms the customer order.
Maintenance Regulation	The technical staff issues a standard maintenance order according to the maintenance regulations.

Table 1. (continued)

Estimating Costs	The orders received are sent to the procurement department in the form of a temporary quotation. The quotation is re-confirmed by the technical department.
Quotation Confirmation Process	Business department sends quotation to customer for confirmation. After receiving feedback from the customer, the order form is converted to a repair form. The trail of correspondence is maintained by the technical department that checks and saves documents.
Repair Service	1. The technical department contacts customers for service dates. 2. Repair services are provided to customers according to the pre-checked schedule.
Check before Acceptance	After completing the service, the business department follows up with a survey measuring customer satisfaction.
Customer Visit	The business department visits customers regularly to keep in touch and discuss needs.
Archiving	The IT staff archives the business department visit reports.

Table 2. The As-is behavior main objects details

Object ○	**Description**
Repair order	Customer equipment repair demand.
Maintenance order	Customer equipment maintenance demand.
Confirmed order	Order confirmed by quality assurance department.
Standard order	Order in standard format.
Quotation	Forms used by manufacturer before official quotation.
Repair form	Forms checked by customer and sent to the maintenance department of the manufacturer for execution.
Accept form	Survey form completed by customers measuring satisfaction toward services.
Profile	All orders, forms and reports are saved in the profile room.

3.2 As-Is Model Problems

After the analysis of the As-Is model describing the sale service processes, several inefficiencies were discovered. First, most data are written as notes and then saved in EXCEL spread sheets. The double entry of critical data lack systematic management and integration. Second, the communications between departments is inefficient and lacks a common platform to view and check ongoing customer service cases. The company experiences difficulties providing a rapid response to customer problems and requests following the as-is business processes.

4 The To-Be Model for Sales Services

The to-be model focuses on improving the weakness of the current sales service practices. An online system is created to integrate all the process into a horizontal platform. All organization role players have authority to login to the system and readily access information and communicate across the matrix organization when there is a need. The manufacturer, the organization members, and the customer communicate with fewer delays and greater transparency which enhances the overall service value.

4.1 Behavior Model

The improved (to-be) behavior model are depicted in Figure 2 and described in Table 3 and Table 4.

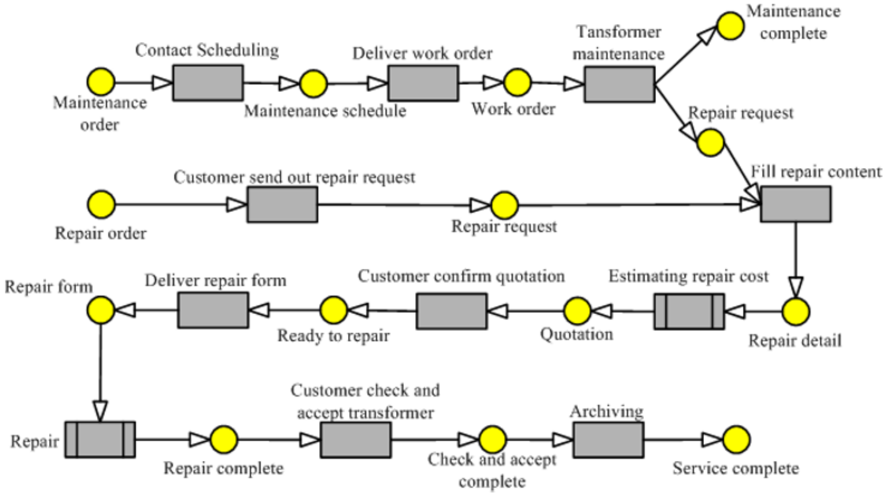

Figure 2. The to-be behavior model for sales maintenance and repair services

Table 3. The to-be behavior activity details

Activity	Description
Contact Scheduling	In regular maintenance, the business department contacts the technology department to record dates and scheduling services.
Deliver Work Order	After the maintenance schedule is determined, the business department communicates with the technology department. The manufacturer generates the work order and delivers it electronically to the technology department.
Transformer Maintenance	The technology department receives the work order, and confirms with the procurement department whether the required materials are available.

Table 3. (continued)

Fill repair content	After the technology department confirms the transformer problem, a repair content order is written.
Customer sends out the repair request	If customer finds problems with the transformer, a repair request is sent to the manufacturer.
Estimating repair cost	The procurement department and technology department estimate repair costs and provide a final quotation form.
Customer confirms quotation	The quotaton is sent to the customer for evaluation and order confirmation.
Deliver repair form	Upon customer quote confirmation, the business department delivers the repair form electronically to the technology department.
Repair	The manufacturer follows the repair schedule and provides the services in sequence.
Customer checks and accepts job completion	After the repair is completed, the customer inspects the transformer. If satisfied, the customer accepts completion of the services.
Archiving	The manufacturer archives the service and repair record.

Table 4. The to-be main objects (data type) description

Object ○	**Description**
Maintenance order	Transformer regular maintenance demand from customers.
Maintenance schedule	The schedule that records all maintenance details.
Work order	The technlogy department work order maintenance details.
Maintenance complete	If there are no transformer problems encountered during regular maintenance, then the maintenance is noted as complete for the time period.
Repair request	There are two states for the repair request. If a transformer problem is discovered during regular maintenance, a repair request is issued by the manufacurer. If the customer discovers a transformer problem during operation, then the customer issues the repair request.
Repair order	Transformer repair order from customer or manufacturer.
Repair detail	The form that records transformer problems and required repair materials.
Repair form	Forms ordering technology department to check and issue repair items.
Repair complete	When the repair is completed, the technology department returns the repair form and files the repair as complete.
Check and accept complete	The customer checks the repairs and issues an acceptance of repairs.

The following figures provide improved processes for estimating maintenance and repair costs and for conducting repair services (Figure 3 and Figure 4).

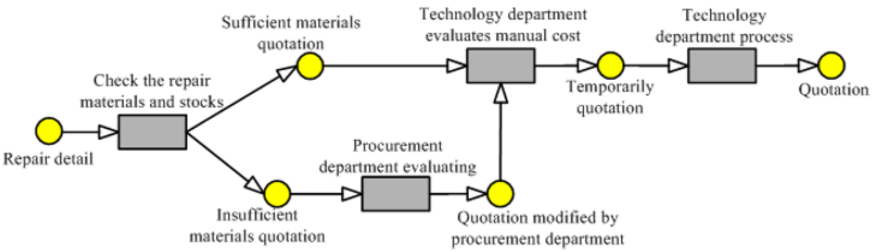

Figure 3. The improved processes for estimating costs

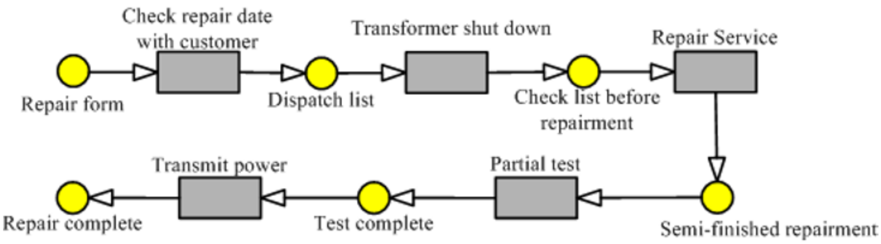

Figure 4. The improved repair services processes

4.2 Object Model for the Sales Services Platform

When service data are needed under current practices, paper based document are physically transferred between departments in the organization hierarchy. In order to structure a means to communicate data across the Internet, a data object model is defined. Eight tables are defined to facilitate the exchange of data manufacturer's departments more easily to exchange data defining repair content, TR_Profile, repair demand, quotation, maintenance, material, company and contact table repair demand, quotation, maintenance, material, company and contacts. Figure 6 defines the relationships and attributes of each table.

The transformer manufacturer executes repair orders and regular maintenance orders. When the order is received, data from the Repair Demand table or Maintenance table is retrieved. These tables have attributes which link to the TR_Profile table. The detailed contents of the repair order are recorded within the Repair Content table. The transformer defect and the repair solution is in turn related to the quotation in the Quotation table. The TR_Profile table contains specifications to help staff process the transformer repair and maintenance order. The table also link to the Company table to provide additional details or delivery and communications.

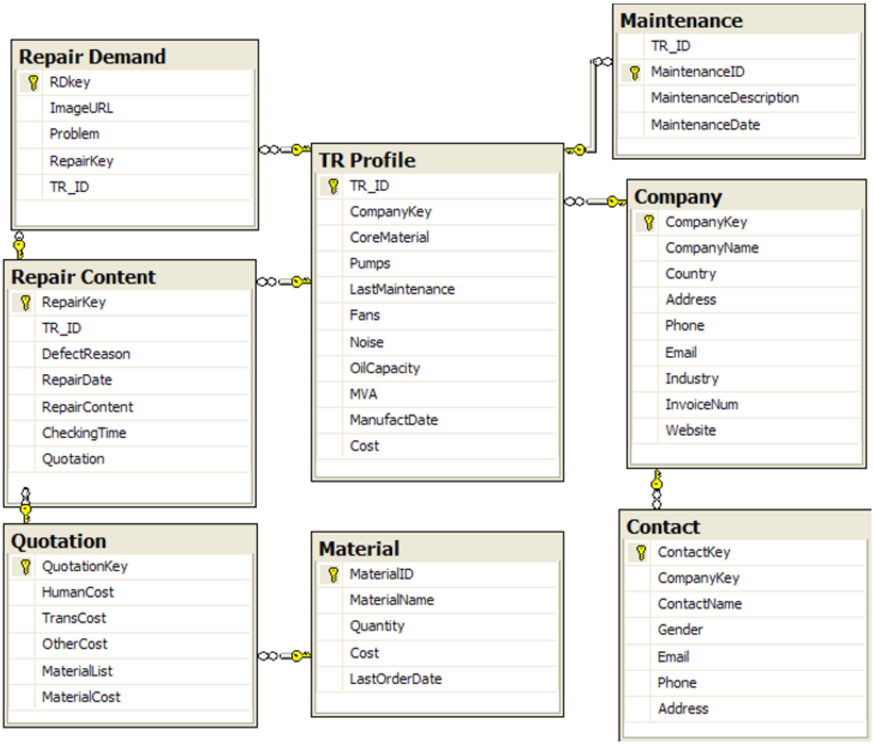

Figure 5. The object entity relationship model for the improved service processes

5 Implementing the Sales Service Online System

This section introduces the Internet based sales service system. The system follows the standard operating procedures depicted in Figure 6. The system starts when the user login, then determining the user's authority and provides the appropriate view of the data for administrators, employees, and customers. It provides treatment for two kinds of repair events, one is a customer request and one is a repair or replacement requested by the manufacturer during routine periodic inspection. When the customer requests a repair, the details of problems are entered into the system and send out. The manufacturer's employees are notified and the technician checks the machine history, specification, and then places a repair request for quotation in the system. When the problem is discovered during periodic maintenance, the technician fills out the online report directly. The managers monitor the status of all ongoing cases and keep the customers informed at each stage of the repair process.

After a case quote is approved and accepted, then all information is available online to management, salespeople, technicians, and the customer. Following management's order, the technicians monitor the working costs, and the purchasing agents supply the required materials. The customers receive both phone messages and e-mail from the sales force. After confirming the quote for repair online, the customer monitors the repair costs and progress online. When the technician completes the repair and records all details, the customer issues an acceptance for work completed that is sent to the database archive.

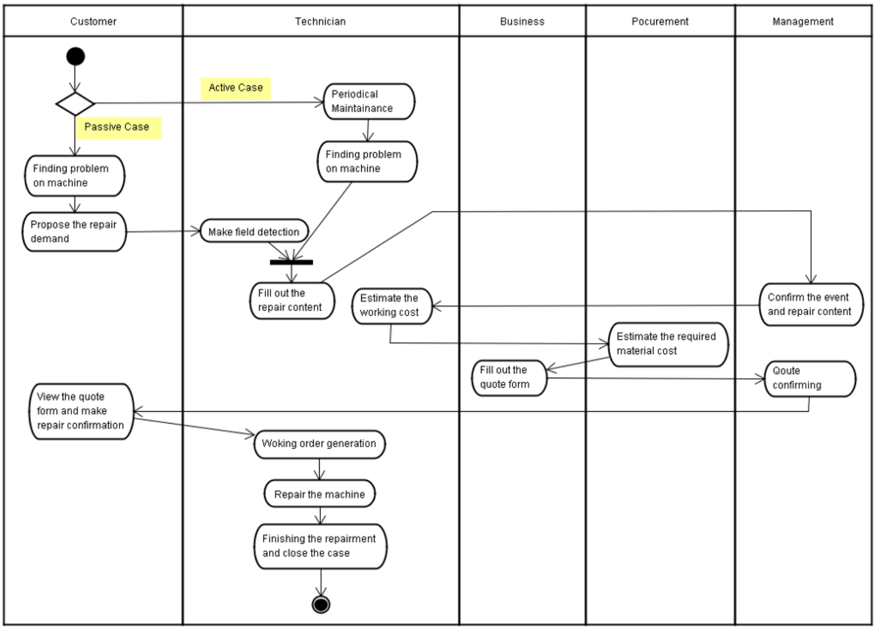

Figure 6. The system's standard operation procedure

6 Comparison

In order to verify process improvements, a set of key performance indicators (KPI) are used to make the quantitative comparison between the as-is and to-be models. KPIs are quantitative measures that help demonstrate progress towards goals and identify areas of improvement (Chan and Chan, 2004). In this case study, service time, error rate, response time, and data maintenance and data security are used for measurement. The KPI's for the INCOME4 simulation run are shown in Table 5.

Table 5. The estmated service performance improvement evaluation

KPI	as-is	to-be
Service Time	10 to 15 days	5 to 7 days
Error Rate	18%	9%
Response Time	3 days	Within one day
Data Maintenance and Security	35 labor hour/month	8 labor hour/month

There is a estmated 50% improvement in average service time and error rate. Response time is reduced from three days to one day when the to-be model is used. The most significant improvement occurs with data processing -- the new business model requirers 27 fewer hours. Data maintenance and security show a 90 percent improvement. All improvements are attributed to the e-business system which enhances service, data processing, and data integrity. In conclusion, the evaluation results show an overall improvement in service.

7 Conclusion

After analyzing the current sales services process, several redundant activities were found. The source of redundancy came from different departments and indicated a lack of cooperation and communication within the firm and with the customer. In order to simplify the processes, an integrated service platform accessible by all stakeholders was implemented. Through information integration, the transformer manufacturer better manages the business activities between customers and service providers. The visibility of all processes and activities helps the customer understand how and when the services are conducted and, thus, builds a positive service attitude toward the manufacturer.

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Supporting Management and Analysis of Quotations in a Design Automation Approach to Customization

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Abstract. A business strategy based on customized products with a high level of variety requires systems for efficient generation of product variants. An area identified in near collaboration with five industrial partners that has not been subject for extensive research is how to support management of different application domains, projects, task knowledge and design information together with the possibility to perform detailed analyses on the data generated by a design automation system implementation. Initially, a number of success criteria were identified and the functionality of a database was perceived as a promising approach. Explorative work was conducted for the purpose to reveal the conceptual model and the principles that a system would reside upon. The work has resulted in an approach, consisting of an information model and underlying principles, presented in this paper to be used when developing a design automation system for quotation preparation. The functionality and usefulness has been demonstrated and validated by a system implementation developed in collaboration with an industry partner. It can be concluded that a system founded on the presented approach supports management and analysis of quotations and product variants.

Keywords. Design automation, management, analysis, quotations, product variants

1 Introduction

Many companies base their business strategy on an engineer-to-order approach providing product concepts that are highly adaptable to different customer specifications. These product concepts appear frequently in the business-to-business market and range from discrete parts to complex products. The companies providing these products are commonly involved in many quotation processes and to be able to respond quickly with competitive prices and a short product delivery time while ensuring company profitability, these companies have to introduce design automation. This implies the deployment of a process view of the product concept and the definition of a product platform for variant designs incorporating engineering knowledge (e.g. mechanical design, production engineering, and cost

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engineering). Automation of product design, process planning, and cost estimation integrated in a system enable design proposals to be generated in a short time with minor effort. Different product variants can be evaluated while cutting off delivery time of products and offers [7], while guaranteeing consistent design calculations. One task suited for automation is quotation preparation including the definition of principle product design, process planning and cost estimation.

The advantages to gain by introducing design automation to support the quotation process are not difficult to see. What become a lot more difficult to answer are the issues related to how it should be realised. The scope and the purpose of this research originate from industrial problems and needs which have been identified within research projects carried out in near collaboration with five industrial partners. The starting-point in industrial problems is in accordance with problem-based research as described by Jørgensen [10] and Blessing's research methodology for the development of design support [1]. The system development method [2] has been deployed as research methodology for the purpose to explore the research issue including the introduction, evaluation, and refinement of new concepts which are perceived as prescriptive models in accordance with the design modelling approach [4].

The main objective of this work is to provide a system foundation for automated quotation preparation. The focus is on a solution that enables generation of different variants based on varying customer requirements as well as changes in product and manufacturing properties. Management of different application domains, projects, task knowledge and design information should be supported together with the possibility to perform detailed analyses on the data generated by a system implementation. The industrial and scientific objective is to provide concepts and principles supporting application system development and utilization for both practitioners and researchers.

2 Related work and state of the art

The research in the field of design automation has been conducted for about half a century [11]. Focus has been on both the automation of the design process and the automation of the design object during the years. As geometry is an important factor in engineering design together with the evolution in CAD software, the work has in the recent years mainly adopted an object oriented view, i.e. the rules have been defined and organized in accordance with a product structure. This has been further supported by the different commercial KBE tools available today for design knowledge modelling (e.g. Catia KWA and UGS NX Knowledge Fusion). The process approach, on the other hand, has gained more success in the area of computing, where engineering tasks defined in different applications are connected for the purpose of simulation and optimization (e.g. ModeFrontier and Simulia Isigth). Two specific areas that have been subject for research are the development process of design automation systems and the modelling of product related information. Hvam et al [8] describes a complete and detailed methodology for constructing configuration systems in industrial and service companies. Stokes [13] describes a methodology for the development of knowledge based engineering applications called MOKA, Methodology and software tools Oriented to Knowledge Based Engineering Applications. A procedure for development of design automation systems has been outlined by Rask [12] where issues about documentation and maintenance are addressed by emphasizing the need and importance of routines regarding versioning, verification and traceability. Claesson [3] have introduced and developed the concept of configurable components for supporting platform-based product development. A system for automated design incorporating functions for knowledge documentation and traceability is presented by Sunnersjö et al. [14]. Elgh [5] introduces principles for the modelling and management of manufacturing knowledge in design automation systems with an associated information model using knowledge objects [6]. The concept of knowledge objects has also been explored by Johansson [9] in a system for aluminium tube bending. However, an area that has not been subject for extensive research is how to support management of different application domains, projects, task knowledge and design information together with the possibility to perform detailed analyses on the data generated by a system implementation. This work intends to contribute to that area.

3 Supporting management and analysis – principles and conceptual model

In order to build, use and maintain a system it is essential to find an information model that agrees well with concepts and working practices used at work daily by the users. Several domains are commonly involved in the quotation process, and the concepts in these domains are linked in a complex way constituting a semantic model. Information related to these domains has to represented, captured, structured and stored, allowing for analysis to be performed on the stored information. In the following sections, an information model will be described and the background for its structure clarified. The approach, the principles and the information model have been developed and used when developing a design automation system for quotation preparation. The system and how it can be used for automated variant design and as tool supporting management and analysis of quotations and product variants is presented in the next chapter. Based on interviews and discussions with companies' representatives a number of success criteria were defined to support structuring, management and analysis, these are: Support mapping of documentation to executable rules, Include means to represent generic product structures, Support variant specific product structures, Include mapping of parameters/variables to both the product and the process, Separate knowledge from execution, Flexible solution sequence, Support working with different applications (knowledge domains) and projects, Include traceability between rules and solutions, Mapping of concepts and attributes for information analysis, and Persistent information storage.

Based on these criteria the use of the technology provided by a database, for data storage, analysis and management was perceived as a promising approach for reaching the desired functionality. Principle system architecture is depicted in Figure 1. However, a database does not by its own provide the required functionality, of crucial importance are the system implemented conceptual models and the principles that the system reside upon.

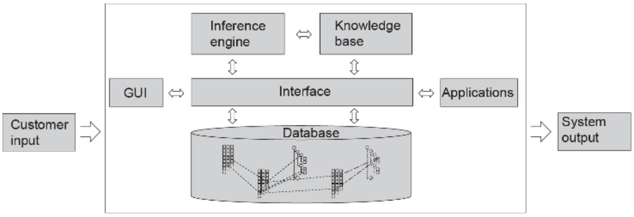

Figure 1. Principle system architecture

Building a system for automated design includes the involvement of different domains. The concepts in these domains need to be formalized, structured, and linked for the purpose of ensuring system functionality and supporting system realization. The definition of concepts is to some extent intertwined with the system development as system development is an iterative process of problem definition – problem analysis – solution synthesis – solution analysis. Based on previous work, knowledge in the problem area and an increasing understanding of the specific problem at hand, the concepts for a system solution can be outlined, Figure 2.

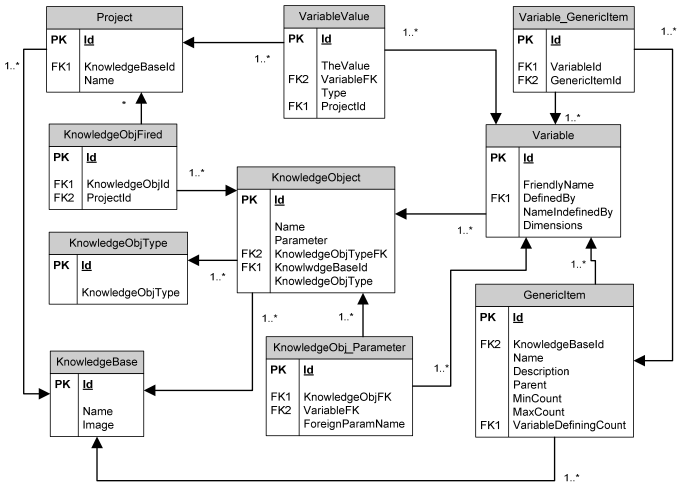

Figure 2. Main concepts

3.1 Knowledge bases and knowledge objects

A *KnowledgeBase*, attributes *Id*, *Name* and *Image*, comprises all the knowledge and information constituting an application for a specific purpose, for example automated design of gearboxes. Setting up an application includes the definition of design algorithms, rules, and relations that transform customer and company parameters to product model variables resulting in a product structure with associated knowledge. If the product is not based on a modular architecture, there commonly exist bidirectional dependencies and/or recursive dependencies involving a number of product items. The adoption of a process approach could untangle these dependencies through the clustering of the items' related statements in tasks constituting executable *KnowledgeObjects* (Figure 3). This is done with a Dependency Structure Matrix, DSM. The dependencies between product items are determined, analysed and grouped into tasks. If a task comprises many algorithms and computational statements it can possibly be divided into subtasks. The different attributes of the *KnowledgeObject* are: *Id*, *Name*, *Parameter* (commonly a path to a file used for its realisation), *KnowledgeObjectTypeFK* (pointing at the concept *KnowledgeObjType* which identifies the application for execution), *KnowledgeBaseId* (pointing at a concept defining the superior domain of application) and *KnowledgeObjectType* (used for classification). One special class is *Specification* which is used for *KnowledgeObjects* not requiring any input.

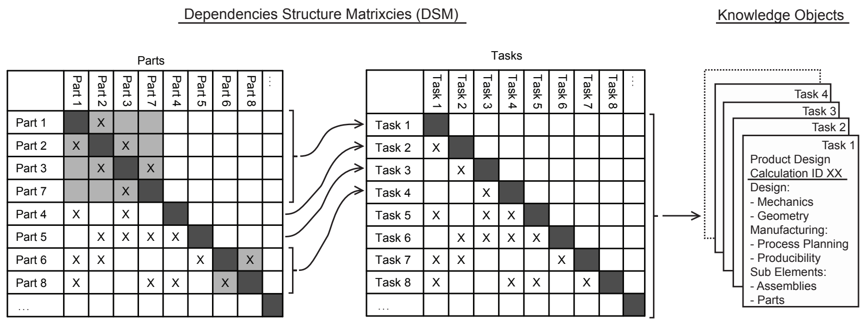

Figure 3. Definition of knowledge objects (Elgh, 2008)

3.2 Variables, parameters and items

Variable is a central concept for the proposed model. A *Variable* is a property defined by a task, i.e. a *KnowledgeObject*. *Variables* can represent different types of properties related to, by example, geometry, material, product structure, manufacturing operations, cost levels etc. The different attributes of the *Variable* concept are: *Id*, *FriendlyName* (can easily be interpreted), *DefinedBy* (pointing at a *KnowledgeObject*), *NameInDefinedBy* (supports the use of a different name in the realization of a *KnowledgeObject*) and *Dimensions* (for type declaration).

An instance's value of a *Variable* is captured by the concept *VariableValue* with the attributes *Id*, *TheValue* (i.e. the actuale value), *VariableFK* (pointing at the superior *Variable*), *Type* (at this moment *String* or *Numerical*) and *ProjectId* (pointing at the project for which the value was assigned).

The execution of a *KnowledgeObject* commonly requires input (parameters). Parameters are defined by other *KnowledgeObjects* which implies that no explicit concept for parameters exists, the required input for a *KnowledgeObject* is instead defined by using the concept *KnowledgeObj_Parameter* which inludes the attributes *Id*, *KnowledgeObjectFK* (defines the *KnowledgeObject*), *VariableFK* (defines the *Variable*) and *ForeignParamName* (supports the use of a different name in the realization of a *KnowledgeObject*).

GenericItem is used for the modeling of the product structure using the attributes *Id*, *KnowledgeBaseId*, *Name* (of part or assembly), *Description*, *Parent* (pointing at superior *GenericItem*), *MinCount*, *MaxCount* and *VariableDefiningCount* (pointing at the *Variable* that defines the number of *GenericItems* in a variant product structure).

For the purpose of assigning a *Variable* to a *GenericItem* the concept of *Variable_GenericItem* is introduced. The concept has the attributes *Id*, *VariableId* (defines the *Variable*) and *GenericItem* (defines the *GenericItem*).

3.3 Projects and fired knowledge objects

For every new request for quotation a new *Project* is created within the applicable *KnowledgeBase*. The concept *Project* is also used when evaluating different variant designs for a specific customer. Attributes related to the concept are *Id*, *KnowledgeBaseId* (defines the superior *KnowledgeBase*) and *Name* (name of the project).

As the execution process is managed by an inference mechanism (Figure 1), allowing for dynamic solution sequences, the actual execution has to be captured for the purpose of providing traceability between the product solution and the applied rules for its definition. The concept *KnowledgeObjFired* intends to provide this traceability. The concept's attributes are *Id*, *KnowledgeObjId* (executed *KnowledgeObject*), and *ProjectId* (the *Project* for which the execution took place).

4 Implementation

A general tool, ProcedoStudio, has been developed and used in collaboration with a company for setting up a pilot application system for automatic design of seat heaters to be used in the quotation process. This application corresponds to a knowledge domain modelled as a *KnowledgeBase* in the tool. The graphical user interface is depicted in Figure 4 with the main window in the foreground showing available knowledgebases and the executed projects for a selected knowledgebase, and the project window in the background used for execution and inspection. Presently there are 20 *KnowledgeObjects* for input specification, file management, electrical calculations, geometry design, manufacturing preparation, and cost estimation. The number of variables manage by the database is 66, although the total number of variables residing in all of the *KnowledgeObjects* is of much higher figure. Application programs used are MS Access 2007, MS Excel 2007, MathCAD 13, and Catia V5R18.

The presented information model has been implemented in a database. The database consists of generic application information and project specific information that is feed into the database at execution. Access to information, structured in accordance with the presented information model, can be gained by the means of SQL statements supporting management and analysis of quotations and product variants. A SQL statement could, by example, correspond to the query: find all the input variables and their values for a specific knowledge object for all the projects within a knowledge base where the value of another variable is within specific range.

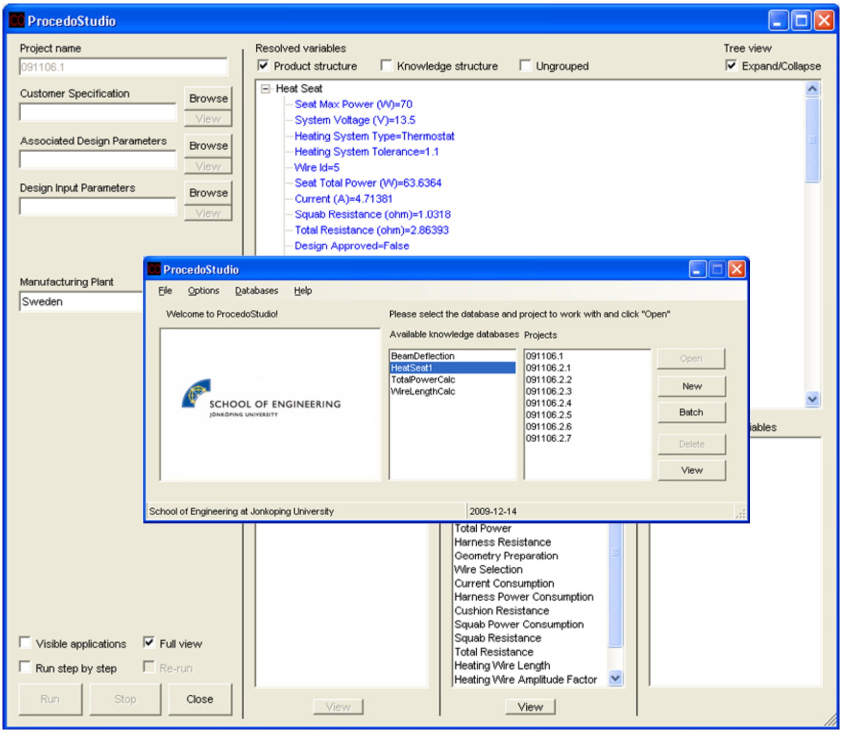

Figure 4. Graphical user interface ProcedoStudio

5 Conclusion

The presented work provides an approach, i.e. an information model and underlying principles, to be used when developing a design automation system for quotation preparation. The functionality has been demonstrated and verified by a system implementation supporting management and analysis of quotations and product variants. Developing a new system should always include an active consideration of using existing databases at the company. However, the approach is considered to be applicable even when setting up a system using legacy databases. Future work includes further system development, user tests, and evaluations. Issues to be studied can include principles for goal-driven execution, how to enable design of experiment specification, multiple executions, and optimization.

6 Acknowledgements

This work was conducted within a Swedish Knowledge Foundation granted project and financial support is gratefully acknowledged. The author would also like to express his gratitude to Kongsberg Automotive for providing information and knowledge about the case of application as well as for collaboration and helpful discussions. Finally, Lars Johansson, Swerea IVF, and Martin Tapankov, Jönköping University, participated in the system development, and their contribution is greatly acknowledged.

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Applying Image Processing for Rapid Customization of Multi-Color Nested Pattern Products

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Abstract. Under competitive environment, customer involvement in product design has been emphasized to increase attractiveness of products. Production process needs preparation to be ready to serve variety of individual needs. Presented in this paper is an application of image processing for implementing design by customer concept on a multi-color nested pattern product, specifically ceramic tile decoration. Algorithms for contour tracing and tile color selection have been developed. Passing through the algorithms, a color input image of multi-color nested pattern design is converted to be ordered sequences of pixel coordinates of all contours, ready for cutting selected tiles. The algorithms have been successfully implemented on LabVIEW software.

Keywords. Nested pattern products, image processing, customization, design by customer

1 Introduction

Advancement of technology has opened up a competitive market that led to the change of product development fundamental from manufacturer-oriented to customer-oriented [1].The competitive environment has made voice of customer more valuable and difficult to overlook. It has given way to customers to demand for better responsiveness [2]. Design of manufacturer in the early days has been replaced by design for customer at the present time.

However, customer involvement has been limited to expressing their voices and “take all or leave it” remains only option until the debut of mass customization. Customers can take a proactive role in their needs and negotiate to meet their requirements [3]. Manufacturers allow customers to involve reconfiguring products during assembly stage. They can mix and match parts to form their own products. Nevertheless, mass customization concept has some limitations when it comes down to implementation. To serve individual needs that quite vary from one person to another, exponential increase of variety will occur and lead to high cost and long lead time. With rigid manufacturing system, manufacturers are required to build up the inventory of variety of components to be

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ready. As a result, mass customization, in practice, remains at a group of customers with similar preference, not yet reached to individual customer.

Lately, a design by customer concept has been brought up in order to serve specific individual customers' personal needs which could not be fulfilled by neither mass production nor mass customization. Customers can get involved in making their own design early in design stage [4]. A research was conducted to investigate the application areas of design by customer concept from customer view [5]. The study concluded that the concept was considered to be applicable to some specific products like gifts and souvenirs but not in general. It also predicted that the concept will be successfully applied when the uniqueness is considered as an important feature of the products. In order to implement this concept, production process must be prepared to produce rapidly variety of quality products at low cost. This preparation is product dependent.

One group of products that this concept can be implemented is multi-color nested pattern products, such as garments, shoes, and especially decorated ceramic tile wall and floor that are the focus of this paper. Patterns and colors, appeared, make ceramic tile decoration more attractive. Several home owners are interested in wall and floor decoration, and many would love to have their own designs. The patterns may come from idea, inspiration, impressive scenery, abstract art or drawing sketch. At this moment, to obtain customized ceramic tile decoration, customer will have to bear with tile manufacturer to prepare all cut pieces before tilers finish the work. This preparation that includes five following key activities: inputting customer designed pattern, extracting information from the pattern, converting it to be tool paths, selecting tiles' color, and cutting tiles is foreseen to be obstacle for implementing design by customer concept.

Recently, Ut and his colleagues [6] presented a research on simplifying abrasive waterjet cutting process. The research has improved man-machine interface that allows inexperience users to complete cutting any complicated contours in very short period of time without writing a single G-code. This makes the implementation of design by customer on pattern products possible. To make the implementation more practical, their work has been extended back, in this research, toward customer side. With an aim to rapidly generate tool paths, image processing technique has been applied to extract contours from the image of designed pattern. Furthermore, color comparison technique has been adopted for selecting tiles' colors, matching with the design. The result is a set of coordinates of all contours that can be used directly to cut their selected tiles. The steps taken are presented in this paper.

2 Rapid Contour Extraction from Image of Multi-Color Nested Pattern Products

Image has become common medium, widely exploited for various purposes from being used for representing information as in computer graphic to being manipulated to extract certain attributes, (e.g. contour and texture) for downstream applications as in image processing and computer vision [7]. It has been used in this research for obtaining a set of coordinates of all contours residing in a multi-color nested pattern of a ceramic tile decorated design.

This development composes of three main stages: image preparation, contour tracing, and color selection. The process starts from preparing edge image. The image of design pattern is converted to be a binary edge image. Next, contours representing pattern profiles on the edge image are extracted. Their coordinates are tracked. Then, the tile's color is determined for each contour. The outputs are ordered sequences of boundary pixels representing all closed contours and assigned tile colors.

2.1 Image Preparation

The input of this proposed process is an image of designed pattern that customer can obtain from various resources such as own drawing, the Internet, scanner, and photograph. The image is processed to be a binary image of one-pixel wide closed contours before feeding to the contour tracing algorithm in the next step. In case of color or grayscale images, they are preprocessed with canny edge detection. For this technique, edges of image are detected from the color contrast of connected pixel in the image [8]. A threshold value is used to compare the resulting edge gradient. If the gradient exceeds the threshold, an edge will be judged present [9]. Morphological boundary extraction can be applied on binary region image to obtain the required input. It is possible that edge detection operation may deliver several open contours instead of closed contours. They must be corrected before feeding into the algorithm.

2.2 Contour Tracing

An algorithm has been developed for tracing a set of one-pixel wide closed contours that may appear as nested contours, interconnected contours or their combination. The concern leading to the development of this algorithm was that processing time for searching all contours can be as long as or even longer than tracing on them. Therefore, the key component of this algorithm is to apply basic morphological operations to achieve the locations on an image of all contours.

As illustrated in Figure 1, the algorithm consists of four main steps: identify area of interest, trace contour(s), identify the presence of additional contour, and determine the coordinates of traced contours on the edge of image. The process starts with identifying the working area. A smallest rectangle that contains all contours is drawn, and the coordinate of its top-left corner is record as a local reference. The contour search is then activated to search for a starting point and to continue tracing on a contour. The tracing is continued on its adjacent contours if they connect. The contour or a cluster of contours is then subtracted from its original image. If there still remains a contour in the result, its image will be fed back to repeat the previous processes until the result is empty. The algorithm then proceeds to translate the coordinate of all closed contours back to the positions on the original image. The detail of the algorithm is available at [10]

2.3 Color Selection

After all contours are tracked, the next step is to select ceramic tiles in the stock that their colors best match. A color selection algorithm has been also developed. The process starts from determining the color of each contour from the original image. An average RGB value is calculated from random sample of RGB values at thirty pixel coordinates inside the contour. To increase accuracy, twenty nine more average RGB values are obtained, and the average of all average RGB values is used to represent the contour color. Since identical RGB value may appear differently depended upon media and condition, the average RGB value is converted to CIE L*a*b* color value that is more sensitive to light source and setup condition before comparing with CIE L*a*b* color values of tiles in stock. The one giving smallest deviation is selected.

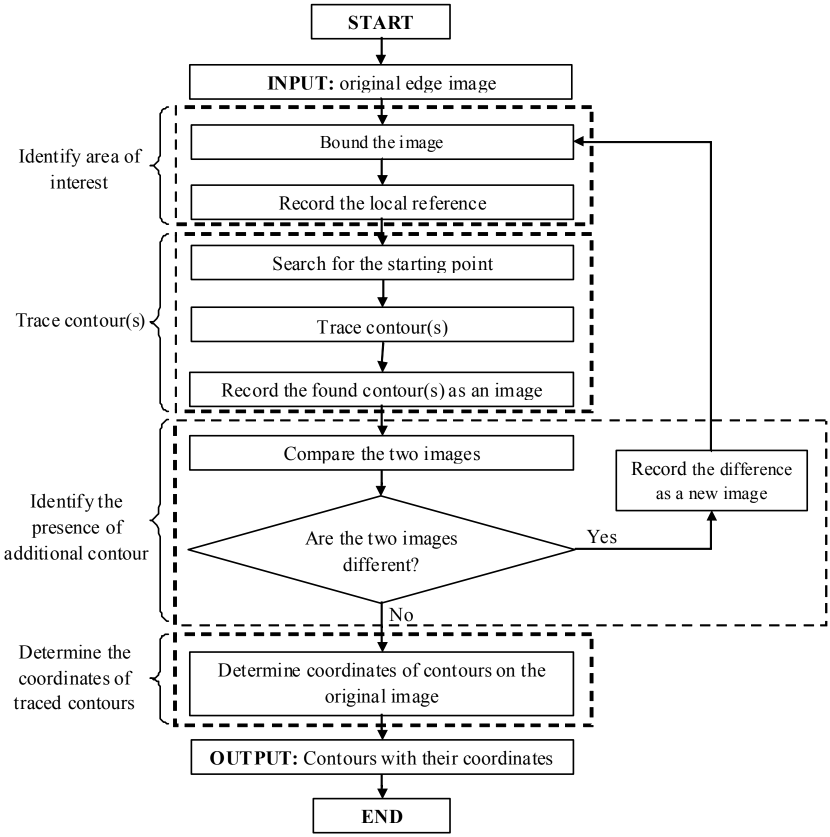

Figure 1. Flow diagram of the developed contour tracing algorithm

3 Implementation

Figure 2 shows a process chain for implementing design by customer on pattern products. An image of a design is processed to be the ordered sequences of boundary pixels representing all closed contours along with their assigned colors. The two aforementioned algorithms for contour tracing and color selection have been implemented on LabVIEW software. Figure 3 shows the screen of the front panel of the contour tracing program. A user is asked to preprocess a color design image to be a binary image of one-pixel wide closed contours before uploading it into the program. The binary image is displayed on the left side of the screen. The two images in the middle section show work in process. The program outputs ordered sequences of pixels coordinates representing all closed contours. They are saved as a text file. The same outputs are also displayed on the right hand side of the screen. The program has been tested with several samples, and able to obtain ordered sequences of pixels of all contours within reasonable time. One of the samples is shown in Figure 4.

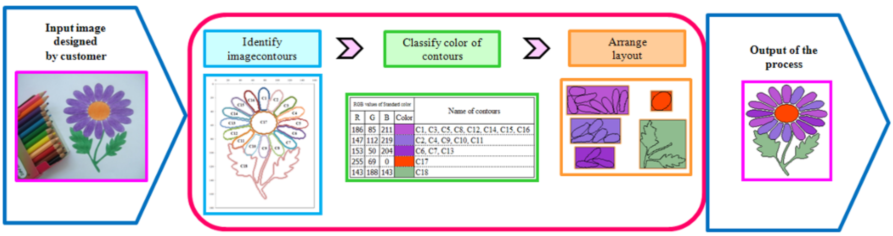

Figure 2. The implementation of design by customer on pattern products

Figure 5 shows the screen of the front panel of the color selection program. The user is asked to upload an original image and its obtained coordinates of all contours. The original image is display on the left side of the screen while the middle one displays the contour under consideration. The right display shows the sampling locations. Colors of contour and selected tile are displayed on the bottom left corner. Illustrated in Figure 6 is the implementation of this proposed contour tracing algorithm during part preparation for ceramic tile decoration. The contour tracing program was used to generate the ordered coordinate sequences of all contours residing in a multi-color nested pattern image of a ceramic tile decorated design. The results were directly used by a waterjet control program to generate commands for cutting each piece of assigned tile.

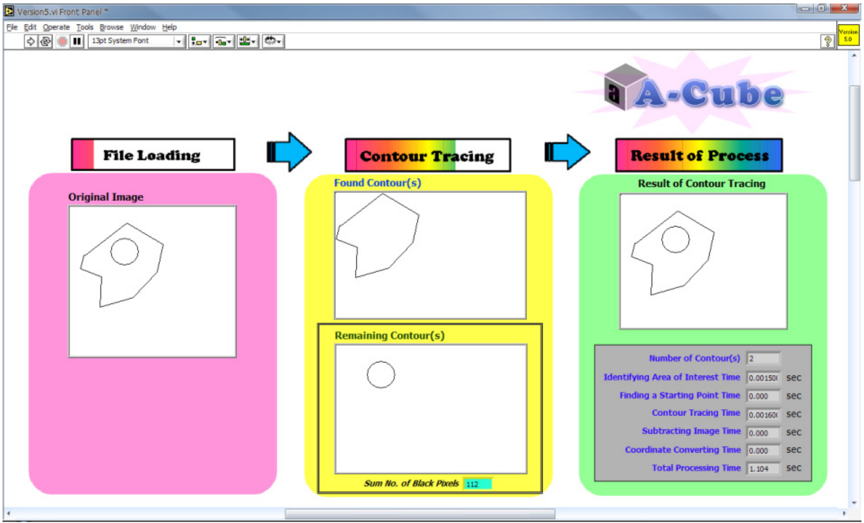

Figure 3. The front panel of the contour tracing program

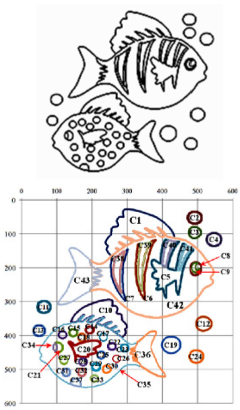

Image information
Dimension: 616×579 pixel
File size: 1.01 MB
Number of black pixels: 8107 pixels
Number of contours: 49 contours

Computation times
Time for identifying the areas of interest: 37.15 ms
Contour tracing time: 99.86 ms

Figure 4. Execution time on a nest of interconnected contours

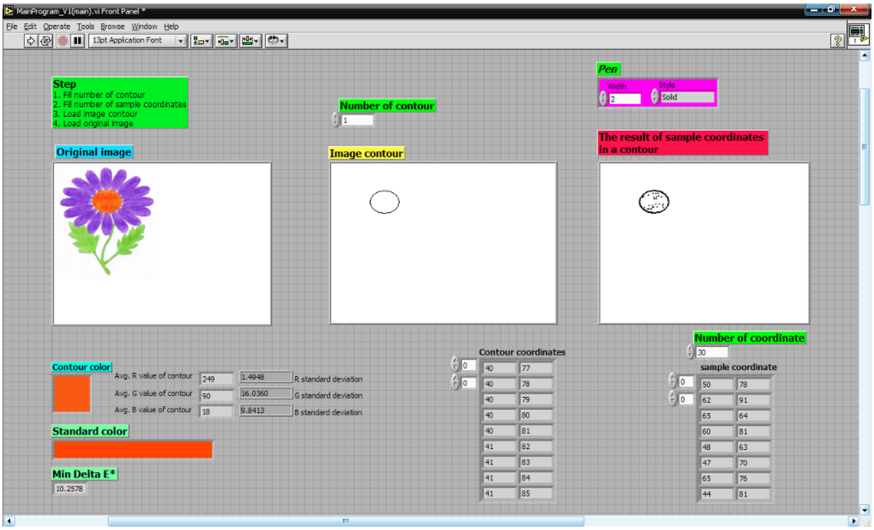

Figure 5. The front panel of the color selection program

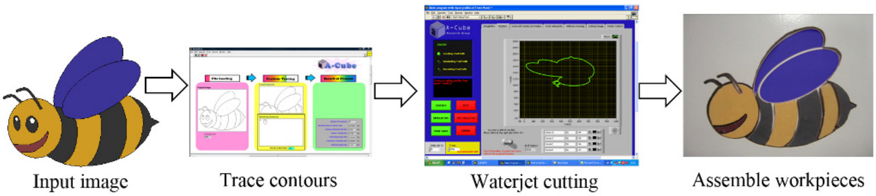

Figure 6. An example of the implementation of the proposed concept

4 Conclusions

To prepare for implementation of design by customer concept on ceramic tile decoration, a multi-color nested pattern product, image processing technique has been applied. Two algorithms have been developed for contour tracing and color selection, and implemented on LabVIEW software. By integrating them with simplified waterjet cutting process, cut pieces can be prepared within a couple hours instead of days. At the moment, the input image is limited to a perfect solid colors image. Further study is required to make it applicable for typical imperfect images.

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A Study on Total Performance Analysis of Service Oriented Eco-businesses

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Abstract. Eco-efficiency [1] has gained more and more attention these days. It is said that hopeful direction in industries to increase the eco-efficiency is de-materialization. In product development, the type of products that are suitably combined with service are often called product service system (PSS [2]). Designing the PSS efficiently will be a key issue in enhancing the eco-efficiency in many industries. The authors have gathered many examples of businesses that would increase sustainability (so-called eco-business) and extracted business rules [34] from the examples. It was found that many PSS are included in the gathered examples. In this paper, we focus on PSS type businesses and try to analyze eco-efficiency of an example based on our evaluation method called Total Performance Anlysis (TPA) [4,5]. And then, the paper tries to clarify the suitable combination of product and service is effective in enhancing the efficiency of the business. And it also concludes that the proposed evaluation method; TPA is helpful in analyzing the eco-efficiency of PSS.

Keywords. Sustainability, eco-efficeincy, product service system, eco-business, total perfirmance analysis

1 Introduction

Eco-efficiency has gained attention for a long time and has been applied to a number of products/services on the markets. It is understood that not only reducing the environmental impact of industry but also enhancing eco-efficiency is the key issue to ensure the sustainable manufacturing. In addition, services have been recognized as a key in industries to decrease environmental impacts, as well. In recent world, it is necessary not only to design new energy-efficient products but also to create the best combination of services and products based on the products characteristics and market conditions. For example, if the product consumes large energy in its usage, such as air-conditioners or automobiles, it is necessary to control usage patterns in addition to the product development. Because, only by the product development, major portion of the product lifecycle will be out of control.

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New business ideas which can decrease environmental impact of industries and enhance customer satisfaction are often called eco-businesses. To create new eco-business ideas, trial and error is not very efficient. It is important to take a systematic and efficient approach to enhance value of the business and reduce the cost and environmental impact, which means the enhancement of eco-efficiency of the business. For the purpose, existing eco-business examples can be good references. In advance to applying the evaluation method, we analyzed many eco-business examples in Japan and in Korea and extracted 12 rules to put eco-business ideas into practice.

2 Eco-business rules and relation between service process

In the former papers, the authors have investigated over 70 eco-business examples. There were many strategies, conditions and rules that made the business successful. And we integrated those unorganized conditions into 12 eco-business rules [3] shown below. Among these rules, not only 'servicizing' but also other rules have relation between service processes. We think that the rules having no relation between service processes are 'technological innovation' and 'application of cleaner methods.' All the other rules contains some service processes, whether it is strong or not.

- Management of lifecycles
- Expansion of the business scale
- Reutilization of wastes / Use one more time
- Utilization of knowledge and information
- Linkage and cooperation among various industries
- Combining various business values
- Technological innovation
- Outsourcing / Contracting for environmental loads
- Servicizing
- Timesharing
- Management of hidden bottlenecks
- Application of cleaner methods to satisfy customer needs

Of course, some rules are combined and applied simultaneously. Table 1 is a part of the gathered information. For example, the business called 'single-use digital camera' consists of 3 eco-business rules. Among the 3 rules 'Reutilization of wastes /Use one more time' is a helpful rule, because 'Reuse of LCD of used mobile phones' can reduce the environmental impact caused by new production of LCD (for digital cameras). And 'Linkage and cooperation among various industries' means that 'Combination of DPE shops and retailers of LCD of mobile phones (=maker)' can offer new service value to users. As it is shown in the example, each example contains information about business provider, consumers, applied rules and brief description of the business.

Table 1 Eco-business examples

Example	Applied rules	Key success factor and it's description	
Single-use digital camera	1. Expansion of business scale	Number of DPE shops	It is necessary that there exist many DPE shops where the service is available
	2. Reutilization of waste/use on more time	LCD of mobile phones	Utilize LCD from used mobile phones for monitor of the cameras
	4. Linkage and collaboration of various industries		Collaboration of camera maker, mobile phone collector and shops is necessary
DPE shops offer single-use digital camera under an inexpensive price. The users return the camera to the shops after about 50 shots and ask for printing. The cameras after use are reused many times. Because the LCD of the cameras are from used mobile phones, it is effective in reducing the price			
Example	**Applied rules**	**Key success factor and it's description**	
Sales of second-hand automobile parts (U-parts)	1. Expansion of business scale	Kinds of parts	Automobile disassemblers make a network to control the stock of second-hand automobile parts. The network enables to procure many kinds of parts and to supply parts to meet various requirements of customers
	2. Reutilization of waste/use on more time	Automobile parts	Reuse second-hand automobile parts
	3. Utilization of knowledge and information	Matching of demand and supply, establishment of inspection standard	It is necessary to construct an inter-company network to adjust demand of second-hand components to its stocks. And, by delivering in-house-made inspection equipments to other companies, defacto standard is established
	4. Linkage and collaboration of various industries	Fixture during the use of vehicles	By collaborating with car insurance company and utilizing second-hand parts, fee for vehicle fixing can be reduced.
	6. Technological development	Reuse engines	Development of inspection equipments
The disassemblers dismantle used automobiles and sell recovered parts as second-hand parts			

By investigation the business examples, we found that most of the examples contain some service processes. For example in the abovementioned two examples, the rule 'servicizing' is not mentioned. However, both examples need 'service' to be successful. In the first example, basic business of DPE shops is to provide printing services for photographs. In the second example, providing information about second-hand automobile parts to car dealers is nothing but service. As well as these examples, by reviewing 77 eco-business examples, we found that 57 examples have some relations with service processes. Thus, it is possible to say that Product Service System (PSS) is the core idea of successful eco-businesses. What this paper tries to do is to evaluate eco-efficiency of eco-business not only product oriented business, but also service oriented business. And we are trying to prove that our method, Total Performance Analysis (TPA) is helpful in evaluating and designing eco-businesses.

3 Proposal on eco-efficiency evaluation of PSS

In present research, we propose an index to evaluate real eco-efficiency of products, by considering product's utility value, cost and environmental impact. Efficiency index is defined by (1) and is named total performance indicator (TPI). Since in existing evaluation indexes the 'value' is usually a fixed value, it cannot consider change of the value throughout the product lifecycle. The proposed index is the simplest combination of environmental and economical aspects. In our proposal, because the utility value of the product can be expressed by integration of occasional values throughout the lifecycle, it can simulate value decrease due to value causes and physical causes as shown in Figure 1.

$$TPI = \frac{\sum_{i=1}^{n} UV_i}{\sqrt{LCC}\sqrt{LCE}} \qquad (1)$$

TPI: Total performance indicator, *UV*: Utility value of the product
LCC: Lifecycle cost, *LCE*: Lifecycle environmental impact

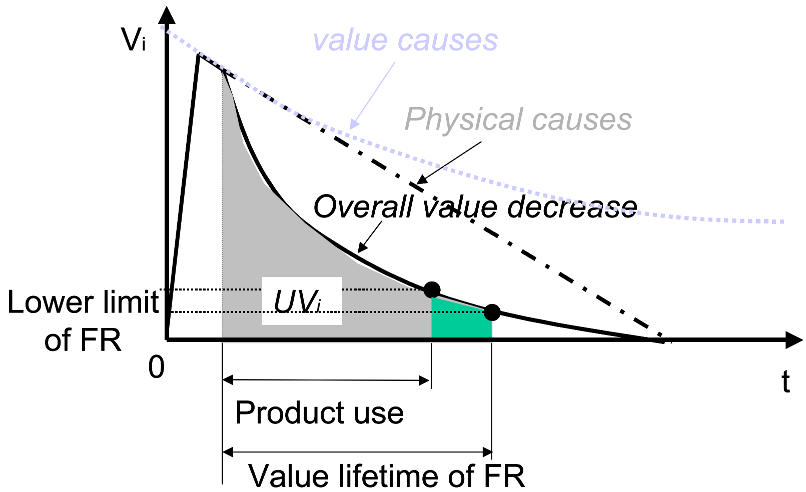

Figure 1. Value decrease through product lifecycle

Since the product lifecycle is a simple purchase-use scenario, the value decrease curve is monotonous as it is shown in Figure 1. However, once service processes such as upgrade, renewal, repair, etc. are considered, the curve will be different. Figure 2 is an example of value change curve with a service process. We defined same equation (1) can be used to evaluate the eco-efficiency of a product service system as shown in the figure.

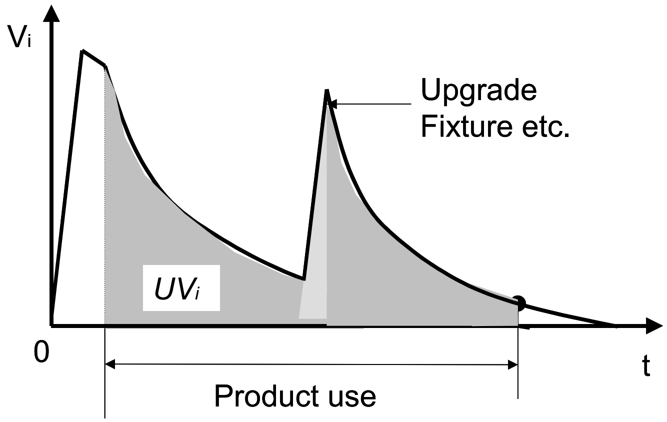

Figure 2. Value change curve with a service process

4 Case study: water purifier

Figure 3. Water purifier [6]

Among all the examples, we choose a Korean water purifier example shown in Figure 3. The supplier provides not only sales, but also some rental services of the purifier and take care of the maintenance, filter exchange, and so on, during the rental contract. Thus, basically there are some different scenarios for the consumption patterns of the product.

Type A: Purchase the new product with 8 years service contract

Type B: Rental the product for 5 years and renew the contract (replacement by a new model)

Type C: Rental the product for 5 years and get the ownership transfer (no replacement)

Type A and B include maintenance service including filter exchange, cleansing, and so on. And in these scenarios, we assumed value changes linearly. It is assumed that each scenario has each value change curve shown in Figure 4 A-4C. And the discontinuity in 4C corresponds to the end of the service contract.

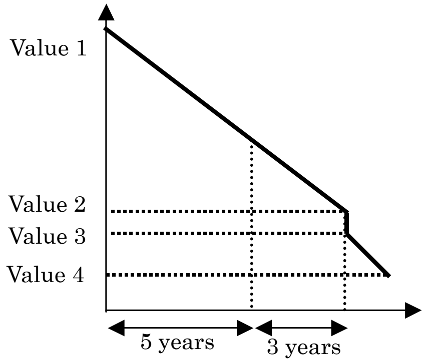

Figure 4A. Purcahse scenario

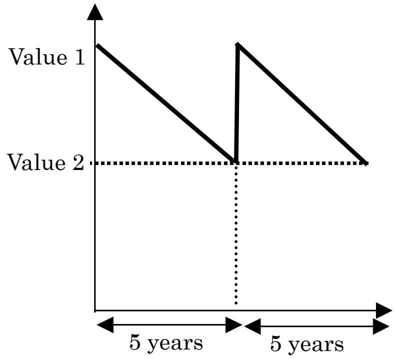

Figure 4B. Renewal scenario

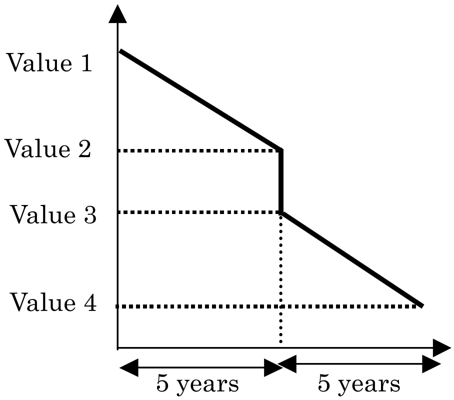

Figure 4C. Ownership transfer scenario

5 Calculation of eco-efficiency based on TPA

In order to calculate total performance of aforementioned 3 scenarios, it is necessary to decide some parameters. First of all it is necessary to determine what are the functional requirements for the water purifier. Table 2 shows the functional requirements and assumed relative importance of each functional requirements. We assumed that among the functional requirements, FR1 and FR2 will linearly decrease to 1/2 during 10 years, because of the value cause. And, also assumed FR4 decreases to 1/2 during 10 years, because of the physical cause. FR3 and FR5 doesn't change, if there is a maintenance service. But, it will decrease to 1/2 immediately, when there the service contract ends. Then, it will decrease to 1/2 during 5 years, if there is no maintenance service. FR6 doesn't change over time. As the result Table 3 shows the value change of the scenarios. Then, it was calculated that the average power consumption of the product is 0.1Kw. It was also assumed that because of the technological progress the new product after the renewal uses 70% power of the old product. This assumption is from the fact [7] that the energy efficiency of home appliances has become almost 2 times in these 10 years. Table 4 shows the assumed costs and environmental impacts for 2 lifecycles (10 years) based on investigations. The costs are expressed by ratio by assuming the initial product price as 100. Figure 5 shows the calculated result of total performance indicator (TPI) of each scenario.

Table 2. Functional requirements of the water purifier

Functional requirements	Relative importance
FR1: Supplies hot/cold water immediately	9
FR2: Supplies sufficienct ammount of hot/cold water	9
FR3: Purifies water appopriately	9
FR4: Looks good as a kitchen furniture	3
FR5: Realiable	9
FR6: Easy movable	1

Table 3. Value, environmental impact, cost of the scenarios

Name of the scenario	Value 1 (ratio)	Value 2 (ratio)	Value 3 (ratio)	Value 4 (ratio)
Purchase	40	31.3	22.3	16.9
Renewal	40	34.8	-	-
Ownership transfer	40	34.8	25.8	11.5

Table 4. Value, environmental impact, cost of the scenarios

Name of the scenario	Impact of using 10 years (kg-CO2)	Impact of production (kg-CO2)	Rental fee (ratio /month)	Cost of electricity (ratio)	Owner-ship cost (ratio)
Purchase	2400	100	-	48	132
Renewal	First 5years: 1200 Next 5years: 840	100*2	First 5years: 2.4 Next 5years: 2.2	40	-
Ownership transfer	2400	100	First 5years: 2.4 Next 5 years: 0	48	0

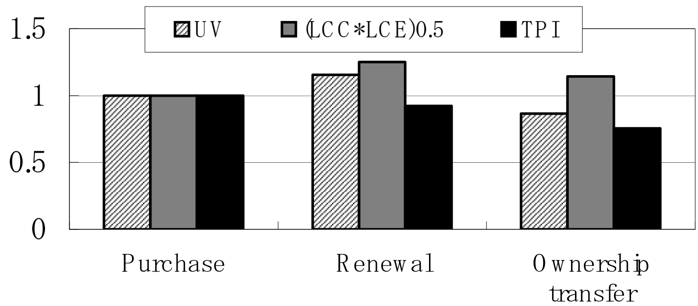

Figure 5. TPI of the scenarios

Figure 5 showed that purchase scenario has the best efficiency, under current assumptions. It shows the rental service of the product is effective in enhancing utility value and reducing lifecycle environmental impact. However, it seems it is not very effective in enhancing the efficiency. Comparing the two options of rental services those are renewal scenario and ownership transfer scenario, the former option seems to be efficient for the consumers. Of course, since many assumptions have made to reach to this conclusion, this is not the final result. But, at least, it is very helpful to analyze the scenario and obtain some quantitative information about environmental impact, cost and efficiency. The authors are trying to develop eco-business database including some quantitative information. And, that will be helpful in supporting creation of new eco-business idea.

6 Conclusions

In the former studies, the authors investigated eco-business examples in Japan and found 12 eco-business rules. In this paper, new examples from Korean industries were added. By reviewing the examples, it was found that most of the examples are combinations of product and service, so-called product service system (PSS). The paper tried to apply Total Performance Analysis (TPA) which is an eco-efficiency type analysis proposed by the authors. The eco-efficiency of several options that have different service processes were estimated by TPA. As the result, 'purchase scenario' has the highest efficiency and the 'service contract renewal' scenario has the second highest. In addition, TPA seemed to be helpful in obtaining some quantitative information for the eco-efficiency of a new PSS. Thus, the method can be an effective tool to support idea generation of new eco-business.

Of course, the calculation in this paper is based on many assumptions. Therefore, more practical and detailed analysis must be carried out in order to prove that TPA is really helpful.

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Part VII
Product Design and Development

Preference Set-Based Design Method for Sustainable Product Creation

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Abstract. The multi-objective satisfactory design including not only physical performances but also sustainable aspects from a global environmental protection perspective is necessary. When it comes to a sustainable life cycle, decision-making at the early phases of design including multiple sources of uncertaintes is important. The previous series of our studies had proposed a preference set-based design (PSD) method that enables the flexible and robust design under various sources of uncertainties while capturing designer's preference. In this papaer, different officially-accepted sustainability indicators are investigated and it is identified which indicators are related to the product development process. Thereafter, the proposed method is applied to a multi-objective design problem including technical performances and sustainable issues. This paper discusses the applicability of the PSD approach for sustainable development using the example of an alternator design.

Keywords. Sustainable product development, set-based design method, lean product development, early phase of design, product life cycle, multi-objective design

1 Introduction

Due to the complexiy of today's products and the incorporated overlapping activities between the lifecycle functions, the multi-objective satisfactory design including not only physical performances but also sustainable aspects from a global environmental protection perspective is necessary. Since essential attributes and characteristics of products are already determined in the stages of product

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development, it is necessary to integrate sustainable aspects into the product development process. The implementation of the concept of sustainable development requires the use of lean product development method in product creation processes. The product properties which are defined during the process of product creation should support and ensure sustainable development throughout the entire product life cycle [1]. When it comes to a sustainable life cycle, decision-making at the early phases of design is important. Moreover, the early phase of design contains multiple sources of uncertainties in describing design. Therefore, handling the uncertainties in the early phase has a great importance. There have been research efforts for incorporating engineering uncertainties into the design process, including interval set-based approach [2, 3], fuzzy set-based approach [4], probabilistic-based approach [5], and so on. Though they differ in the conditions under which they are used. A common feature is the use of set values instead of precise single values to represent engineering quantities.

The previous series of our studies had proposed a preference set-based design (PSD) method that enables the flexible and robust design under various sources of uncertainties while incorporating designer's preference structure at the early phase of design [6]. This paper presents a new approach to sustainable product creation based on the PSD method and discusses the availability of our proposal for obtaining the multi-objective satisfactory solutions not only about technical performances but also about sustainable issues. Finally, to verify the new approach, the adapted PSD method is applied to an alternator design.

2 Preference Set-Based Design Method (PSD Method)

The PSD method consists of four steps, the set representation, set propagation, set modification and set narrowing, which are described in the following [6]. Figure 1 shows the procedure of the proposed method.

2.1 Set Representation

To capture the designer's preference structure on a continuous set, both an interval set and a preference function defined on this set, which is called the "preference number (PN)", are used. The PN is used to specify the design variables and performance requirements, where any shapes of PN are allowed to model the designer's preference structure, based on designer's knowledge, experience, or know-how, as shown in Figure 2. The interval set at the preference level of 0 is the allowable interval, while the interval set at the preference level of 1 is the target interval that the designer would like to meet.

2.2 Set Propagation and Modification

The set propagation method, which combines the decomposed fuzzy arithmetic with the extended interval arithmetic (*i.e.*, Interval Propagation Theorem, IPT [7]), is proposed to calculate the possible performance spaces which are achievable by a given initial design space. Afterwards, if all the performance variable spaces have the common spaces (*i.e.*, acceptable performance space) between the required performance spaces and the possible performance spaces, there is a feasible subspace within the initial design space. Otherwise, the initial design space should be modified in set modification process.

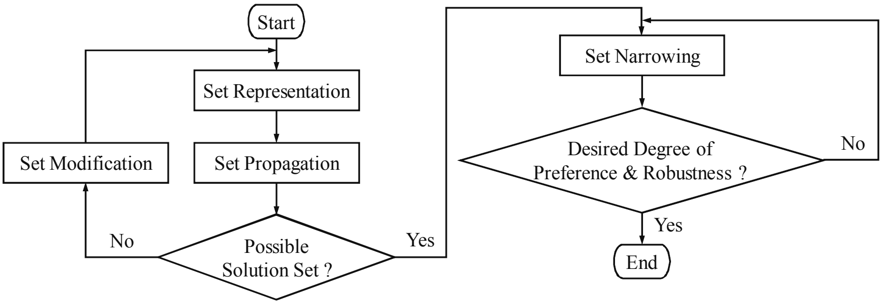

Figure 1. Procedure of set-based design method

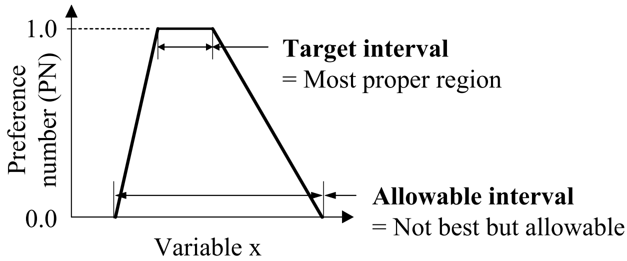

Figure 2. Representation of designer's preference

2.3 Set Narrowing

If the possible performance space is not the sub-set of the required performance space, there also exist infeasible subspaces in the initial design space that produce performances outside the performance requirement. Then, the next step is to narrow the initial design space to eliminate inferior or unacceptable design subspaces. To select an optimal design subspace out of those feasible design subspaces, the design preference and robustness are evaluated to eliminate infeasible design subspaces.

2.4 Design Metric for Design Preference and Robustness

New design metric for design preference and robustness, what is called the preference and robustness index (*PRI*) had been proposed [7]. Since more than one performance variable are commonly considered in the multi-objectives design problem, the *PRI*s for multiple performances need to be aggregated, what is called aggregated *PRI* (*APRI*), to provide the effectiveness of the design alternatives with respect to all performances. A family of parameterized aggregation functions is used for the multi-objective decision making problem, based on the weighted root-mean-power:

$$APRI_s((PRI_1,\omega_1),\cdots,(PRI_n,\omega_n)) = \left(\frac{\omega_1(PRI_1)^s + \cdots + \omega_n(PRI_n)^s}{\omega_1 + \cdots + \omega_n}\right)^{1/s} \quad (1)$$

Finally, the set narrowing method first eliminates infeasible or unacceptable design subspaces that produce the performances outside the performance requirement, and then selects an optimal one from a few feasible design subspaces, which are more preferred by the designer and provide better design robustness (*i.e.*, the highest *APRI* measure).

3 Investigation of Sustainability Indicators

3.1 Sustainability Indicators

In order to consider the sustainability of technical products, different officially-accepted sustainability indicators were investigated. The National Institute for Environmental Studies (NIES) in Japan has reviewed indicators on sustainable development which were developed by national governments and international organizations, and considered what types of indicators were being used as a database (2006-2008) [8]. This database includes 1,528 issues of sustainability indicators, which can be searched by using a web search engine. Using the database, 31 sustainability indicators which are related to the development process of products were selected and then categorized into three aspects: ecological, economical and social aspects.

Furthermore, two sustainability indicators from the selected indicators were chosen for further consideration: the CO_2 emissions and the mass of products. Both indicators are related to all sustainable aspects and can be calculated quantitatively. The carbon dioxide is one of the green house effect gases and relates to climate change. The goal of sustainable development from an ecological perspective is to not increase the emission amount of CO_2. The transportation emission including CO_2 is a very important factor, as it is an economical aspect. If the emission amount of CO_2 increases, the temperature rises, the amount of production of foods decreases and the price of foods are increasing; finally poor nutrition occurs because of the difficulty for people to gain foods. Therefore, CO_2 emissions are related to health as a social aspect. Weight saving of products is related to the CO_2 emissions, the efficiency of transport and the protection of our natural resources.

3.2 Evaluation of Environmental Loads Based on Life Cycle Assessment

The Japan Vacuum Industry Association (JVIA) has proposed the “JVIA Life Cycle Assessment (LCA) model” which assists designers in figuring out the environmental loads of manufacturing equipment and inventory analysis for environmental loads at the process of product design. The objective of this model is to get information which is needed for LCA of a product. The model can calculate the inclusive sum of environmental loads at each product life cycle process, such as manufacturing process, using process, maintenance process, reuse process, recycle/disposal process. Moreover, this model can also analyze environmental loads at a portion of product life cycle process.

4 Case Study: Application to an Alternator Design

4.1 Setting of Design Problem

In this paper, a design of an alternator structure is chosen to illustrate the effectiveness of the proposed system. The parametric CAD model as shown in Figure 3 was created by defining the design parameters which effect the required performances including physical and sustainable aspects. Many design parameters which effect the required performances exist, but this case study necessitates simplification. The purpose of this design is to find the values of two design variables including a height of rotor coil (= height of stator) (X_1) and a radius of rotor (X_2) as shown in Figure 3.

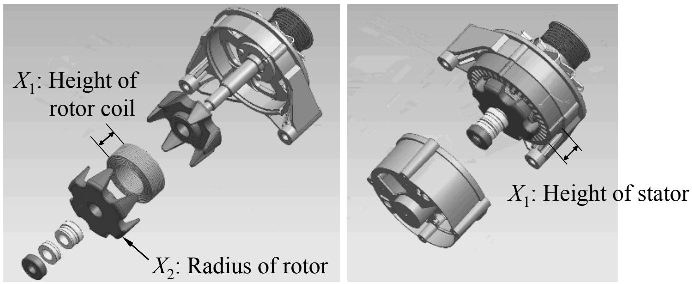

Figure 3. CAD model and design variables of the alternator

The performance requirements include the considerations on physical performance of the alternator: power (Y_1) calculated by Equation 2 and on performance for sustainable aspect: mass (Y_2) and CO_2 emissions (Y_3).

$$Y_1 = \frac{\pi \cdot n_{revolution}}{30} \cdot I^2 \cdot \mu \cdot n_{layer} \cdot n_{pole} \cdot \frac{X_1}{r_{coil}} \cdot X_2 \tag{2}$$

Whereas $n_{revolution}$ is the number of revolutions per minute: 2000 rpm, I is current: 70A, μ is magnetic permeability: $2\pi \times 10^{-3}$, n_{layer} is the number of layers of rotor coil: 10, n_{pole} is the number of poles of rotor: 12, and r_{coil} is the radius of rotor coil wire 0.25×10^{-3}m. In this study, the values of the parameters except the design variables (X_1 and X_2) are fixed. The mass of each part can be calculated out of the CAD models using NX as a CAD system.

4.2 Life Cycle Options for the Alternator

In this study, life cycle options for an alternator have been defined. The strategic focus of the options is on the end-of-life (EoL) stage thus the possibilities are remanufacturing, recycling or reuse for each component of the alternator.

Information for the development of possible sustainable futures of each component of the alternator can be extracted. The alternator is mainly characterized by standardized parts which are connected with each other by standardized interfaces. This allows that parts could be used in different products and/or product classes. Eventually, standardized interfaces and internationally accepted standards and guidelines allow the manufacturer to globally develop, manufacture and distribute individual parts and assemblies. Once the powertrain reaches EoL, it is returned to the manufacturer. Assemblies are partially processed for remanufacturing. This study has an assumption that the components of the stator, rotor coil, rotor, driveshaft, belt fitting, bearing and slip rings are recycled, and the fan and spacer are reused. In general, when it comes to the EoL, the alternators have to be returned to a collection station. The average distance is 800km and the transportation machine is a heavy duty truck (10t, light oil). To specify this data is necessary to calculate CO_2 emissions using the PSD method.

4.3 Application of PSD and Results

In order to align technical performances with sustainable issues, the PSD method is extended to various sustainable aspects. Due to the high complexity of real sustainable systems, the approach necessitates simplification. This study focuses on CO_2 emissions and mass as a sustainable aspect because both factors have economical, ecological and social impacts on the entire product life cycle.

When a design object has some required performances, there are more highly weighted performances or lower weighted performances. To reflect the importance of the required performances in the structure of the alternator, the weight of each required performance is classified: the case of technical performance-orientation (power ω_1: mass ω_2: CO_2 emissions $\omega_3 = 10:1:1$) and sustainability-orientation (ω_1: ω_2: $\omega_3 = 1:10:10$) by Equation 1.

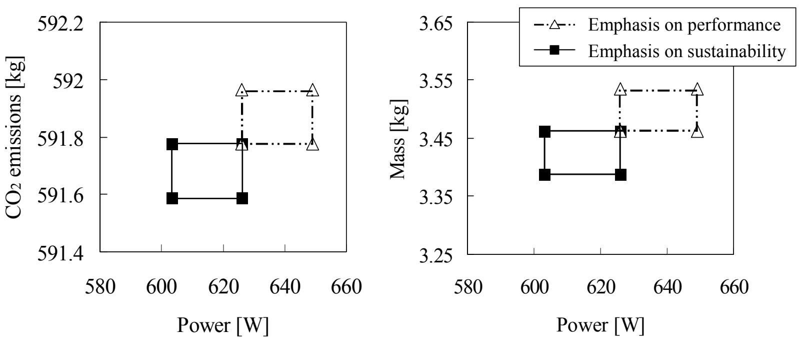

Figure 4. Possible distributions of performance-orientation and sustainability-orientation

Figure 4 compares the obtained possible distributions of the power, the CO_2 emissions and the mass between the case of performances-orientation and the case of sustainability-orientation. It is confirmed that the value of the power performance in case of performance-orientation is higher than the one in case of sustainability-orientation. On the other hand, CO_2 emissions and the mass in case of sustainability-orientation are lower and smaller than the one in case of performance-orientation.

Figure 5 shows the ranged set of solutions of design variables: the height of rotor coil and the radius of rotor. This result indicates that all of the ranged sets of solutions of design variables as shown in solid line are narrowed from the initial preferences of design variables as shown in dotted lines. It is confirmed that the design set solutions in case of sustainability-orientation have a narrower rotor coil and rotor with higher preference value because the case of sustainability-orientation fulfills sustainable issues better than the case of performance-orientation. These results show that the multi-objective satisfactory design solutions reflecting the importance of the required performances and designer's intention can be obtained by our proposed PSD method.

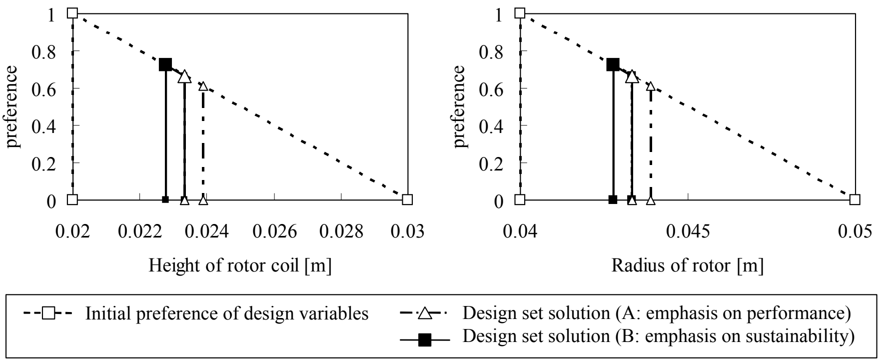

Figure 5. Design set solutions of performance-orientation and sustainability-orientation

4.4 Obtaining a design solution from ranged set of solutions

In fact, a designer uses a design value when they draft a design object. The proposed PSD method obtains a ranged set of design solutions. Therefore, definition of a point solution as a design value from the ranged set of design solutions is needed. This study has an assumption that a designer selects a point solution from the highest value of preference of a design variable as shown in the Figure 5, which means designer's most preferable region, as a design value.

Figure 6 shows the difference of achievable performance value between performance-oriented solutions and sustainability-oriented solutions. The design values by the performance-orientation can achieve high power but heavy mass and high CO_2 emissions, meanwhile which by the sustainability-orientation can achieve light and low CO_2 emissions but low power. These results indicate that designer's preference reflect the alternator.

5 Conclusions

This paper applied our proposed PSD method, which enables the flexible and robust design under various sources of uncertainties while capturing designer's preference, to a multi-objective design problem including technical performances and sustainable issues. This presents the applicability of the PSD approach for obtaining the multi-objective satisfactory solutions not only about technical performances but also about sustainable issues.

Further research about product-related sustainability indicators must be carried out. Thereby a major challenge is to quantify the social dimension of sustainability. What has to be achieved, are products that are economically more successful, ecologically more viable and socially more responsible.

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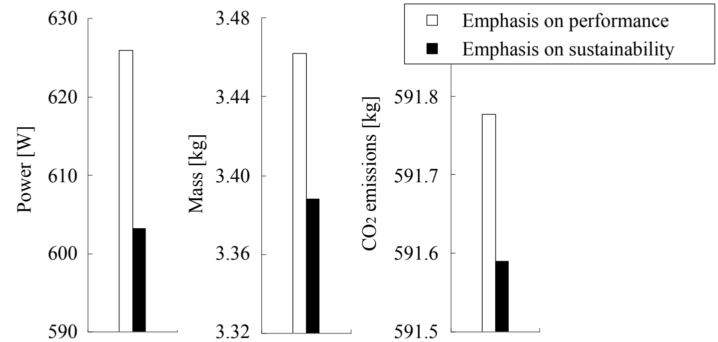

Figure 6. Comparison of achievable performance values between performance-oriented solution and sustainability-oriented solution

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Co-innovation and the Value-time Curve: A Case Study on the Dassault Falcon 7X and Embraer 170/190 Series

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Abstract. Little quantitative research has been done about the effects of an open innovation methodology and its relationship to the 3C model [5], value-time curve and other lean metrics. This study seeks to determine the value-time curves for the Embraer E-170/190 and Dassault Falcon 7X aircraft and substantiate the theories embodied in the 3C principles. Both these aircraft have seen recent market introductions, with development investments on the same order of magnitude during their development phase, making them relevant candidates for this study. The value-time curve will be used as a basis to derive the first and second order derivatives, which represent directional and growth coefficients respectively. Both cases are analyzed for their relevance to the 3C model.

Keywords. Value-time curve, lean enterprise, co-innovation, supply chain management, 3C Model, risk-sharing, production multiplier, investment multiplier, concurrent engineering.

1 Introduction

Lean Enterprise has taken a pivotal role redefining the long-term value prospect of companies. Companies such as Dell and Cisco have used lean principles effectively to create value by optimizing business operations, allowing them to focus on growth strategies and employ capital more efficiently.

A main objective in the aerospace industry is to reduce the development risk and time to market by means of faster innovation models, by sharing development and production value with suppliers, by investing in development and producing on own risk (risk-sharing). The 3C model embodies the principles of concurrent engineering (CE) by involving multiple partners with the co-development and subsequently co-production of for instance aircraft. The 3C model uses the Investment Multiplier (IMP) and Production Multiplier (PMP) as a means to gauge value creation and lean efficacy.

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This paper will examine the innovation and risk sharing approach within the supply chain of the Dassault Falcon 7X and Embraer 170/190. This paper will seek to answer:

1.) Can the value-time curve be established for an aerospace industry context?

2.) Within the Dassault Falcon 7X and Embraer 170/190 project context, do the IMP and PMP substantiate the lean methodology embodied in the 3C principles?

This paper will begin by introducing the reader to the value-time-curve and the 3C model, and will then introduce the concepts of IMP and PMP and their application to the Dassault Falcon 7X and Embraer 170/190, concluding with preliminary findings and present recommendations for future research.

2 Research framework

The time value curve provides the theoretical background against which the 3C principles are based. The time value curve is a representation of the investments placed in a development initiative, which relates to the product life cycle as shown in Figure 1.

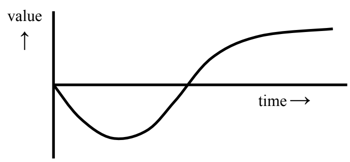

Figure 1. The value-time curve for a typical aerospace initiative

Within the context of this paper, there will be two ways in which the value-time curve will be plotted. Firstly, the IMP (1) will be introduced as a means to gauge the overall investment in aircraft development versus the investment made by the focal aerospace OEM-company, including loans and invested equity. Secondly, the value-time curve will be modeled by the PMP (2). This statistical measure will be modeled by the value of produced aircraft, incorporates the production value contributed by suppliers, versus the value contributed by the focal aerospace OEM-company. The value shifts under influence of outsourcing towards the supply chain. As a consequence the aerospace OEM focuses on co-development by concurrent engineering and co-production to integrate the aircraft. Both indicators show how lean the enterprise is operating.

$$IMP = \frac{total\ \ innovation\ \ investments}{own\ \ innovation\ \ investments} \tag{1}$$

$$PMP = \frac{total\ \ production\ \ value}{own\ \ production\ \ value} \tag{2}$$

The directional coefficient (3) is an indicator of the potential value (V) of a product, whereas the growth coefficient (4) indicates the rate of change of the directional coefficient. Both these indicators are measures of the lean value chain.

$$Directional\ coefficient = \frac{dV}{dt} \tag{3}$$

$$Growth\ coefficient = \frac{d^2V}{dt^2} \tag{4}$$

The 3C model is also relevant in this context. The 3C model is a theory that links the precepts of open innovation, lean value, and the supply chain.

Open innovation is a process which more companies have started to embrace. It emphasizes the involvement of co-developing suppliers engineering subsystems at a concurrent manner to create customer value. Within open innovation, inbound and outbound innovation can be identified. Inbound open innovation leverages the innovations of others, while outbound open innovation markets technologies by means of the business models of external organizations [3]. Its metrics of value-leverage consist of the value drivers; continuation, conception and configuration.

Continuation: customers adopt the innovation and generate value, thus ensuring continuity. As such, customers can be identified as part of the value system [13]. Beelaerts and Santema [2] identify the market share (MS) as the primary indicator for the continuation driver. Break-Even Time (BET) is the secondary indicator for this driver measuring the value generated due to innovation adoption by customers versus the time necessary to recoup investments in innovation.

Conception: the needs and desires of the customers can be used as input for the development of new products or services [15]. To optimally benefit from the driver given above, the development process should be organized such that (expected) value is optimized while minimizing the risks, costs and development time, which is something that can be achieved using early supplier involvement [17]. The primary indicator of the conception driver is the innovation investment multiplier (IMP) which is defined as the total innovation investment divided by the own innovation investment.

Configuration: This driver is defined by the production multiplier (PMP), as given by [2] which can be calculated as the total production value divided by the own production value.

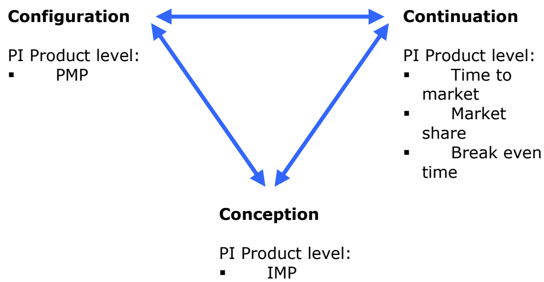

Figure 2. The value-leverage 3C model on product level [4]

3 Research methodology

The research methodology is based on previous research based on the value-time curve and the 3C model regarding product level. The steps that will be taken are as follows:

1. The MS, TTM, BE, IMP and PMP indicators will be calculated based upon information from literature and financial reports.
2. The value time curves and directional and growth coefficients of the two cases are plotted and analyzed to identify relations between variables and compare.
3. Measured indicators and value time curves are compared to the value of co-development and co-production of aircraft.

4 Analysis

The two cases that are analyzed and compared are those of the Dassault 7X. The value-time curve will be established first, after which the directional and growth coefficients will be determined. Both cases are described in relationship with the 3C model.

4.1 Dassault Falcon 7X

The Dassault 7X entered the market in 2007 [13]. Risk-sharing partners ranged from Pratt and Whitney Canada for engines, to different suppliers for avionics, air and power and braking systems to suppliers for flap and fuselage sections.

Value-time curve

Le Figaro claims investments over the development trajectory to be total €700 million [16], or approximately US$784 million. According to Dassault, 7X development will cost the risk-sharing partners (not including the engine manufacturer) US$265 million [9]. The IMP can of the Dassault 7X is 1.4. This represents a participation of 73% by Dassault in the development and production phase. The break-even point is reached when 300 aircraft are sold [10]. Given this, the profit margin will be 7.9%. The resulting profit for Dassault will be approximately US$2.3 million per aircraft, while the partner's profit will be approximately US$0.9 million per aircraft.

Relation with the 3C model

When the development of the Dassault 7X is evaluated with the 3C model [2] the following can be summarized.

Continuation

To create competitive advantage by means of a short development trajectory and swift market introduction, several innovative solutions were introduced, including a virtual plateau, which gave all stakeholders an integrated working environment. This significantly reduced time-to-market and created a cost-effective development phase. The company realized a 50% reduction in assembly time, 66% decrease in tooling costs and a successful, first-time assembly [9].
The market reception and acceleration of building up market share are demonstrated by the orders received already (78 orders in 2005, 26% of the aircraft to break even (GIFAS, 2006)) and the estimation of Aboulafia (2005) that with the Falcon 7X the market share of Dassault will increase from 16.7% to nearly 19%. The sale of 300 Falcon's should allow to break even, according to the vice president of Dassault [9].

Conception

During the development phase, approximately 190 of the 350 engineers were Dassault employees, while the remainder of work was shared among the 18 risk-sharing partners [9]. The engineers were all working on one single concurrent engineering platform, which consisted of Dassault Systems CATIA, ENOVIA and DELMIA Solutions [9]. The total development phase took five years, the total development cost was approximately US$965 million, excluding the engine manufacturer [13]. Dassault carried US$700 million, which gives an IMP of 1.4.

Configuration

The production value contributed by suppliers is approx. 50% of the total aircraft value, as Dassault produces the wings, horizontal stabilizer, front fuselage, center wing box and integration of the aircraft, which counts for the other 50% of the aircraft value. The resulting PMP is 2.

4.2 Embraer 170/190

The Embraer E-jets series are twin-turbofan-powered regional transport aircraft, consisting of the Embraer 170, 175, 190 and 195 models.

Value-time curve

Sixteen risk sharing partners participated in the concurrent engineering and development and co-production trajectory, with twenty-two partners serving as main equipment and component suppliers, with total development costs of US$850 million, of which US$290 million was borne by contributions from risk-sharing partners [7]. Embraer made numerous references to the unique partnering agreements to increase innovative capacity and share cost risk across the supply chain, as compared to its previous development efforts.

Relation with the 3C model

Continuation

It is clear that the 170/190 has been a large factor in making Embraer the world's fourth largest airline manufacturer [8]. As of 2007, accounting for the Embraer 170/190 model range, Embraer had a 42% market share in the world's up-to-120-seat segment [12]. According to the value-time curve, the break-even point of the Embraer 170/190 trajectory is in 2008. The Time to market (TTM) E-170 is 5 years.

Conception

The total development cost for Embraer 170/190 was approximately US$900 million. US$600 million of these costs were borne by Embraer, while US$300 million was provided by the risk sharing partners. This results in a IMP of 1.5.

Configuration

The PMP of Embraer is 3.3, as 70% of the aircraft value is supplied by systems and component suppliers (Forecast International, 2009).

Comparison of Dassault Falcon 7X and Embraer 170/190

The differences amongst the value time curves can be attributed to several factors. The 7X enters a market valued at US$10.50 billion in 2008 [1], while the 170/190 enters a market valued at US$31.5 billion (Forecast International, 2007). For the 170/190, there is the opportunity to capture more market share (MS), as the continuation metric of the 3C model reiterates, in addition to allowing four models to be built from one design effort. The approximate break-even point of 13 years for the 7X versus 9 years speaks to this. The TTM for both is five years. For the continuation aspect, Embraer has adopted a more successful approach into incorporating this into the value system.

Considering investments, Embraer had a structurally better approach at involving suppliers early. Relating to the conception metric of the 3C model, this results in an earlier break-even point.

As table 1 indicates, the IMP and PMP for Embraer are significantly higher than that for Dassault. The higher PMP and IMP indicate that Embraer has more effectively leveraged resources, leading to a more successful open-innovation approach resulting in a shorter time to break-even for its research and development trajectory (table 1).

Table 1. Comparison variables Embraer-Dassault

OEM-company /variable	**Embraer E-170/190**	**Dassault 7X**
Start of the curve	1999	2001
Market share	**42%**	**16,7%**
Time To Market	**5 y**	**6y**
Break-even	**9 y**	**13,5 y**
IMP	**1,5**	**1,4**
PMP	**3,3**	**2,0**
Highest investment level	**-/- $465 million**	**-/- $700 million**

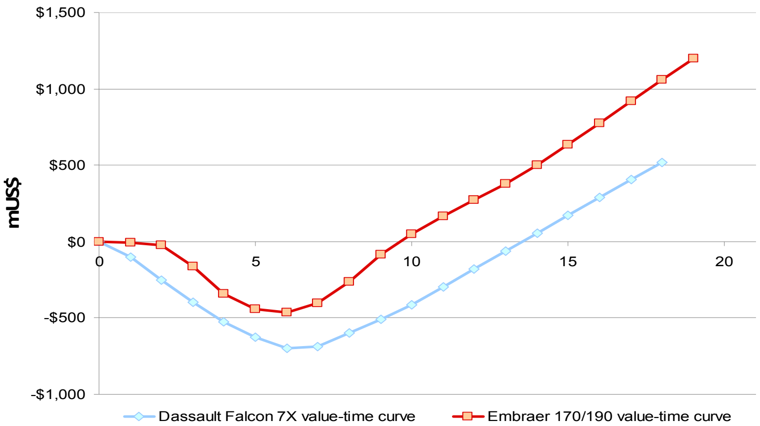

Figure 3. Dassault 7X and Embraer E-170/190 value time curves

When considering the conception metric of the 3C model, the structural differences in the approach to co-innovation amongst Embraer and Dassault become strikingly apparent. Embraer incorporated suppliers from the very beginning of the development trajectory. This resulted in an initial 85 potential partners, of which 58 were pre-qualified and eventually 16 were chosen [6]. This allowed Embraer to take on a “system integrator” role, and letting itself focus on the most valuable business processes for itself and those where it had a clear competency. It is clear that co-innovation was embodied early in the development cycle; Embraer invited international partners to become shareholders to aide in its in-house technological development, with Dassault Aviation, the European Aeronautic Defense and Space Company (EADS), each having bought 2.2 percent of Embraer’s total shares [8].

The 170/190 project is a unique case to illustrate the advantages of the 3C model. Some risk sharing partners went so far as to build new on-site factories in Brazil, substantially increasing co-innovation potential and lean supply chain principles, while decreasing currency fluctuation and supply chain risk, allowing Embraer to focus on key technologies in house and leaving the production and development of other parts to companies that can produce them more efficiently. Remarkably, many risk sharing partners, including Gamesa, Latecoere, Kawasaki and Enaer didn't have any mentionable history or competency in the aerospace industry prior to their participation in the 170/190 program [6].

The end result of this co-innovation trajectory is striking. Of note is the fourth quarter 2004 report [11], in which Embraer acknowledges that US$140 million from risk sharing partners would be recognized as operating income over the coming years. Second quarter 2006 research and technology expenditures further substantiate this phenomenon. In this quarter Embraer acknowledges positive research and development revenue – remarkable for an investment of the 170/190 magnitude – let alone from an aircraft maker that faced bankruptcy only eight years ago.

5 Conclusions and recommendations

This paper has sought to address the following research questions, (1) Can the value-time curve be established for an aerospace industry context? And (2) Within the Dassault Falcon 7X and Embraer 170/190 project context, do the IMP and PMP substantiate the lean methodology embodied in the 3C principles?

The value-time curve for the Dassault 7X and Embraer 170/190 were established from published investments and those from risk sharing partners. The break-even point is of Dassault 13 years after the start of development. The 170/190 has a break-even point nine years after commencing development.

It was also established that the IMP and PMP strongly reflect the principles embodied in the 3C model. Its three value drivers, continuation, conception and configuration, place an emphasis on the IMP and PMP.

A conclusion of this report is that the 3C model effectively embodies the lean methodology's emphasis supported by lean PD and concurrent engineering on time-to-market, overall investment costs by means of an investment velocity, and break-even point.

Recommendations for future investigations include a closer collaboration with Dassault into its research and investment outlays dedicated to the 7X's development. This would most likely need to be done by consulting Dassault, as little information on the investment profile is in the public domain. Further recommendations include quantifying the affects of currency hedging inherent in the risk-sharing emphasis of the 3C model. It is also recommended that more aircraft development trajectories be compared to further substantiate the precepts and benefits of the 3C model.

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Method for Evaluating VR-based Tools for Collaborative Design

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Abstract. Virtual Reality systems can impact on quality of collaboration design processes. In the present work is defined a structured method to classify, qualify and select VR-based tools for supporting co-design activities by adopting a set of benchmarking metrics. Attention is focused on collaboration scopes and requirements, participants' behavior and exploited interaction modalities. The method has been applied to synchronous and remote collaboration that actually represents the most critical communication in industry. Three different types of collaborative VR tools have been investigated and compared. Experimental results highlight how the proposed method is able to identify the main collaboration requirements by selecting the most proper supporting technology and show also the contribution to collaboration success.

Keywords. Collaborative design, virtual reality, benchmarking

1 Introduction

The need to manage cooperation in the extended enterprise has driven to the development of a new paradigm of the Collaborative Product Develpoment, that is the Virtual Enterprise (VE). VE can be defined as a temporary network of companies, which cooperate in order to exploit the rapid evolving business opportunities. A great number of independent variables have been identified and widely studied in order to support collaboration from all perspectives: group size, group composition, nature and objectives of the task, media and communication channels, interaction between participants, IT supporting system, etc. [1]. Each aspect is separately investigated without analyzing the mutual effects on collaborative performance. Measurements on co-design tools performance lack in analyzing effects of adopted technology on cognitive processes, collective creativity, mutual engagement, etc. Otherwise, studies on collaboration processes tend to lose system-based measurement in terms of achievable timesaving, product quality, task completion, etc.

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The present work, part of a more extended research [2-4], aims at finding a synthesis among these separate issues, by defining a method for selecting the proper co-design virtual environment that enhances team working in different CPD processes. This goal is achieved by: 1) observing multidisciplinary team work inside and outside manufacturing companies; 2) identifying the main critical collaborative processes among multi-sites company departments and their suppliers; 3) classifying different co-design systems to support both synchronous-asynchronous and remote-co-located collaboration; 4) measuring tools performance taking into consideration not only the provided functionalities, but also their ability to support product perception and cognition, design issues comprehension, mutual engagement and collective creativity.

In order to support system-based measurement, a set of heuristics and relative metrics are defined. They allow assessing the performance of co-design virtual environment in different CPD stages that differ for temporal (synchronous or asynchronous) and spatial contexts (inter and intra companies), for team composition, task goals and adopted interaction modalities (verbal, non-verbal, graphical, etc.).

2 Collaborative design processes classification and supporting tools

Design collaboration is based on sharing data, knowledge and concepts in order to efficiently achieve the process goal [5]. Current CPD process is increasingly carried out by multiple specialized participants, consisting of individuals, teams or even entire organizations. Each actor is potentially capable of proposing additional value for improving the process as he/she evaluates each choice from his/her perspective. He/she acts towards mutual understanding and maximizing outcomes by working on non-routine cognitive tasks and satisfying not only their goals but also those of other team members [6].

In this context, there is a variety of collaboration typologies involving different actors. As described by Barratt [7], collaboration can be either internally developed or can include customers, suppliers and others organizations. Furthermore, cooperation implies different combinations of time and space: groupware activities can be characterized by different timing and location. Timing depends on whether participants act at the same or different time: synchronous or asynchronous collaboration. Location depends on where actors geographically are: in the same place (co-located collaboration) or in different sites (remote collaboration).

These processes have to be supported by dedicated tools that allow sharing information (CAD models, Digital Mock-ups (DMUs), activity planning, workflows, etc.) during collaboration sessions. Information needs to be properly organized, collected and retrieved; users need to efficiently interact with each product/process representation. The complexity of CPD requires also managing team structure and roles, decision-making activities, etc. [8].

Widespread co-design tools correspond to a wide family of methods and technologies, frequently called groupware tools. They aim at supporting both face-to-face meetings in an interactive way (electronic whiteboards, tools for sharing desktop applications, etc.) and connecting people by internet-based technology (web conferencing tools, instant messaging, interactive whiteboards, etc.). A second generation of groupware systems consists of Web 2.0 applications. They adopt the concept of network as a platform for enhancing asynchronous work. Web 2.0 is exploited by several Computer Supported Cooperative Work (CSCW) applications whose functionalities vary from data visualization, to 3D models representation, real-time rendering, product models mark-up, audio-video communication support, etc [9]. In the recent years, new Human-Computer Interfaces (HCI), based on Virtual Reality technologies, have been introduced. Thanks to the advances in technological and applicative domain, they can be adopted to support collaborative networked organizations carrying out numerous design activities in shared human-scale virtual environments. Thanks to the enforcement of emotional components of communication, they improve participants' involvement, enhance product experience, facilitate mutual engagement and enrich shared creativity and cognition [10].

In order to achieve high presence communication during real time and remote collaboration, avatars have been introduced. They are virtual actors living in the shared environment, supporting communication among distributed team members. Several studies have investigated the role of avatars in enhancing communication and personal experience for co-design activities [11-12]. Examples of commercial systems based on avatars are: Sun Microsystems' Wonderland platform [13], Linden Labs' Second Life virtual world environment [14], the Croquet Consortium's Croquet virtual world platform [15].

A matrix has been used to classify the above-mentioned tools (Fig. 1).

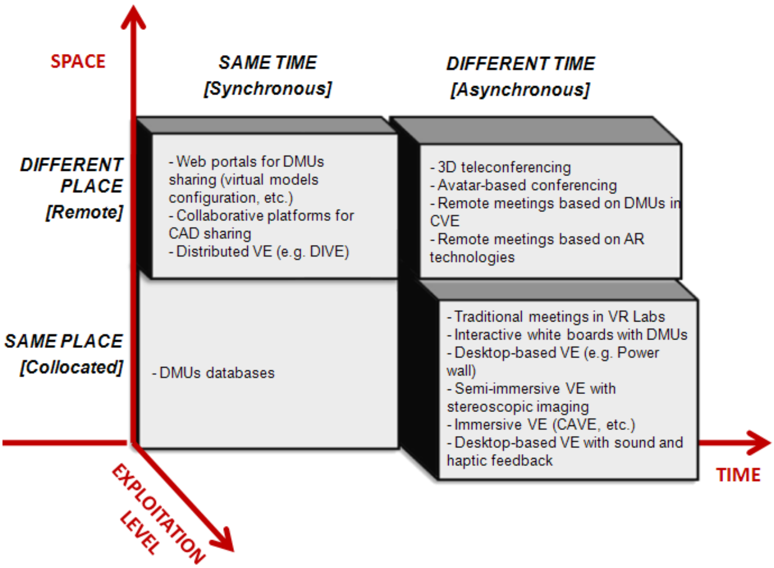

Figure 1. Relation between space-time dimensions and co-design tools

The exploitation level, that indicates if the tool is diffuse or not, highlights that Virtual Reality is widespread enough for co-located and synchronous activities (same time and same space), but it is not used for supporting asynchronous collaboration. Despite the potential benefits of VR-based technologies, some open issues still limit their application in real industrial design contexts: the high cost, the low usability in terms of users satisfaction (it is difficult to keep the participants concentration on tasks goal high while interacting with complex tools immersing them in the virtual space), the difficulty to identify the proper technology for the specific collaboration needs, the low sense of presence that influences a scarce mutual engagement among virtual teamwork participants. The above mentioned limitations can be overcome by searching for a compendium among all conflicting aspects: co-design needs, technologies potentialities and provided functionalities.

3 Protocol for assessing VR technology in Co-design process

In order to support companies in evaluating supporting tools and selecting the most appropriate one in relation with collaboration needs, a structured method has been defined. It applies the QFD (Quality Function Deployment) technique [16] to benchmark different VR-based technologies by matching co-design activities requirements with tools functionalities and human cooperation performance.
The method consists of four main steps (Fig. 2).

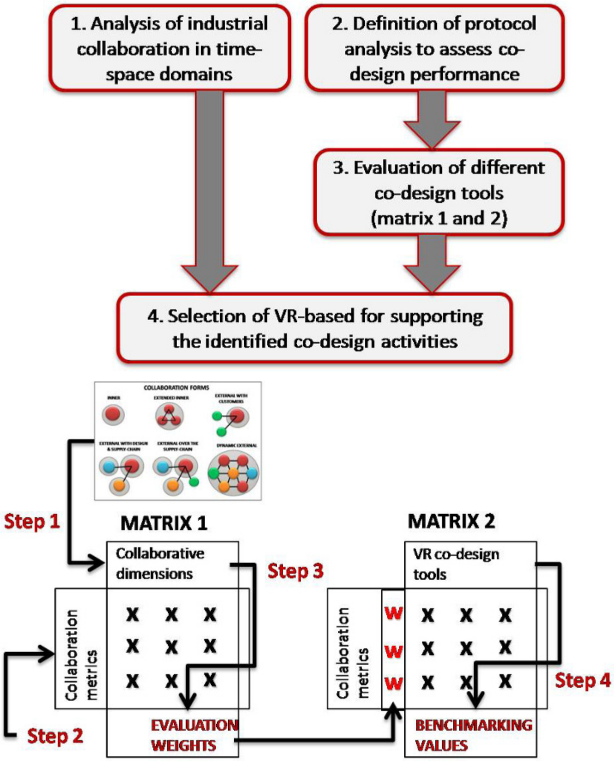

Figure 2. Steps of method for evaluating the collaboration dsign tools

1) **Analysis of industrial collaboration in time-space domains**: it defines which is the prevalent collaboration form (as classifuied in section 2) in the investigated context and which aspects characterize it.
2) **Definition of the protocol analysis in order to assess co-design performance**: protocol analysis is accepted as an experimental technique for exploring human behaviour at work. The protocol consists of data collection, segmentation, coding and analysis. This last step is carried out by measuring different heuristics able to objectify teamwork participants' behavior. Heuristics are expressed by evaluation metrics and relative measurement units.
3) **Evaluation of different supporting tools:** the protocol is applied to several working sessions supported by different VR-based technologies. Metrics are first estimated to calculate the evaluation weights for each collaborative form (matrix 1 in figure 2). Results are used to properly weight the performance of different co-design tools in relation with the collaboration needs (matrix 2 in figure 2).
4) **Selection of the best tool for supporting the identified co-design activities**: the highest value for relative importance in matrix 2 indicates which technology better satisfies the specific collaborative dimension.

3.1 Definition of the protocol analysis

A proper set of heuristics has been defined in order to estimate the collaboration performance. The recognized heuristics are: Teamwork, Communication, Human Involvement and Cognitive Reaction. For each heuristic, a set of evaluation metrics have been defined in order to highlight the critical issues of the multidisciplinary teamwork, to detect the requirements of different industrial collaboration forms and to decompose the whole process into its main aspects (Table 1).

Table 1. Heuristics and the related metrics

COLLABORATION HEURISTICS		DESCRIPTION	EVALUATION METRICS	UNITS
TEAMWORK	*1-Decision making process stage*	It measures the distribution of the design activity during Design Review and the communication stages used by participants	P = Presentation D = Discussion S = Solving E = Evaluation	Time (min) - %
	2-Design Content	It refers to the content that actors are talking about during design activity	U = Usability and ergonomics M = Market and trends A = Aesthetical features T = Technical-technological features F = Functionality	Occurrences - %
	3-Actors Skill	It measures the actors' experience and confidence in adopting the representational tools	1) Low 2) Poor 2) Medium 3) Good 4) Excellent	Likert scale judge
COMMUNI CATION	*4-Interaction Style*	It measures the modality preferred by actors for interacting with the model. Three different levels of action can be identified	1) by referring to the model (talking about, pointing out, etc.) 2) by physically interacting with the models (manipulating, touching etc.) 3) by simulating actions on the model (uses, etc.)	Occurrences - %

	5-Verbal Communication Style	It refers to the characteristics of verbal communication used by actors	1) Referential language 2) Highly descriptive language 3) Emotional language 4) Reflective-introspective language	Occurrences - %
	6-Nonverbal Communication Style	It refers to the characteristics of nonverbal communication used by actors	1) Poorly gesture-marked communication 2) Highly gesture-marked communication (expressing feelings) 3) Graphical-marked communication (writing, sketching, etc.)	Occurrences - %
HUMAN INVOLVEMENT	*7-Mutual Engagement*	It measures the modality preferred by actors for interacting with the supporting environment, focusing on the involvement dimension	1) Spatial dimension (shared spaces and objects) 2) Temporal dimension (shared temporary structures) 3) Conceptual dimension (shared ideas and abstract items)	Occurrences
	8- Collective Creativity	It measures the actors' ability of creating new ideas and the modality of merging different creative ideas inside the team	1) Help seeking 2) Help giving 3) Reflecting reframing 4) Reinforcing	Occurrences
	9-Stimulate imagination	It measures the actors' ability of being imaginative and forecasting solutions and/or problems	1) Low: actors are strongly linked to physical objects 2) Poor: actors partially refer to virtual models 2) Medium: actors refer to virtual models 3) Good: actors are able to extract features from the model and talk about them 4) Excellent: actors are able to image new concepts, solutions, problems, etc.	Likert scale judge
COGNITIVE REACTION	*10-Cognitive Reaction to model*	It measures how participants interact with models. It measures the participants' cognitive reaction to the model in terms of actions on it. Actions refer to physical operations on virtual objects (selection, placement and relocation of objects in the scene, assembly explosion, sectioning or measuring, mark-ups, etc.).	1) Actions before modelling 2) Actions during modelling 3) Actions after modelling	Occurrences
	11-Cognitive Perception of model	It measures the actors' cognitive perception of the model's elements	1) Attention to model elements 2) Attention to relations between model elements 3) Attention to model elements' locations	Occurrences
	12-Cognitive Decision Making	It measures the actors' decision making process for a cognitive point of view	1) Elaboration of a new solution 2) Application of a solution that is already known	Occurrences

3.2 VR-based technolgy benchmarking

The protocol application allows defining the specific collaboration requirements for each collaborative dimension in order to obtain a set of evaluation weights.

Further it allows assigning a set of performance values to every analyzed tool depending on its ability to meet the collaboration needs, expressed by heuristics.

The benchmarking method is structured as follows. Metrics are weighted by three experts in Human Computer Interaction (HCI) and two industrial experts in product design. They fulfil matrix 1 by assigning values to each metric for each collaborative form by adopting a 5-point scale (from 1 to 5). The average value mij is calculated for each of them and 5 intervals are identified by properly dividing the data span. Values in matrix 1 represent sets of expected values (wi) for each specific collaboration context (Fig. 3).

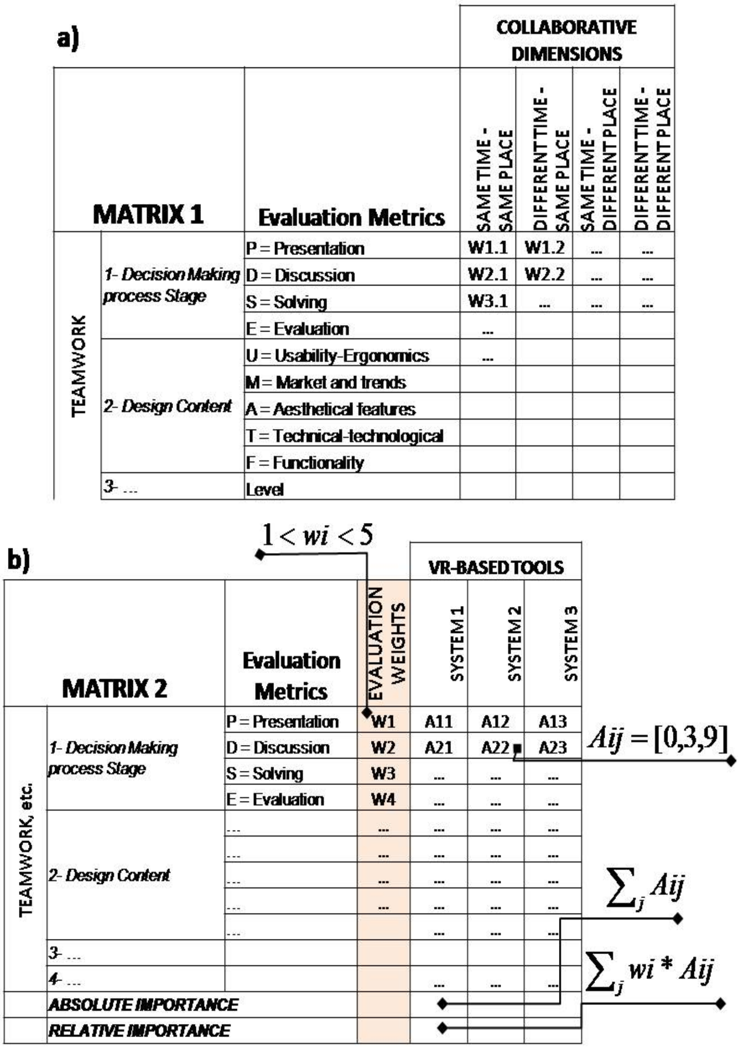

Figure 3. Matrices and used formulas to fill them

They allow properly scaling the technological evaluation according to the collaboration requirements for next step.

Then, metrics are estimated by the direct observation of several teamwork activities supported by different co-design systems. Audio-video recording and interviews are adopted to collect data regarding with participants' behaviour and interaction modes. Experts collect and analyze experimental data to fulfill matrix 2 by assigning 3-classes values (0-3-9). For each specific collaborative dimension, the relative set of evaluation weights (wi) by matrix 1 is introduced in matrix 2 in order to correlate the collaboration requirements with tools performance.

The final benchmarking is obtained by multiplying each absolute value for the relative weight and hence, calculating the relative importance each assessed tool. The resulting values allow comparing different technologies for a specific collaborative context and select the one that better answer to the expressed needs.

4 Case study

Experimentation is carried out to assess co-design virtual environment performance in synchronous and remote collaboration. Such dimension has been chosen as VR tools exploitation in CPD is still poor. The protocol has been adopted to evaluate three different systems (Fig. 4) during product design feasibility analysis and preliminary design reviews.

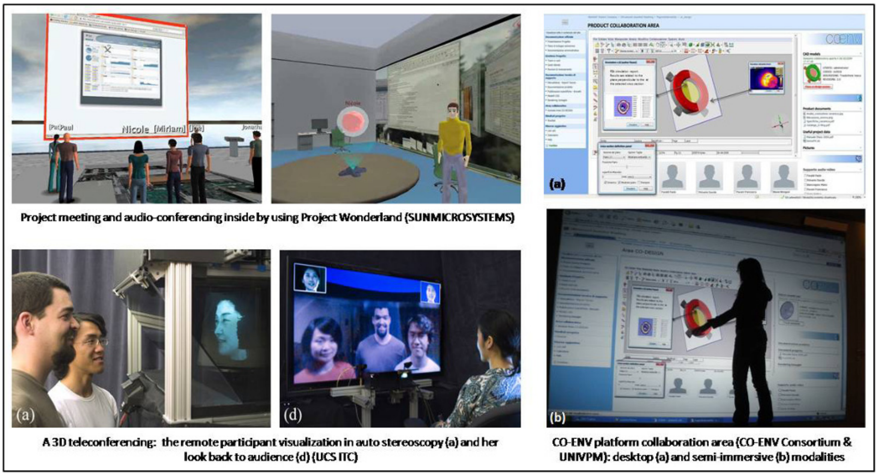

Figure 4. User interfaces of the three analyzed co-design systems

Two of the analyzed co-design tools are properly VR-based: one uses avatars in a completely immersed environment and the other one video avatars reproducing the participants facial expressions. The third is almost based on virtual prototyping exploiting DMUs in a shared space.

The first system is Wonderland by Sun Microsystems. It is an open source software toolkit for building virtual spaces where people are represented by avatars acting in the same space. An applicative example is MPK20, a 3D virtual environment designed for business collaboration and adopted in the Sun Labs' offices. Inside the MPK20 virtual world people can carry on business, interact with team members and have chance encounters with colleagues, also in a closed workspace. The second one is the 3D teleconferencing system by UCS ITC (University of Southern California, Institute of Creative Technologies). It represents a novel approach to videoconferencing that enables eye contact in one-to-many communication. It is based on real-time 3D face scanning system and large 2D video feed screen in order to correctly produce rendered eye contact between a three-dimensionally transmitted remote participant and a group of observers [17]. The last one is the CO-ENV platform (www.coenv.it), developed by Polytechnic University of Marche. It is a web-based collaborative platform that integrates different modules, such as a collaborative portal server (Microsoft Office Sharepoint Server 2007), a CAD-based tool (AutoVue by Oracle), an instant messaging and communication tool (Skype), a commercial Workflow Management System (softFlow by Metisoft) and a novel module to dynamic handle unpredictable events. The platform allows managing product knowledge and co-design reviews by sharing different types of documents and involving multiple users both in real time and in remote way. It can be accessed via desktop-based technologies and human-scale displays.

Results of the protocol analysis application are reported in figure 5. Matrix 1 has been filled by experts. The weighting values are defined by translating the assessed traditional ICT limitations into the necessary level to obtain a successful co-design process. They have been introduced in matrix 2 to correlate tools performance with expected CPD needs. The achieved evaluation column highlights some interesting issues for remote and synchronous co-design.

Presentation (5 points) and evaluation (3) stages are the most important ones in design review activity. They are mainly focused on aesthetic (5) and technical-technological (4) features discussion. The most successful interaction style is based on simulating action (5), due to the necessity of reaching a shared and immediate understanding among all participants. Communication is referential (5) and highly descriptive (4), especially when team members need to present and detail specific design issues. Drawings and sketches (5) are frequently used for supporting conversations. The conceptual dimension is the most strategic for mutual engagement (5), as design reviews requires to stimulate the exchange of new ideas and concepts and the mental elaboration of the analyzed product features. As a consequence, the imagination level should be highly enhanced (5) to realize innovative and original products. The supporting environment needs to be barrier-free and encourage natural and intuitive interactions. Decision-making activities should be based on finding new solutions (5) rather than reuse already known cases. Reflective reframing is crucial for having collective creativity processes (5). About cognitive interaction, physical operations on objects (such as selection, placement, sectioning, mark-up, etc.) are required during product design modeling (5) in order to support direct and instinctive human reactions. Finally, model perception is preferably referred to relations between product elements (5).

MATRIX 2		Evaluation Metrics	EVALUATION WEIGHTS	VR-BASED TOOLS: WONDERLAND (SUNMICROSYSTEMS)	VR-BASED TOOLS: 3D TELECONFERENCING (UCS - ICT)	VR-BASED TOOLS: CO-ENV PLATFORM (CO-ENV & UNIVPM)
TEAMWORK	*1- Decision making process stage*	P = Presentation	5	9	3	3
		D = Discussion	2	3	0	3
		S = Solving	0	3	0	3
		E = Evaluation	3	3	0	3
	2- Design content	U = Usability-Ergonomics	3	3	0	3
		M = Market and trends	1	9	3	3
		A = Aesthetical features	5	3	0	3
		T = Technical-technological	4	3	0	9
		F = Functionality	1	0	0	3
	3- Participants	Level	4	3	3	9
	Relative importance for Teamwork			**117**	**30**	**132**
COMMUNICATION	*4- Interaction style*	1) referring	3	9	3	9
		2) physically interacting	1	3	0	3
		3) simulating actions	5	3	0	3
	5- Verbal communication style	1) Referential	5	9	0	3
		2) Highly descriptive	4	3	0	9
		3) Emotional	3	3	9	0
		4) Reflective-introspective	1	0	9	0
	5- Nonverbal communication style	1) Poorly gesture-marked	3	9	3	0
		2) Highly gesture-marked	1	3	9	0
		3) Graphical-marked	5	3	0	3
	Relative importance for Communication			**156**	**63**	**111**
HUMAN INVOLVEMENT	*7-Mutual engagement*	1) Spatial dimension	3	9	0	3
		2) Temporal dimension	1	3	3	3
		3) Conceptual dimension	5	3	0	3
	8- Collective creativity	1) Help seeking	4	9	9	3
		2) Help giving	4	3	3	9
		3) Reflective reframing	5	3	9	3
		4) Reinforcing	3	3	9	0
	9- Stimulate imagination	Level	5	9	3	3
	Relative importance for Human Involvement			**162**	**138**	**105**
COGNITIVE REACTION	*10-Cognitive reaction to model*	1) Before modeling	1	3	0	3
		2) During modeling	5	9	0	9
		3) After modeling	3	3	0	3
	11-Cognitive perception of model	1) Elements	3	3	3	9
		2) Relations	5	3	0	3
		3) Locations	3	9	0	3
	12-Cognitive decision making	1) New solution	5	0	0	3
		2) Already known solution	2	9	3	9
	Relative importance for Cognitive Reaction			**126**	**15**	**141**
RELATIVE IMPORTANCE				**561**	**246**	**489**

Figure 5. Protocol results for the 3 analyzed systems

Matrix 2 allows quantifying the different VR-based tools performance and underlining their strengths and weaknesses. Experimental results highlight that the SunMicrosystems' tool is the best tool while the CO-ENV platform is also able to support synchronous and remote activities (561 for system no.1 vs 489 for system no.3). On the contrary, the UCS 3D teleconference tool is not suited for the identified co-design target.

The relative importance values interpretation allows understanding why the use of the three systems is substantially different. Teamwork is well supported both by system no.1 (117) and no.2 (132). The CO-ENV platform is able to answer to technical feasibility needs due to the sharing of CAD models and the real-time modeling. They are significant functions in feasibility analysis and preliminary design reviews. Communication is better supported by the Wonderland system (156), because it integrates an enhanced audio-video tool providing a strong sense of being there and participation. The CO-ENV supports only standard communication channels (chat, audio-video conference, e-mail). The resulting value is quite acceptable but not enough to enrich the mutual engagement (111). Human involvement is better stimulated by Wonderland (162). It triggers good spatial perception and virtual environment awareness. It is able to highly stimulate imagination thanks to hyperlinks and shared applications. From this point of view, the CO-ENV platform should be improved since human feedback is poor (105). Cognitive reaction to product models is better stimulated by the CO-ENV system (141) than Wonderland (126) as the first one better supports technical data visualization and models mark-up, spatial and functional relationships perception and information tracking.

Focusing on systems functionalities, Wonderland allows sharing numerous applications and easily recovering enterprise data, thus people can create, edit and share documents within the virtual world as well as in their office. It adopts a powerful immersive audio system in order to create a sense of social presence: this aspect clarifies the achieved high values in communication and support to human-based tasks. The main strength is the ease-to-use and the naturalness of being located inside the virtual space. This aspect can explain high values in teamwork tasks. The CO-ENV platform is specifically arranged for inter-companies co-design tasks. It allows participants to carry out specific design actions such as real time sharing of different files typologies, easy uploading of CAD-CAE assemblies, real time co-modeling, applying mark-ups and notes, accessing project data and dynamically managing workflows involving all team members. Such aspects explain the obtained high performance in cognitive reaction and decision-making metrics. Otherwise, communication needs to be improved. The 3D teleconferencing tool by UCS turns out to be rather inappropriate for synchronous and remote co-design purposes (246 is the total relative importance). In particular, it is unsuitable for supporting cognitive reaction (15) because any interaction with CAD models or products representations is not provided. Teamwork purposes are not well managed (30) due to the lack of design tools and a shared design space. However the UCS's tool achieves good values in human involvement (138). This depends on its ability to reproduce the effects of gaze, attention and face gestures that characterize face-to-face meetings, make teamwork experience more absorbing than traditional videoconferencing.

On the basis of achieved results, an ideal technological set-up can be identified for synchronous and remote collaboration. Teamwork communication can be carried out inside Wonderland where human involvement is supported by an advanced teleconferencing tool such as the UCS's one able to improve the sense of presence and mutual engagement. Oriented co-design tools should be integrated to create a shared platform to visualize virtual prototypes, exchanging technical documents, manage workflows, support models modifications and interaction in a natural manner, etc.

5 Conclusions

The present work aims at selecting the proper VR-based technology among numerous co-design virtual environments. It can be considered a step toward the exploration of VR systems for co-design activities carried out in different time-space domains.

Instead of focusing on system-based measurement in terms of achieved timesaving and provided functionalities, the proposed benchmarking method allows assessing human, cognitive and communication aspects of collaboration, starting from expected performance values. It provides a tool to investigate systems ability to stimulate mutual engagement, collective creativity and interaction support. As a consequence, it represents a novelty regarding with current methods, mainly based on processes stages analysis and time performance evaluation. The main scientific contribution consists in the evaluation of co-design virtual environments performance from a human and cognitive point of view by objectifying the cognitive-perceptual mechanisms of collaboration. The few experimental test cases demonstrate that the technological benchmarking is quite accurate and detailed: tools can be analyzed by multiple viewpoints, represented by the protocol heuristics. The method applicability is not limited to virtual environments supporting remote and synchronous design collaboration. It is general enough to explore limits and potentialities of different co-design tools for the extended enterprise processes.

In order to improve the approach and the evaluation accuracy, the method should be applied to additional case studies. Future works will be oriented to determine the ideal VR-based technology features for remote and synchronous co-design and try to develop it.

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How to Support Mechanical Product Cost Estimation in the Embodiment Design Phase

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Abstract. An efficient mechanical product design process implies the evaluation of many alternatives in a short time and rapid product changes on the basis of emerging needs. Product cost is one of the main factors in order to choose the most promising solution. Hence its accurate estimation in the design phases is fundamental. The main problem is the vast amount of knowledge that has to be managed in order to make robust evaluations. Features based 3D CAD models implicitly contain part of needed information. But such information has to be elaborated by adopting suitable rules based on manufacturing knowledge. In this context, the paper presents an approach and the related knowledge-based system able to automatically make reliable cost estimation starting from the 3D CAD model. The approach is based on the manufacturing knowledge formalization, on the geometrical and non-geometrical feature automatic recognition and, finally, on the mapping between manufacturing operations and modelling features. In order to validate the system performance case studies are reported.

Keywords. Cost estimation, feature recognition, knowledge-based systems

1 Introduction

The difficult market conditions force companies to adopt new approaches to improve the competitiveness. The offer of customized products can be a successful solution but it implies a relevant attention to production costs. Hence, companies have to apply methods and tools in order to respond to the dynamic customer needs while maintain a constant control on product cost. In this scenario the product development process has to be based on lean design methodologies that have to provide methods in order to early identify critical factors. One of the main aspects of lean design lies in the ability of product designers to perceive the key factors in order to manage new customized technical solutions and to estimate the related cost.

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The idea of the present approach is to provide designers with a Knowledge-Based (KB) tool that analyzes the product design information by using a manufacturing knowledge base in order to automatically obtain the estimation of manufacturing cost. Manufacturing and process planning rules are collected in the knowledge base. On the other hand, the 3D parametric and feature-based CAD model contains the product structure that is concretized through features, components, assemblies, and not geometrical data (roughness, tolerances, material, etc.). The knowledge-based tool analyzes the CAD data structure and extracts design information that it needs. The manufacturing operations are automatically linked to the product features, defined as advanced manufacturing features and simple modelling features. Finally, software system generates the cost estimation.

The developed tool, currently, manages the main manufacturing operations from machining to welding. Starting from the shared knowledge base it has been conceived to be used in different company departments: the design department, the product-engineering department and the purchasing department. The tool is under test in collaboration with a company that realizes woodworking machines.

2 Related works

The Design for Cost (DfC) methodologies have been studied and formalised since 1985 [1]. The DfC problem can be resumed in the following way: studying and developing methods and tools allowing the designer to calculate costs in the early design phase by managing the knowledge of production processes and, hence, costs incurred therein [2]. Many CAPP (Computer Aided Process Planning) systems have been developed during the last years but they are too complex to be used in the design phase because they require a lot of information beyond the product characteristics and they are, generally, not available during the first stages of design process.

A large number of approaches and methods for cost estimation have been presented in literature [3]. An interesting classification has been reported by Duverlie and Castelain [4]. In Niazi et al. [5] a detailed review of the state of the art in product cost estimation covering qualitative and quantitative techniques and methodologies are described. The qualitative techniques are further subdivided into intuitive and analogical, and the quantitative ones into parametric and analytical. A recent review concerning the cost estimation software systems usable during the product development process is reported in Cheung et al. [6].

According to Weusting et al. [7] cost estimation can be divided into two basic methodologies: generative cost estimation and variant based cost estimation. In the first case, the estimate is based on the decomposition of costs related to the expected production processes. In the second case, the analysis of similar past products allows the evaluation of new ones.

Parametric feature-based 3D CAD modeling systems can provide the practical support to manage cost information along with functional product definition and its virtual representation. Several feature-based costing technology applications are reported in scientific literature, an overview is provided in Layer et al. [8]. For example, in Ten Brinke [9] an interesting system for estimating costs of sheet metal components is described.

However, there exists no satisfactory computer-aided support for the cost estimation task related to all manufacturing operations domain. Important research works have been carried out in machining operations [10-11], but the developed systems are not well integrated in the design process flow. An improvement has been described in aircraft design field by Watson et al. [12]. An approach where cost estimation has been applied during design phase is reported also in Germani et al. [13]. The work shows how a cost estimation method can be used effectively within a framework in order to manage the configuration of a product variant. Other interesting cost estimation approaches usable in the early design phases are described in Shehab and Abdalla [14] and Mauchand et al., [15]. Both papers propose methodologies and tools in order to support designer choices oriented to optimise manufacturing cost at early design phases, i.e. selection of material, selection of process etc. These rules are important in conceptual design phase. An interesting applicative example representing a step towards the applicability of cost estimation in the early design stage is reported in Castagne et al [16].

From a technological point of view commercial software packages are not still available for cost estimating without excessive effort in manufacturing process modelling, i.e. Delmia by Dassault Systemes.

The proposed system try to overcome the state of art by developing a robust KB system able to support the whole product development process in the most critical phases by providing the right level of detail of product cost information.

3 Cost estimation approach

During product development three main departments are involved in product cost generation. Firstly, the product design department where the product cost is generated. Secondly, the product engineering department where the product feasibility is studied, all manufacturing operations are defined and the cost is calculated in detail. Finally, the purchasing department that interacts with suppliers in order to establish prices and choose the best supplier. The operators of these departments interact with product cost from different viewpoints.

In order to optimize the product design process it is essential above departments base their activities on a shared cost model and a unique cost estimation tool. Otherwise, the lack of this kind of approach determines a scarce awareness of designer to the cost problem, shifting toward the product engineers all cost evaluation activities. This work aims to overcome the problem by developing a software tool dedicated to the design department but also providing a specific view of the product cost model for the other two user typologies (figure 1).

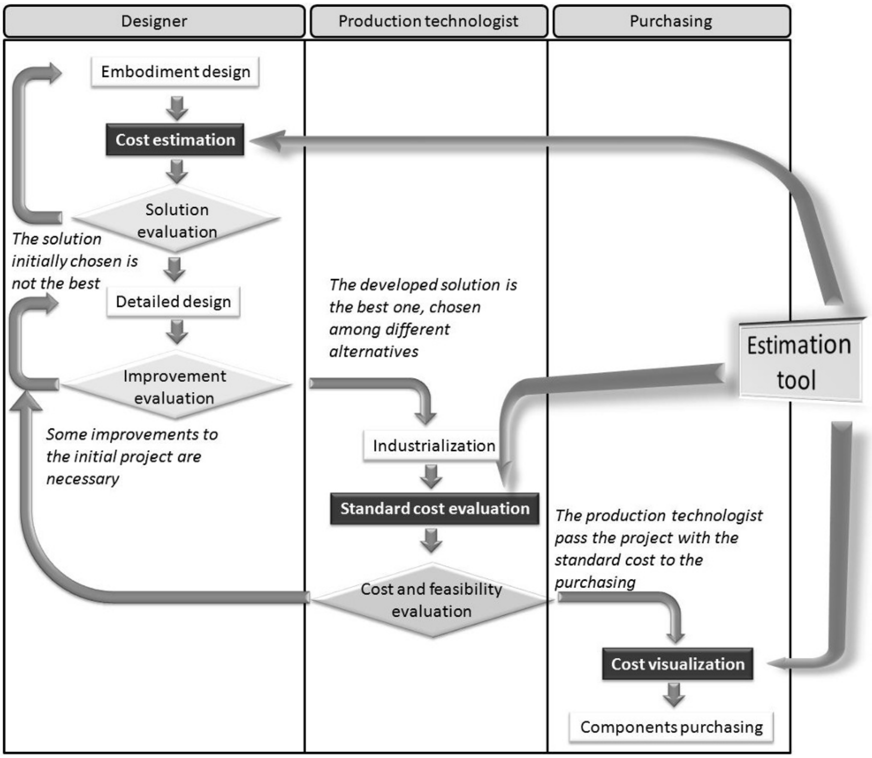

Figure 1. Cost estimation process related to the three different departments

A shared manufacturing knowledge base is used as common element in order to support this multilevel framework. Referring to figure 1, "Cost estimation" is the phase where designers estimate manufacturing cost and can accept a certain error, while "Standard cost evaluation" is the phase where the production technologist evaluates the exact manufacturing cost.

In order to make usable this framework to all users, it is necessary to develop a detailed estimation method aimed to satisfy the deepest user, who is the product engineer.

As cited above, estimation methods can be classified in four typologies: intuitive, analogical, parametric and analytical. Among them, the most coherent with the proposed objective is the analytical method. In fact, it allows evaluating product cost by the decomposition of work required into elementary activities (an example of an elementary activity is a machine tool operation).

At the design stage, by using the analytical approach it is necessary to determine all activities needed for component/assembly manufacturing. While product engineers have experience for cost estimation, the designer rarely has the same kind of knowledge. Hence, it is essential to formalise the manufacturing knowledge in order to apply it during cost estimation.

3.1 Manufacturing knowledge formalisation

The product engineer knowledge has been structured in order to support the analysis of product design information and translate it in manufacturing operations and, hence, in manufacturing cost.

Manufacturing technologies have been analyzed and divided into classes as follows: chip-forming machining, mechanical carpentry, painting, thermal treatments, superficial covering, metallic alloy molding and plastic molding. Classes have been further divided into categories, for example the machining class has been subdivided in milling, turning, grinding, gear cutting, broaching and slotting. Within these category have been defined the operations, for example typical operations for milling are face milling, slot execution, etc. Then, the geometrical parameters have been determined in order to univocally characterize the operations. For example the face milling operation is characterized by length, width, depth, geometrical tolerance (planarity) and roughness.

In the proposed knowledge base, operation is the most important level of data aggregation. The operations have been univocally mapped with a specific set of geometric and non-geometric elements that have been defined *advanced manufacturing features*. In this way the product model can be represented as a collection of advanced manufacturing features and simple modelling features. The recognition of these features on product model allows establishing operations and their sequence.

In order to realize the cost estimation process (figure 2), knowledge has been categorized at two levels. The first one (first knowledge level) is used to determine the list of operations required to manufacture the component by starting from product model geometrical and topological information. The second one (second knowledge level) is necessary in order to calculate the cost of every operation and the total cost of the end-item. Into this second level is stored the estimation technique that product engineer uses.

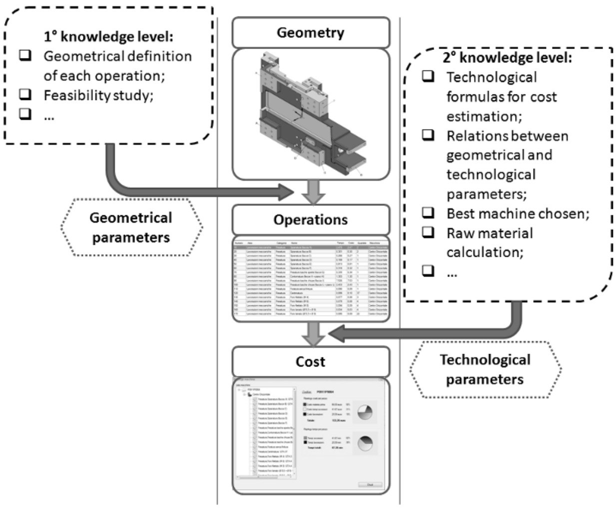

Figure 2. Cost estimation process and the two different levels of knowledge base.

In order to apply the right estimation rules a definition of all advanced manufacturing features has been necessary. They are a set of geometrical elements (faces and axis) conveniently arranged in a recognisable topological shape with specific dimensional constraints and with specific manufacturing information (tolerance and roughness). This information determines a group that can be associated to a specific operation. The advanced manufacturing features have been defined because it is not always possible link the CAD modelling feature to a machining operation. In the following table (table 1) examples of advanced manufacturing features are reported.

Table 1: Examples of advanced manufacturing features.

Advanced Manufacturing Feature	Definition
External cylindrical slot	External cylindrical surface enclosed by surfaces with a diameter greater than reference one, and the cylinder length is greater than 6 mm., furthermore it should be guaranteed the radial accessibility of the tool
External cylindrical turning	External cylindrical surface which does not have any faces with a radial range greater than the machining surface diameter, moving from the machining surface to the tailstock, furthermore it should be guaranteed the radial accessibility of the tool.
Frontal slot	Planar surface enclosed by cylindrical surfaces (one external and the other internal) in order to form a solid angle greater than π. It should be guaranteed the axial accessibility of the tool.

In other cases simple CAD modelling features can be directly linked to the operation; for instance the thread hole definition as represented in the CAD model data structure is sufficient to determine the corresponding operation.

The second knowledge level is oriented to determination of manufacturing cost, starting from the operations list with their geometrical parameters. This level is based on definition of algorithms that product engineer uses in order to determine all technological parameters necessary for cost estimation process. These algorithms need a lot of data (raw material cost, standard equipment time, etc...) and relations (material-cutting speed, material,-machine-tool-feeding rate, welding speed-bead dimension-material, etc...) that can be stored within a technological database. The values extracted from database are elaborated by specific formulas used to calculate the estimation parameters and the final component cost.

3.2 Example of the approach application

In order to understand how the proposed approach is able to estimate the manufacturing cost a simple example is reported. It interests the *external cylindrical slot* advanced manufacturing feature (figure 3). The taxonomic definition of this feature is reported in table 1.

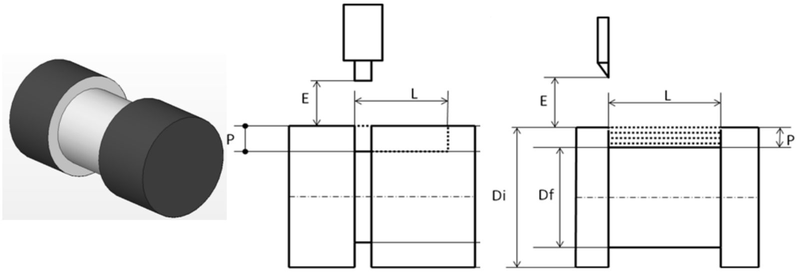

Figure 3. On the left, the grey faces represent the external cylindrical slot. In the centre and right the first and second phases of the turning operation are respectively shown.

The data structure of the 3D CAD model is analyzed and proper algorithms compare the definition of *external cylindrical slot* feature with the geometric model in order to recognize it with its geometrical parameters: initial diameter (Di), final diameter (Df), radial allowance (P), slot length (L) and roughness (R).

Once the geometry has been identified it is possible to determine all activities necessary for slot execution. In this case by using a rule based on the roughness value can be chosen the needed activities and the machines tools for machining:

IF	$R \leq 0.8\,\mu m$	**THEN**	*turning (roughing and finishing) + grinding*
IF	$0,8 < R \leq 3,2$	**THEN**	*turning (roughing and finishing)*
IF	$R > 3,2\,\mu m$	**THEN**	*turning (roughing)*

Hence, the necessary phases for slot realization are: the execution of the initial relief and the external cylindrical turning. Taking into account only the second phase, the formulas used in order to calculate the machining time are as follows:

Roughing passes $$NPs = \frac{P}{Pp} \quad (1)$$

Medium diameter $$Dm = \frac{Di + Df}{2} \quad (2)$$

Rotational speed $$n = \frac{1000 \cdot Vc}{\pi \cdot Dm} \quad (3)$$

Roughing feeding rate $$VAs = n \cdot As \quad (4)$$

Finishing feeding rate $$VAf = n \cdot Af \quad (5)$$

Working time $$Time = \left(\frac{L + E}{VAs} \cdot NPs \right) \cdot 1.25 + \left(\frac{L + P + E}{VAf} \cdot NPf \right) \cdot 1.25 \quad (6)$$

Where Pp is the cutting depth, Vc the cutting speed, As the roughing feed, Af the finishing feed, NPf the pass number for finishing, E the extra traverse and 1,25 is used to consider the rapid traverse.

By linking a specific database where companies store the unit cost of each machine, that comprises also the overheads cost, it is possible to quantify the feature cost. In order to completely estimate the cost of component it is also indispensable to define the cost framework. It is determined summing the cost of the stock with the machining cost, composed by fixed (cost which must be subdivided for the number of lot components, such as equipment cost) and variable cost (it is the direct cost of machining). In the same way is performed the welded assembly cost estimation; in this case before each component is separately evaluated and then the welding cost for assembling them. In this way labour cost, proportional to time of manual operations, and material cost are considered.

4 *LeanCost:* Knowledge-based system for product cost estimation

The described approach has been implemented in a software tool called "LeanCost". In figure 4 is represented the system structure.

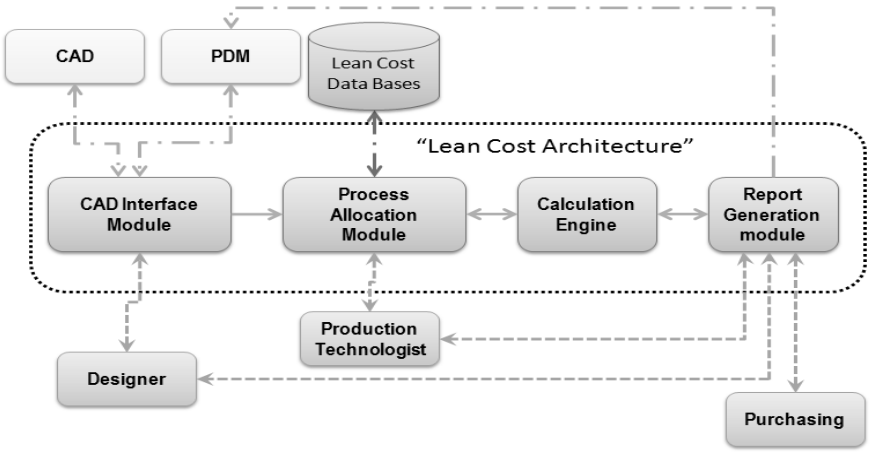

Figure 4. LeanCost system structure

This tool is a Windows-based application that currently can estimate the cost of components and welded assemblies. In particular it has been implemented taking into account the context of companies where Product Lifecycle Management (PLM) systems are present. LeanCost interacts with the PLM system in order to extract the needed geometric and non-geometric information.

The structure includes also specific databases about machine tools, materials and cutting parameters (cutting speed, setup time, etc.).

The LeanCost application supports three different user access levels:

- **Designer user:** the access is integrated within the CAD system user interface; the system automatically performs the cost analysis.
- **Technologist user**: he/she inherits the cost analysis from design phase; this user verifies results and analyses various reports in order to plan manufacturing activities. The technologist user can set the process and working cycle parameters.
- **Purchase department user**: this access level is limited to the cost reports; they are used to choose the most suitable suppliers.

As shown in figure 4 the LeanCost tool is composed of four main modules:

- **CAD Interface Module**: this module, analyses the CAD model and the related not geometrical information in order to identify the advanced manufacturing features. This module is linked to the PLM system (in this research is used Solid Edge.20, by Siemens Gmbh). The extraction of information from the CAD model is made by reliable classes and functions properly developed. They perform a topological analysis of all geometrical entities. The module generates as output an ordered set of advanced manufacturing features represented through geometrical entities, dimensions, finishing, tolerances and physical properties (mass and density).

- **Process Allocation Module**: the set of ordered advanced manufacturing features and simple modelling features are converted in a set of operations using this module. This tool establishes the necessary processes to manufacture component. This module interacts with external databases that store machine tools, materials and cutting parameters.
- **Calculation Engine**: a stand-alone module calculates manufacturing time by using proper computation functions related to different processes.
- **Report Generation Module**: it manages all calculated data and processed by the other tools.

A typical cost estimation work session implies the following stages. The designer works on the project for each product model (component or assembly). He/she uses the CAD system and generates the product cost estimation by using LeanCost. By analyzing cost of different solutions, designer can identify the best one. The created project is stored into a shared database, so technologist can retrieve it. This user works on project elaborated by designer in order to refine the estimated cost and modify, if necessary, the cost of specific processes. The calculated cost with notes related to feasibility or improvements can be sent back to the designer. When this iterative process is completed the project is released. The released project by manufacturing technologist, then, is ready to be sent to purchasing department for supplier selection.

5 Experimental results

The Lean Cost preliminary test has been performed in collaboration with a world leader company that produces woodworking machines (Biesse Group S.p.A.). It has been chosen a new functional group that had to be designed. Two mechanical assemblies (carpentry) and two components have been approached. The first two are respectively composed by five sheets metal and ten beams (P0610P0081 code, figure 5) and one sheet metal and three beams (P1213P0064 code). All these components are welded among them. The two single coomponents are obtained starting from an aluminum die cast stock, which are further machined by using a CNC milling.

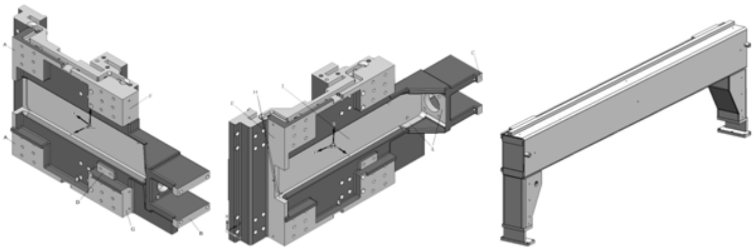

Figure 5. The left and middle pictures show, in clear grey, the faces machined for the P0911P0064 component. The right figure shows the 0610P0081 carpentry

In parallel two design teams have been activated. One of them has used the traditional tools (PLM system, excel spreadsheets, etc), on the other hand, the second team has used the PLM system and LeanCost. In this way it has been possible to make a comparison in terms of time and process efficiency.

In table 2 the cost of the main manufacturing operations for the P1213P0064 is estimated (column 2) and compared with the measured cost on machine (column 3). After time calculation, thanks to formulas previously defined, the cost is obtained by multiplying time for unit cost of machine where operation is executed. This cost is defined directly by the company, considering parameters such as its depreciation charge, working hours in a day and cost of the operator.

Table 2. Cost estimation of the some operations on the P0911P0064 component.

Operation	LeanCost Estimation [€]	Process Cost measured [€]	Deviation [%]	Machine tool
Face "A" flattering	2,47	2,47	0	Horizontal milling
Face "B" flattering	0,31	0,30	3,2	Horizontal milling
Open pocket milling	7,52	7,45	0,9	Horizontal milling
Closed pocket milling	2,43	2,40	1,2	Horizontal milling
Drilling and threading M4 hole	0,21	0,21	0	Horizontal milling
Boring Ø9 Hole	0,06	0,06	0	Horizontal milling

Table 3 shows the accuracy of the estimated cost compared with the real cost calculated after functional group manufacturing.

Table 3. Deviation analysis between estimated cost and real cost for test case components.

Code	Lean Cost Estimation [€]	Real Measured Cost [€]	Deviation [%]
P0610P0081 (carpentry)	464	460	-0,9
P1213P0004 (carpentry)	144	156	7,6
P0911P0064 (die cast stock with milling operation)	134	145	8,2
P0914P0878 (die cast stock with milling operation)	106	112	5,6

Finally, in table 4, the efficiency of new process is highlighted in terms of time saving both during design phase and detailed cost estimation phase. The time saving evaluation was carried out analyzing time spent by designer during his work, from the conceptual design to detailed one. From the point of view of a PLM item, this time starts with the “drawn” state and finishes with the “approved” one.

The main results after this preliminary test can be resumed as follows. By using LeanCost product designer is able to rapidly evaluate if design solution can be manufactured or it must be substituted by another one with similar characteristics but with smaller cost. Due to the early check of design solutions designers can autonomously identify the main manufacturing errors related to an excessive cost in the conceptual and embodiment design phases. In this way, the number of iterations between design and product engineering phases is significantly reduced. Finally, the inexperienced designer can continuously acquire competencies on manufacturing operations with a better awareness to final cost.

When used by the manufacturing technologist the main advantages connected to the use of LeanCost tool are: a relevant reduction of time necessary for standard cost determination (in fact the task is limited to verification of cost calculated by the estimation tool during the design phase), the project modification is very easy, because all formulas and data used for cost evaluation are stored within the tool, finally, it is able to make reports in order to trace all cost items, classified according to specific demands.

Table 4. Evaluation of the main advantages due to the implementation of the developed estimation tool within a real industrial context.

Code	Product design time saving [%]	Time saving (technologist) [%]
P0610P0081	20	70
P1213P0004	15	70
P0911P0064	12	50
P0914P0878	12	50

6 Conclusions

Agile product development requires the improvement of all processes starting from the most strategic ones. Product cost estimation is one of them. In fact product changes have an immediate impact on product cost. This paper describes a knowledge-based system that can be used in order to develop a shared cost model based on analytical methodologies for cost estimation of components and welded assemblies. The developed system has been tested on different real case studies. The numerical results are really encouraging in terms of deviation in respect to the traditional processes. Also the time saving and the process efficiency are meaningfully improved.

The future work will be dedicated to the extension to other manufacturing operations, assemblies and disassembly and the improvement of estimation accuracy. Furthermore the system will be applied in different fields in order to investigate the robustness of approach.

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A Geometric Modelling in the CAD System from the Medical Images to Support Prosthesis Design

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Abstract. This paper discusses the feasibility of individually designing human prosthesis for surgical use and proposes a methodology for such design through mathematical extrapolation of data from digital images obtained via tomography of individual patient's bones. Individually tailored prosthesis designed to fit particular patient requirements as accurately as possible should result in more successful reconstruction, enable better planning before surgery and consequently fewer complications during surgery. Fast and accurate design and manufacture of personalized prosthesis for surgical use in bone replacement or reconstruction is potentially feasible through the application and integration of several different existing technologies, which are each at different stages of maturity. Initial case study experiments have been undertaken to validate the research concepts by making dimensional comparisons between a bone and a virtual model produced using the proposed methodology. Future research directions are discussed in the final section of this paper.

Keywords. Geometric modeling, CAD, human prosthesis, image processing, medical information, tomography examination

1 Introduction

Advances in manufacturing technology accompanied by accelerated design techniques that are enabled through electronic information exchange and management are increasing the feasibility of very fast and accurate production of individually tailored or personalized products. There are many potential benefits to be gained through these approaches particularly in the context of medical applications. This paper discusses the feasibility of individually designing human prosthesis for surgical use and proposes a methodology for such design through mathematical extrapolation of data from digital images obtained via tomography of individual patient's bones. Individually tailored prosthesis designed to fit particular patient requirements as accurately as possible should result in more successful

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reconstruction, enable better planning before surgery and consequently fewer complications during surgery.

There are very substantial, international requirements for reconstructive or replacement surgery. In Brazil, it is estimated that 12% of the people are physically disabled, i.e. approximately 19 million people. The reasons for their deformities are varied, but the main reasons include car accidents, accidents at the work, radical sports, genetically-based malformation and pathological and degenerative illness [5].

In the UK, bone reconstruction and replacement is successfully undertaken by surgeons in many types of routine and elective surgery. This is a major area of expenditure within the health service, since for example 147,000 knee and hip treatments were carried out in [11]. Bones from hips, knees, shoulders, ankle and elbows can all be routinely replaced and typically last for approximately 15 years. There are also many more difficult and challenging cases of bone reconstruction (e.g. jaw and skull) due to congenital or traumatic conditions as well as for elective cases.

The current method in which a prosthesis is produced for bone replacement is either by choosing an approximate prosthesis (using the experience of the Surgeon) from a pre-formed selection (typically made from metal, high density polyethylene or ceramics) or by hand-making an appropriate prosthesis, or by performing reconstructive surgery whilst the patient is in theatre. These methods have consequences on quality and on operational costs, since normally the prosthesis are geometrically irregular obligating the surgeon to make adjusts during the surgery process. These adjustments can increase substantially the surgery time and costs and, also can cause, in certain cases, traumas to the patient. In this research the authors has proposed a methodology for modeling geometrically prosthesis design using medical based on images as a support. The article presents as well a dimensional comparison between of 3D geometric modeling generated in a CAD system and a 3D dimensional coordinates measure machine (DEA - Sirroco).

2 Background Technologies

Fast and accurate design and manufacture of personalized prosthesis for surgical use in bone replacement or reconstruction is potentially feasible through the application and integration of several different existing technologies, which are each at different stages of maturity [3, 2, 4, 1, 8, 9, 10].

2.1. Images Processing (Three Dimensional - 3D)

The discovery of X Rays, which allow indirect access to the human body, enabled diagnostics to be made from images. However, the incorporation of the computerized tomography in the 1970’s and subsequent advances in the processing of three dimensional images have vastly improved capabilities in human body visualization, providing valuable tools for diagnosis and treatment of many conditions. Data from tomography scans can be captured and extracted in the DICOM - Digital Imaging and Communications in Medicine format [6]. However, before this data can be used in the design of prosthesis, it needs to be converted, "cleaned" and pre-processed into a form suitable for transfer to a computer aided design (CAD) system [1, 7].

2.2. Geometrical 3D Modeling in CAD Systems

These days CAD systems are very valuable tools in the design of most (if not all) products. An aim of this research therefore is to determine a feasible methodology for the creation of virtual models of human prosthesis in a CAD/CAM system. However, despite their common usage, existing CAD systems still have several limitations that must be addressed if they are to be used in this context. The main problems for the complex three dimensional reconstruction that is required for the design of personalized prosthesis (based on individual patient's bone and body shapes) are bifurcation and open borders problems, as existing CAD software systems cannot solve these problems automatically.

The problems are largely due to the geometrical complexity of the individual human bones, indeed, they are so complex that it is hard to find mechanic components with such complexity. In the several CAD systems with solid and surface modellers that currently exist on the market, there are several common functions (e.g. loft, swept, rule, through curve, and others) that are utilized to generate the surface of the borders and produce a 3D model. As the geometry stays totally closed, the union of these surfaces can be transformed into a solid geometry. In short, the essence of this environment is to create surfaces or solids from parallel borders. The surfaces are obtained by the interpolation of a built curves sequence, most of them, in a parallel plane. Thus the following constraints exist which restrict our use of CAD in this application area: i) limitation of only one border by plane; ii) the border/curve must be closed; and iii) some systems may not have the superposition of the borders/curves.

These problems largely have to be addressed in the cleaning and pre-processing stages, prior to importation of the data to the CAD system. It may also be necessary to simplify the region to be built. The image data must also be converted into an appropriate format before importing it into the CAD system to model the surfaces, since the CAD/CAM systems work in polygonal format (vector) and not in the matrix format (raster).

2.3. Virtual Machining Modeling (CAM)

Assuming that a solid geometry can be generated by the CAD system, based on the tomography image, the dimensions of the raw material needed for the CAM process (machining) can be determined. The virtual machining process can then be defined by dividing the model basically into two parts: external surface, for the representation of the external part of the bones; and internal surface for the representation of the internal part of the bones. Each part can then be defined in the software using the geometry of the model, the dimensions of the raw material and a definition of a point of reference (zero point).

With the defined geometry, to generate the trajectory of the machining, it is necessary to select the suitable tools, to obtain the most suitable surface finishing quality and the machining strategies. After these steps, a simulation is realized and if all elements are visually correct, the code CNC can be sent to the machining tool via DNC.

2.4. The Methodology for Prosthesis Modeling in the CAD System

The methodology is depicted in figure 1 which can be divided in two main functions: i) the acquiring and conversion of the tomography image and the creation of the geometrical model in CAD; and ii) the virtual machining of the model. In this article we only will explore the first part of the proposed methodology in order to convert the tomography image into a 3D geometric model in the CAD system.

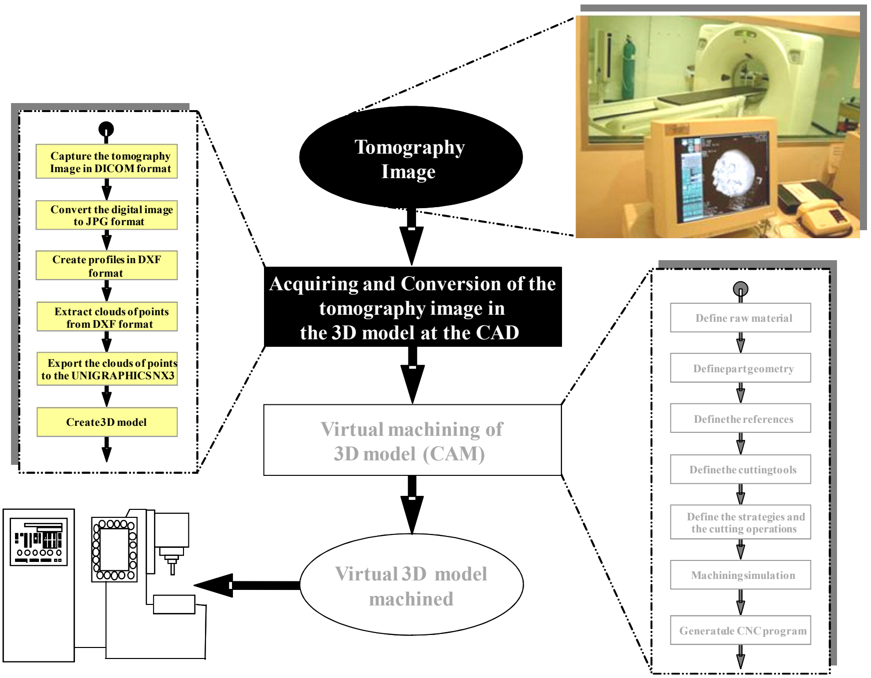


Figure 1. Conception and manufacturing of prosthesis models.

3. A Case Study

In order to test the concepts of this research presented in section 2 an initial case study work has been carried out at Pontifical Catholic University of Paraná (PUCPR), in Brazil. The case study experiments aimed to validate the research theories by making dimensional comparisons between a bone and a virtual model produced using the above methodology. In this initial experimentation, a femur bone from a cow was used, as it was easily purchased from a specialist supplier as shown in figure 2. To demonstrate the feasibility of creating a virtual model for the reconstruction of only part of the femur, a section of the bone was selected for the experiments. The chosen part was near to the intermediate part, and large enough for about 40 tomography cuts to be taken. The part of the bone studied is shown in the left side of figure 2.

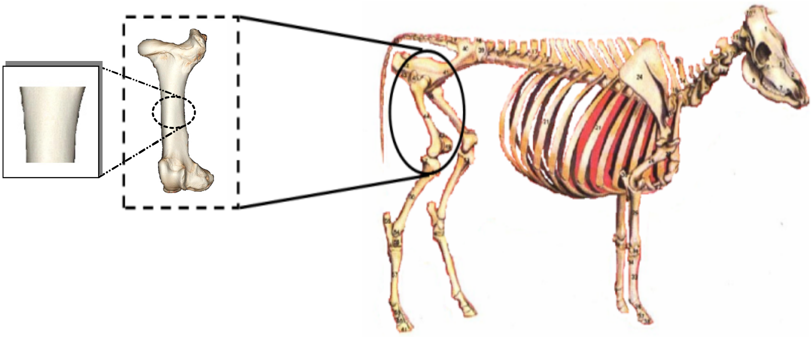


Figure 2. Part of the femur to be studied.

3.1 Data Acquisistion

The tomography examination of the femur was made in a helicoidal tomography scan machine from General Electric Medical Systems, model HiSpeed CT, as shown in figure 3 and the software used for the image acquisition was the Image Works System, also from General Electric. The bone was lined up on the tomography scan machine with its "Z" axis coinciding with the machine scan directions where 288 tomography images were obtained, starting from the base of the femur and going up in the scan axis (z) a millimetre and a half for each tomographic image.

Figure 3. Bone in the tomographic scanner.

3.2 Data Analysis

The procedure for cleaning and pre-processing the tomography cuts is now discussed, by using the example of cut number 100. Each cut was treated in a similar manner, and cut number 100 was made at 151 mm from the base of the bone, in relation to the "Z" axis. Firstly, the digital image was extracted from the DICOM archive, as shown in figure 4. From the image we can extract the ROI (Region of Interesting) in order to cutoff the undiserable data located at the bottom of the image.

The following 5 steps were applied to obtain the points of clouds data. The results of each step are shown in table 1. In the first step the image was cleaned to remove unwanted lines and imperfections due to the bone porosity. A filter can also be applied to improve the image intensity. The internal edge was then removed in the second step, whilst the external edge was maintained by keeping the original pixel values. The edge detection techniques (differentiation method) were applied in third step and then a prepared the image for the capture of the Cartesian coordinates was made in step four. The edges of the image were split into two parts called left and right side. This division is necessary to avoid incoherency in the Cartesian coordinate's vectors obtained by the scan. Finally, in the step 5, the acquisition of the Cartesian coordinates. This capture was made in two stages: first the left side coordinates were captured and then the right side. After the capture, the coordinates were united to form a single vector.

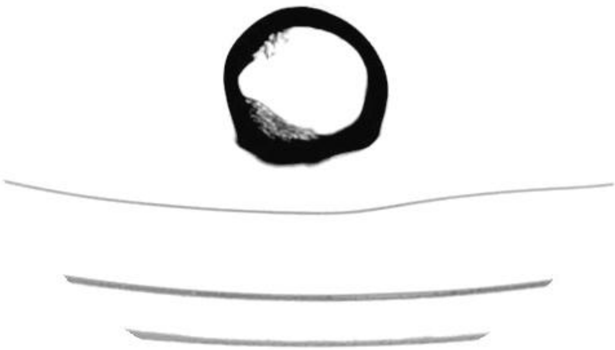
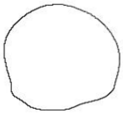
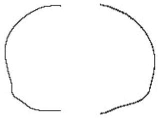
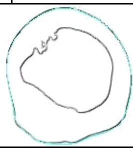
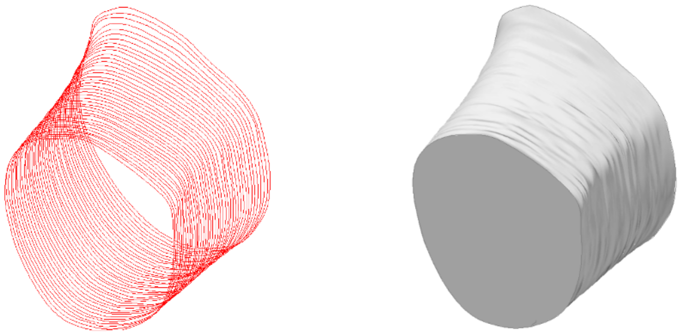


Figure 4. Tomography cut number 100.

After these five steps of processing, the cloud of the points archive was obtained. It is important to note that the values were initially obtained in pixels and were later converted to milimeters (mm). When the cloud of points archives had all been processed in this way, the data was imported into the CAD system (figure 5a) and the repositioned planes were used in the loft command. Forty cuts (from the two hundred and eighty eight) were used for the reconstruction. So, the loft command was then applied to the data to obtain the solid model as depicted in figure 5b that illustrates also the union of the profiles.

Table 1. Five steps to create the profile of each cut.

STEP	IMAGE	STEP	IMAGE
1		2	
3		4	
5			



a) Cuts positioned for the application of loft technique.

b) Application of loft command (to the parallel profiles).

Figure 5. Geometric part of the bone modelled in the CAD System.

3.3 Data Validation

To prove the dimensional results of the virtual model, the tomography femur was dimensioned. The first step was to precisely define which part was reconstructed by the methodology. As previously, explained, the interval of the analysed cuts started at the CUT 100 and finished at the CUT 140. The cut 100 is at 151mm from the bone base, the cut 140 is at 211 mm. Approximately 60 mm of the femur had therefore been studied and modeled. After the interval of interest was determined, three marks were made to prove the dimensioning, at the beginning, middle and end of the sample (cuts 100, 120 and 140). The Figure 6 shows the position of these marks in the part. The dimensioning was made through a tri dimensional coordinates measure machine (DEA - Sirroco) with a certainty of 3 microns.

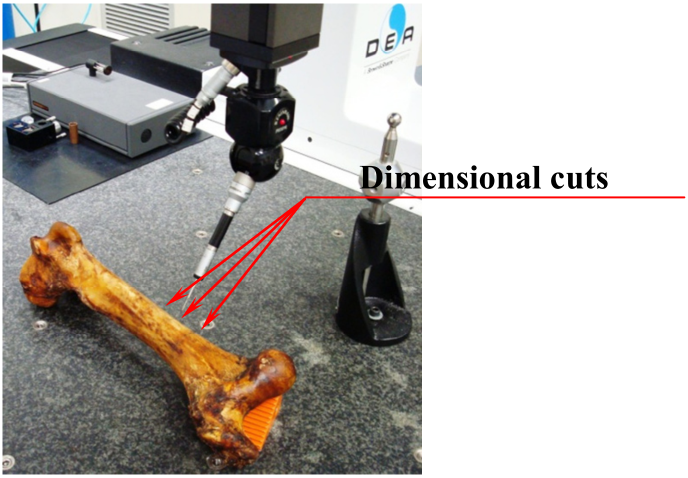


Figure 6. Marks in the femur.

3.4 Comparative Analysis of the Cartesian Points

Through the acquisition of the Cartesian points which were obtained with the help of the tri-dimensional machine the profiles at the positions of the three marks were reconstructed. The points were obtained through the contact, at each mark, of the pointer of the equipment with the bone part. An average of 18 points was captured for each curve. Figure 7 shows the reconstruction of the straight line segments from the points obtained.

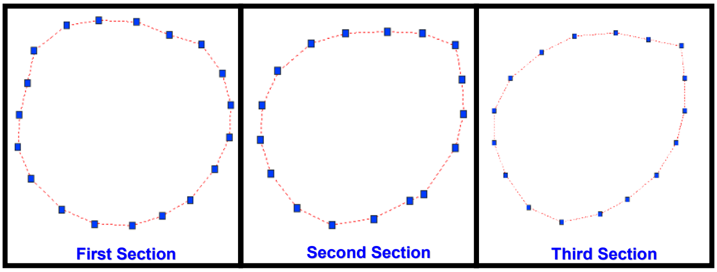


Figure 7. Re-design of the profiles through tri-dimensional coordinate measurement machine software.

The virtual model obtained by the methodology and the virtual model obtained by the tri-dimensional were compared at eight referential points in order to verify their accurate comparison. These points were generated from the division of the profile in eight parts, from its centre, considering the origin of the Cartesian plan. Figure 8 illustrates the referential points for each marked location.

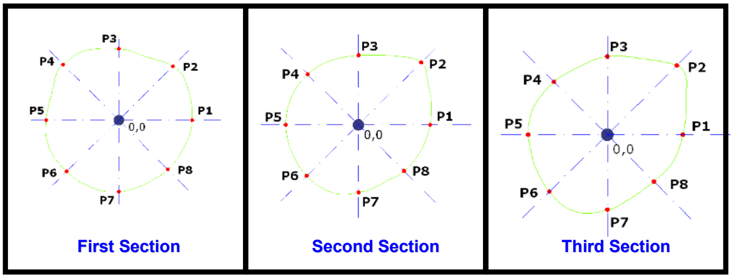


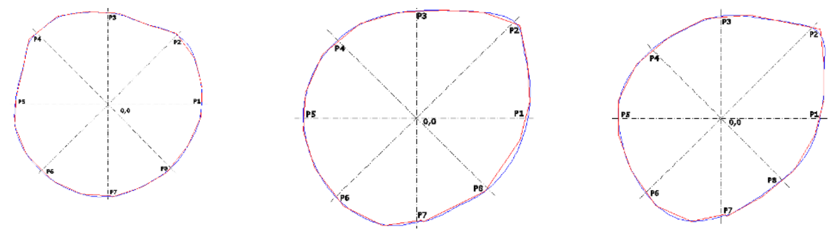
Figure 8. Points references for each mark.

The comparation between of re-designed profiles through tri-dimensional coordinate measurement machine software and the profile generated by the CAD system is showed in table 2. The point 6 (P6) had the greatest error, 0,201 mm in the "XY" axes. The biggest error in the "X" axis is in the point 5 (P5), the value is 0.164mm; in the "Y" axis the biggest error is in the point 7 (P7), value of 0.232 mm.

Table 2. Referential points for the first mark.

REFERENCES POINTS						
POINTS	CAD MODEL		TRIDMENSIONAL MODEL		"X" errors (mm)	"Y" errors (mm)
	X (mm)	Y (mm)	X (mm)	Y (mm)		
P1	22.934	0.000	22.907	0.000	0.027	0.000
P2	16.930	16.930	17.040	17.040	0.110	0.110
P3	0.000	22.412	0.000	22.436	0.000	0.024
P4	-17.484	17.484	-17.514	17.514	0.030	0.030
P5	-22.842	0.000	-22.678	0.000	0.164	0.000
P6	-16.442	-16.442	-16.241	-16.241	0.201	0.201
P7	0.000	-22.519	0.000	-22.287	0.000	0.232
P8	15.349	-15.349	15.269	-15.269	0.080	0.080

Figure 9a, compares visually the two curves obtained at the position of the first mark. As the curves are very similar and overlap, they have been shown in contrasting colours, i.e. blue for the curve obtained by the methodology and red for the curve obtained by capturing the points using the tri-dimensional coordinate measuring machine.



a) Overlap curves for the first mark.

b) Overlap curves for the second mark.

c) Overlap curves for the third mark.

Figure 9. Overlap curves for the marks.

For the second mark, as table 3 illustrates, the point 2 (P2) presents the biggest error, in both axes the error was 0.232. The biggest error in the "X" axis is in the point 1 (P1), value 0.405mm; in the "Y" axis, the biggest error is in the point 7 (P7), value of 0.236 mm.

Table 3. Referential points for the second mark.

REFERENCES POINTS						
POINTS	**CAD MODEL**		**TRIDMENSIONAL MODEL**		**"X" errors (mm)**	**"Y" errors (mm)**
	X (mm)	**Y (mm)**	**X (mm)**	**Y (mm)**		
P1	20.269	0.000	19.814	0.000	0.405	0.000
P2	17.751	17.751	17.519	17.519	0.232	0.232
P3	0.000	19.778	0.000	19.645	0.000	0.133
P4	-14.391	14.391	-14.184	14.184	0.207	0.207
P5	-20.599	0.000	-20.446	0.000	0.153	0.000
P6	-14.690	-14.690	-14.626	-14.626	0.064	0.064
P7	0.000	-19.171	0.000	-18.935	0.000	0.236
P8	13.027	-13.027	12.898	-12.898	0.129	0.129

Figure 9b, compares the two curves obtained at the position of the second mark. As the curves are very similar and overlap, they have been shown in contrasting colours, i.e. blue for the curve obtained by the methodology and red for the curve obtained by capturing the points using the tri-dimensional coordinate measuring machine.

Finally, the third mark as illustrated in table 3 and can be compared visually in figure 9c. The point 4 (P4) presented the greater error, in both axes the error was 0.246mm. In the "X" axis there was no bigger error than point 4; in the "Y" axis the biggest error is in the point 3 (P3), value 0.259 mm.

Table 4. Referential points for the third mark.

REFERENCES POINTS						
POINTS	**CAD MODEL**		**TRIDMENSIONAL MODEL**		**"X" errors (mm)**	**"Y" errors (mm)**
	X (mm)	**Y (mm)**	**X (mm)**	**Y (mm)**		
P1	19.561	0.000	19.462	0.000	0.099	0.000
P2	18.026	18.026	18.072	18.072	0.046	0.046
P3	0.000	20.372	0.000	20.111	0.000	0.259
P4	-13.777	13.777	-13.531	13.531	0.246	0.246
P5	-20.511	0.000	-20.385	0.000	0.126	0.000
P6	-15.033	-15.033	-14.813	-14.812	0.221	0.221
P7	0.000	-19.526	0.000	-19.303	0.000	0.223
P8	12.047	-12.047	12.205	-12.205	0.158	0.158

4. Conclusion and Further Work

This paper has discussed the feasibility of individually designing human prosthesis for surgical use and proposes a methodology for such design through mathematical extrapolation of data from digital images obtained via tomography of individual patient's bones. Fast and accurate design and manufacture of personalized prosthesis for surgical used in bone replacement or reconstruction is potentially feasible through the application and integration of several different existing technologies, which are each at different stages of maturity. Initial the case studied has been undertaken to validate the research concepts by making dimensional comparisons between a bone and a virtual model produced using the proposed methodology that was explored in section 3. Whilst the case study discussed in section 4 effectively demonstrates the feasibility of the concepts of this research, there is substantial extra research needed before these concepts could become a practical reality with more complex geometry. The authors therefore propose to continue this work in several areas including:

Understanding and investigating the information needs of both surgeons and patients in reconstructive surgery for bones;

Evaluating the feasibility of the existing model for extrapolation of mathematical data from digital tomography of patients' bones to create virtual individually tailored human prosthesis;

Further investigation of data cleaning and pre-processing techniques required to achieve the accuracy of alignment and sharpness of image from processed tomography sections for them to be used as the basis for initial design stage;

Further investigation of image processing techniques for conversion to 3D models using CAD/CAM standards for more complex bones geometries.

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Development of White Goods Parts in a Concurrent Engineering Environment Based on DFM/DFA Concepts

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Abstract. The classical way to manage the product development processes for massive production has been changing as the high pressure for cost reduction, higher quality standards and market seeking for innovation lead to the necessity of new tools for development control. This context and the learning from the automotive, aerospace industries and others segments were the starting point to understand and apply manufacturing and assembly oriented designs to ease the task of generate goods and from this to obtain at least part of the expected results. This paper demonstrates the applicability of the concepts of Concurrent Engineering and DFM/DFA (Design for Manufacturing and Assembly) in the development of products and parts for the White Goods industry in Brazil (major appliances as refrigerators, cookers and washing machines), showing one case concerning to the development and releasing of a component. Finally, it shows, shortly, how using these techniques as a solution had provided cost savings and reduction in delivery time.

Keywords. Concurrent Engineering, DFM/DFA, Design Management, White Goods, Product Development, Interoperability.

1 Introduction

Pressure caused by competent and strong competitors, reduction in markets and costumers demanding more value for money are reality. So that, the majority of the industries are now working with conceptual changing and costs reductions allied

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with the release of the product in the shortest time, especially for the White Goods (major home appliances as refrigerators, cookers and washing machines). Because of this, the necessity for more suitable ways of managing product and component development has become higher than ever.

To match those conditions and using the example from the aircraft and automotive industries, the DFM/DFA and the Concurrent Engineering proved to be, by themselves, powerful alternatives to run the design management methods, bringing together some interesting advantages. [3, 20, 4, 6, 18] have showed a well known panorama - a design must be accepted and discussed by all teams responsible for the product: the design, the design engineering , the process engineering, the manufacturing, the quality team and processes and so on.

The design systems have been assisted, nowadays, by different expertise engineering groups working as much as possible in integrated environments, with a range of software tools supporting design activities during the entire product life cycle, as well as the interoperability between systems that will supply these teams with right information in real time avoiding duplication and unexpected data [29, 10, 1, 28, 26, 15, 9]. Therefore, this paper aims to show a product developed under this synergy, explaining, also how CE and DFM/DFA have helped designers and engineering teams to reach the target of developing a new and more affordable part, with quality improvements, reduced time of assembly and with shorter release time.

2 Research Methodology

This research is an explanatory case study and according to [27] and [30] this sort of case can use pattern-matching techniques that conduct the study to examine the reason why some research findings get into practical use. The authors used a well-founded research design as the unit of analysis, where the topic was a constant but the design was variable [23].

The development of the case explored, a complex part that replaced a set of parts which was already complete, functional and on normal production, was based on the methodology developed by [3] and [5] which shows that it is possible verify if one part may or may not be excluded from an assembly. The part grouping (process where the main objective is to decrease the number of the part from a complex multi-component and sub-assembly to a multifunctional single part) can be ruled by three simple questions:

1) Does the part need to have a relative movement to the others parts located/positioned around (conditions concerns movement)?

2) Does the part need a different kind of material from the others around it?

3) Is the analysis of the part presents any impeditive to be assembled to another part? If there is any impeditive then must be repaired.

These concepts can give to the designer an orientation of what part can be joined and assembled (no other request will give different result).The advantage is the simplicity of the analysis that can be done from the shop floor to the design or from the engineering to the production, with no complex data request or special resources. The answers to these 3 questions must be essentially three negative responses which mean that the part does not need to be separated from all of others parts that are located/positioned around.

From this and based on observations, studies, tests, researches and literature review was identified an opportunity for application of DFM/DFA/CE and a solution was proposed. The research was divided in phases: 1- there was the identification of a design that could offer possibilities for improvement and discussions over the deficiency of the recent management methods and practices applied in the design/manufacture/assembly leading to the opportunities to develop a new part using DFM/DFA/CE methods and concepts; 2- these methods emphasized the process and controlling activities; 3- the conceptual design was carried out as a product and the detailed methods were given to the engineering teams in order to them to share information supporting the multiple viewpoints. In order to understand the method it is necessary to consider each step separately, it must be understood that each stage has its own inputs and outputs and whether each of them are or are not independent of the others, this is the conceptual basis of the CE.

The conceptual development phase began with the first sketches of the design once the minimum necessary data still not complete or even did not exist yet, making the design not clear to the teams involved. So that, it was made an analysis considering the needs, urgency and return of the product to be developed, taking into account if there were minimum conditions of applicability, manufacturability and product engineering allowing the allocation of resources for design development. It can be said that the completion of a thorough analysis of market opportunity, the project's initial conceptual alternatives, market strategy and implementation of the product on the market were key reasons why the bill moved to the next stage of development.

In Feasibility Analysis Phase presented in this article were analyzed the conceptual, economic, constraints and eventual needs of the specific design of the final part as well as its comparison with other solutions that could be the alternatives. Additionally, we have carried out technical, financial and schedule phase-in of the new phase and phase-out of the former, taking into account the policies of assurance to the consumer part in the process of deactivation, the support phase-out the suppliers and the process of training and capacitation of the network of repair.

Afterwards, analysis of manufacturability and enforceability were needed. Therefore, information concerning the possibility of manufacturing the material, the criteria for acceptance of the areas involved have been clarified, as well as the processes throughout the resources, both financial and strategic, were released. So that, it was determined the criteria which the design would be defined and subsequently measured and verified and the analysis of the supply chain, the production capacity and reliability of suppliers resulting on the approval of the design.

The Implementation Phase executed the concepts proposed in the previous phases (based on the methodology of DFM/DFA/CE). At this stage a chain of responsibility involving purchasing, logistics, engineering, quality, delivery and production teams were developed and the array of responsibilities has been properly constructed by assigning each area to their respective responsibilities.

Also, the material acceptance was prepared following the special design according to what was defined together with the supplier. The mold and the prototypes were built and verified by the company responsible and adjustments were made to both, the mold and the parts, in order to meet the design specifications. Manufacturing was supplied and the part production was performed. The part was, then, incorporated into the product structure and the final assembly was requested and held, as a result, the functional part of its allocation points was obtained concluding the implementation phase and the final component was designed. The conceptual challenge is "how to develop a new product finding the best cost-effectively in the shortest time, taking in consideration all different opinions without loosing the acquired knowledge about processes and also fitting the costumer necessities" [7, 21].

The design will determinate the manufacturability of a product even when it is considered a product with a very high level of sophistication, however it will not determinate the manufacture itself. In fact, this level of sophistication (maybe considered also as automatization) will reinforce the necessity of a well-elaborated design [9, 10, 11].

Traditionally a productive process has some basic steps, according to [17] as follows: i) the identification of customer's needs and desires as an input; ii) an output represented by product or service to match the majority of the needing expressed in the input; iii) between them a productive transformation process is fed by information and resources (as materials and machinery) and iv) the market demands. However, this simple interpretation does not take in consideration all the information that flows throughout the transformation process. Yet, the information itself shows the limitations or it not expresses the needs for changing or improvements.

The modern White Goods factories have been working simultaneously with several products in one assembly line and it is not rare that a component is used in similar conditions on different platforms. This can happen even with different technologies, products or market segments. Also, most of the well known trademarks reduced the investments in new products making only upgrades to the existent ones, so that it is necessary to maintain, for at least a couple of years, the assembly line, methods and machinery to ensure the supply of spare parts for these products.

The apparent undesirable conditions may present a very good opportunity to rethink the product development process based on the: i) experience obtained from previous designs; and, ii) the knowledge of where the weakest points can reveal a path to start a production based on oriented design methodology. In this way, DFM/DFA and CE (both production oriented designs "ways") offer a substantial advantage since they permit to run activities simultaneously, in opposition of the tasks sequencing. Also, they allow the use of simulation techniques and a full synergy between the teams making possible to find design failures or deviations, fixing them before the development ends [25]. [16] has discussed how the using of design and manufacture techniques can "hear the voice of production line" and at the same time be virtually near to the information. [8] agreed to this point of view stating that DFM/DFA/CE allow the designer and engineer bring considerations about the product assembly and manufacturability. Yet, [8], [14] and [22] defended that the most significant advantage of DFM/DFA is the encouragement for the integration between design and manufacturing teams. This encouragement will improve the reliability of the final product concept and it will generate reduction of costs/time by decreasing the number of parts that are used in the product.

It is necessary to understand well what are the necessities to drive a design using Concurrent Engineering techniques. [10, 24] stated that in a multiple viewpoint manufacturing and design system all the opinions must be considered among interdependent domains. Thus, the common overlap points must be decided in an intelligible form that can allow all the elements of the productive chain to express their necessities and limitations clearly to any other part connected to it.

The last part of development with CE and DFM/DFA techniques is related to the time management and activities should run parallel in a design. [13] had observed that in multidisciplinary teams, the behaviour of the local rework caused by an activity with adverse results is much smaller then a global restructuring of a design and a global redesign might be impossible due to the costs. According to [19] the inclusion of a change in a running design is more expensive as closer as the product gets to its launch into the market.

3 DFM/DFA and CE in the White Goods Industry – A Case Study

DFM and DFA are tools which help the design process to fit the necessities and constraints of the shop floor. So, a methodology must be granted to the design that are able to take advantage of the tool because they can analyze a complex number of factors in the manufacturing process by simply using three basic concepts described in the item 2, which can result in the part number decreasing.

Applying these concepts of DFM/DFA and CE to a new part development, in a Brazilian White Goods industry, could illustrate the advantages of a multidisciplinary part development. The task was to substitute a complex assembly of different parts made of press worked metal and plastics by an aggregated function single solution with cost reduction, short-time tooling payback, quality improvement and most important: ease to assemble in line. To achieve the aim, the 3 questions (item 2) were answered as follow:

To the first question, the answer was no since the part is a fixed stand where any of the parts would move and therefore it was not necessary to be isolated but could be fixed in the set to the others. The answer to the second questions is negative, as the parts did not need to be constructed from different materials of the set of parts. And finally, the third answer, as the previous ones, was negative, as there was no impeditive to assemble the parts to the others around.

The result of this analysis, the 3 negative answers as request by the methodology, made possible the appliance of the DFM/DFA/CE in the development of this product.

Based on the literature review, especially in the recent developments of the automotive and aerospace industries, and considering the expertise of the teams on plastic injection, it was decided to search for a solution using injection of thermoplastics, even considering the restrictions of the high-low temperature cycles and severe mechanical duty.

The temperatures limitations on a plastic material are more severe than in a press worked metal, and, also, include the possibility of deformations, flowing and resistance downgrade. [2] referred to the risk of consolidate parts by injection process. Those risks have to be considered before the design takes the final decision. The DFM/DFA principles offered a possibility of assembly improvement and a less possibility of fail.

The original assembly composed of plastic parts and press worked metal lead to nineteen attaching, two riveting and one screwing sequential operations. The assembly condition demanded two working positions and needed specific equipment and care. Also, the attaching manipulation was fully manual and highly sensible to errors due to the complexity of joining all parts together in a high productive line. Thus, the riveting operation had its own difficulty, in the case of an imprecise attachment the rivets could not be placed properly causing an off-line rework call and stopping the production flux. After all, the conditions to do the attachment of another metal part over a glued curved tempered glass-metal part were an additional complexity.

Avoiding these inconveniences, exposed in the previously, and to fit the high level of reliability required, a new injected component was designed under the DFM/DFA and CE philosophy to aggregate in a single plastic construction the maximum of the original parts and an error free mounting. It was expected to result in one high manufacturability development made from a productive low cost heavy duty material and designed to join six other components resulting in the maximum exclusion of intermediate operations.

The multifunctional part was able to permit the exclusion of seventeen from the original nineteen attaching operations and took out one of the riveting tasks due to the substitution of one rivet by a pivot. DFM/DFA analysis revealed that, even the remaining rivet could be extracted of the sub-assembly (directly emerged by the structure of the multifunctional part). This pivot, which is normal to the foundation of the part, was designed to be one partial anchorage and attached to the structure, ensuring the right placement of the whole assembly.

Other anchorage is offered by the upper cover 90° cross-phased from the pivot and grooved to fit the construction of the column where the part is mounted on which by its geometry reduce around zero the possibility of a wrong assembly. The bush is also 90° cross-phased from the other two attachments, ensuring the full locking of the component to the environmental geometry, causing a full complete assembly, even when the other components (not treated by this development) present variations outside of the tolerance levels.

All that were presented and the extreme easiness to produce an injected part results in 80% reduction in the assembly and 15% reduction in the composition of costs, as well as a short term payback of the injection mould and will be discussed in the next section.

4 Discusion About the Results

This article has shown an application for the concepts of DFM/DFA inserted in a Concurrent Engineering (CE) collaborative context for the development of a new part for the white goods industry (home appliances) focused in low-cost, high manufacturability, long-term reliability and resistance to severe working duty. The design of the part was based in the industry-level and literature review and demonstrated the application of the concepts and its advantages in the development of products with high manufacturability.

Concerning to the development of the part, the value added by DFM/DFA and CE was very important, more than just the development process, the part itself needed special care due to its own special heavy-duty working environment. The reliability of a structural part is delicate since the design process had to change from a part made of steel to one that is made of plastic, mainly when high temperature, aggressive humidity, use and chemical agents collaborate in the mechanical stress of it. The DFM/DFA and CE were especially useful because they permitted a better communication between all involved teams. Also, these philosophies helped the product life cycle movement from Product Engineering to Production and Industrial Engineering. During this movement a parallel between design and manufacture were create allowing the development of tools (mould and assembly devices) and the shop floor of manufacturing area. Figure 1 makes a comparison between 2 design considerations of the part: the detail “A” shows the initial configuration before DFM/DFA and CE; the detail “B” shows the final part designed according to DFM/DFA and CE concepts.

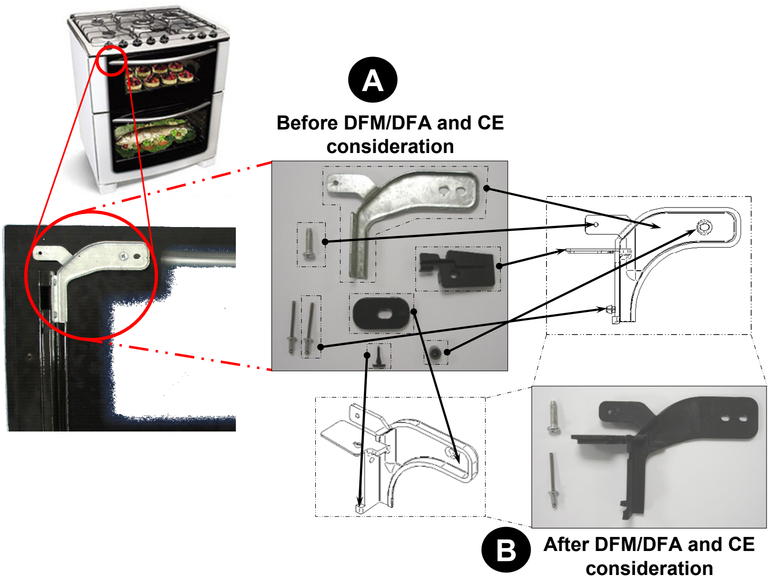

Figure 1 Direct comparison between parts (copyright by Electrolux do Brasil S/A).

The used concepts were decisively important because of the advantages of time saving through easier communication process. The mould was made as expected by the product developers, therefore the product could be manufactured correctly, avoiding rework. Despite the part had to be designed several times, the final component was injected only once, saving money in prototypes, tests and working time. The component was designed based in the production line (fewer parts and assembly-line speeders as fast locks, pins in place of rivets or screws, preassembled features, self-positioning parts and adaptable robust-design) in order to make the production teams more productive teams, saving money. The production of fewer parts has an impact of 15% over the whole assembly costs, directly in the materials price with the advantage of improving logistics, the shop floor space and avoiding the searching for different suppliers.

Finally, another advantage of the application of the DFM/DFA and CE concepts in the design product development was the finding of a new way of working, where different expertise teams could apply their knowledge in a simultaneous and integrated way. The result of this in the last part of chain was a more precise product, and in the most of the time, faster and cheaper, as showed in table 1.

Table 1 Direct comparison between achieved data.

ISSUE	ORIGINAL DESIGN	DFA/DFM/CE DESIGN
Number of parts	8	3
Number of the operations required	13	3
Attachments	3	2 (1, considering individuals)
Cost (proportion)	100%	30.21%
Time over assembly line	48 seconds	13 seconds
Manpower (workers)	3	1

5 Conclusion

This research has explored DFM/DFA and CE concepts to create a synergy of different engineering group, working in an integrated environment, in order to create a component for a white good. The results of applying these concepts were: i) a changing in the concept of how the teams should work; ii) the substantial costs reduction in design and production development.

Regarding to the costs reduction, the applying of DFM/DFA allowed the design takes out the non-essential parts of the assembly, (Figure 1),and even though the time spent in this phase could be increased significantly, the design will be more elaborated and precise, bringing benefits for the next phases of the product.

With the fewer steps and less necessity of people and machinery to run out, the production had a substantial cost reduction. An example of this was the direct substitution of several assemblies (several parts joined and fixture) by only one injected part, moulded, die-pressed or casted.

The component was developed aiming cost reduction purposes. The difference between the past budget and the new one was not only based in component or raw material prices, but also connected to the price of the labor affected by the necessity of organize sub-assemblies, which has not only operational cost, but, also, investment on special machines, tools and equipment required to joint those assemblies. When comparing values of materials used before and after the DFM/DFA, the direct cost of materials (considered here only BOM component individual price) was reduced in 69.79%, with no quality or featuring restrictions. This change leads also to a manpower reduction – from three operators to only one. The assembly economy was 67%, as showed in Table 1, which brings some information, where more relevant data could be observed, mainly, the values of assembly cost and time.

The investment on a specific new tool (injection mould) for a 2-sided complete plastics part, only for the main component, was 10% lower than the necessity of a new die-pressing tool. Also, the new plastic part avoided the demand for a new high temperature stove (about US$ 150,000.00) that used to be used for a further process of glass-metal joining which required a special adhesive, with a touch-time of thirty minutes under a specific temperature near to 140°F, by using the resource of a complex three-dimensional geometry which could not be reached by die-pressing. In the figure 1 it is possible to see the mentioned complex geometry and, also, the reduction of parts, the conditions that makes clear the assembly time reduction.

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Sustainable Logistics – Example Automobile Manufacturer

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Abstract. In its capacity as a company operating across the world with a global production network, the automobile manufacturer under consideration in this paper, hereafter referred to as 'the Company', naturally moves large quantities of materials and products. About one-third of the emissions of noxious substances that occur during vehicle production are generated along the transportation chain. To keep the transportation-related environmental stress at a minimum, all commodity flows are constantly being analysed and optimised from procurement to delivery. Here, intelligent transportation logistics achieves the optimum transportation services with a minimum of environmental stress, see [3, 4, 8].

Company environmental protection can only be "holistic" if it really covers all the links in a production chain. For this reason, the Company aims to establish high environmental standards both for itself and for its approx. 3,000 suppliers and service providers. To improve supply chains with environmental requirements in mind, the planning of logistics systems needs the early consideration of requirements including risk analysis, which will be shown in an example.

Keywords. Ecology, transportation, packaging, risk analysis, standards, supplier selection

1 Introduction

The Company's logistics planning and transportation logistics regulate the supply of production locations with production materials and components as well as the delivery of spare parts and accessories to the dealerships and, of course, the distribution of new vehicles. That corresponds overall to a transportation capacity of about 14 billion ton-kilometres per year.

Around 2,700 supplier locations and all service workshops worldwide are integrated into the Company's goods flow management. Approximately two million shipping containers made of steel and plastics are used to deliver parts and components to the individual locations. Logistics planning and transportation logistics ensure that efficient logistics structures are developed and utilised. The elaborate environment-friendly transportation solutions of the logistics experts are in accordance with the logistics and environmental guidelines. The reason: circa one-third of the emissions of noxious substances that occur during vehicle production, are generated along the transportation chain that extends from the suppliers, through deliveries between locations to the delivery of the vehicle to the customer. The high transportation volume, the complex supplier and production

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network and the high emissions of noxious substances requires new environmental friendly solutions. In order to reduce environmental impacts, the logistics experts are working on specific projects to

- shift transportation to a more ecologically compatible means of transportation, for example from road to rail, and minimise air cargo,
- cut the volume of freight by optimising packaging, container filling and the capacity utilisation of the means of transportation and traffic networks,
- and reduce the materials used to protect the surfaces of the new vehicles during transportation,
- planning of a packaging plant including risk analysis,
- set high standards for suppliers and logistics

The logistics strategy results in exactly defined environmental objectives as well as process descriptions for the operative implementation in planning and purchasing. Using an environmental management system that has been certified to DIN EN ISO 14001 since 2003, the Company records key figures such as the share of vehicles delivered by rail or the share of air cargo in deliveries from Europe to overseas plants. The CO2 emissions in relation to the transporationt performance in ton-kilometres serve as an indicator for progress in the field of environmental management. Key figures are used to find out how much its logistics solutions contribute to environmental protection.

2 Efficient and Ecological Transportation Logistics

For the transportation of goods, the Company prefers the mode of transportation with the lowest emissions. Accordingly, the shipping of goods via air freight is avoided as far it is possible. Road traffic is eased by choosing ports near the plants as the point of origin for ocean transportation. For the vehicle transportation from the plants to the ports and sales operations, the manufacturer prefers to use railways.

2.1 Shifting from Road to Rail

The companies logistics experts cannot directly influence the transportation performance from the supply market to the various locations of the production network. However, since they are involved in the selection of suppliers, they ensure that ecological aspects are also taken into account during transportation from the suppliers to the plants. The logistics experts also have no direct influence on the transportation of the finished automobiles to the sales market. After all, the development of the sales markets and plant allocation, i.e. the plant at which a particular vehicle is produced, determine the transportation performance. However, the logistics experts are working on the development of ecological transportation structures for the transportation of automobiles from the plants to the sales markets.

Thus, infrastructure projects at individual plants promote the increased use of rail transportation. For example, all new cars destined for the UK market are now loaded directly onto railway wagons in the plant in southern Germany. Deliveries to Germany's Rhine-Ruhr conurbation as well as to Belgium, Italy and Spain, have also been shifted from road to rail. With the introduction of the new compact model, around 60 percent of the new cars from the plant in southern Germany are delivered directly by rail. This means 15,000 fewer truck journeys a year and, as a consequence, a significant reduction of the burden of heavy traffic in this area. This shift to rail transportation for deliveries from the German plants to Italy and Spain alone reduces emissions of CO2 by 12,200 tons a year.

In South Africa and the USA, around 70 percent of new vehicles now leave the plants by rail. From 2003 to 2004, the Company increased the share of rail transportation for its new vehicles worldwide by around eight percentage points to 60 percent. In 2004, further adjustments were made at the three German plants so that more materials could be supplied and more vehicles dispatched by rail. In order to supply the German plants with materials, the Company currently uses five rail links for freight trains.

The use of trucks for the worldwide supply of spare parts, which is organised by the centralized spare parts distribution centre in southern Germany, has also been reduced. Trucks based at this centre used to travel 190,000 kilometres a year in order to supply the distribution centre with spare parts from the external warehouses. In June 2005, the Company opened a new store and logistics centre, which is located near the plants. This centre replaces almost all the external warehouses and thus significantly reduces the transportation performance each year.

2.2 Combining Rail and Sea

The Company also chooses ecologically favourable routes to ports for its overseas transportation. For example, it changed the port of departure for vehicles produced in Germany for the UK market from Belgium to Cuxhaven/Northern Germany, thus relieving road traffic of 4,300 truck journeys each year. This shift also reduced transportation time. Rail links to the respective ports are also used for the global supply of spare parts from the plant in southern Germany and for the supply of the plants in USA and South Africa. For example, a new rail link has been specially opened between the vehicle distribution centre in South Africa and the port of Durban. Each day it is used to transport two hundred new vehicles that are either leaving the plant or being imported for the South African market.

The efforts to shift traffic within the plants to ecologically equitable means of transportation, such as rail and sea, have already been successful. In 2004, 15 percent of transportation was by road and six percent by rail, while sea transportation accounted for the lion's share of around 79 percent of the total.

2.3 Avoiding Transportation Packaging

One of the objectives of environmental management in the field of logistics is to reduce the environmental impact of the materials used to protect vehicle surfaces during transportation to the customer. Up to now, vehicles were protected from the elements and transit-related damage during transportation by adhesive film, protective covers or wax. After an environmental performance evaluation concluded that a closed transportation or an open transportation with subsequent cleaning of the vehicles is much more environmentally friendly, the Company is in the process of successively phasing out its surface protection for automobiles.

In 2006, 53.4% of the vehicles from the plants were delivered without surface protection; in the year before, it was 42.5%. Since the start of the project in 2004, this has dramatically reduced the use of solvents and chemicals. Furthermore, about 5,000 tons of CO2 emissions, which occurred during the manufacture, application and de-waxing processes, were prevented. Without this surface protection and with the subsequent cleaning following transportation, there were 80% fewer CO2 emissions.

2.4 Planning of a Packaging Plant Including Risk Analysis

The Failure Modes and Effect Analysis (FMEA) is a development and planning accompanying system and risk analysis. It is integrated in the specialist departments and includes the system optimisation as well as the risk reduction. As an important methodical instrument, the FMEA allows possible failures to be identified at an early stage, in order to prevent their occurrence beforehand. This is important in new concepts and developments as well as for the further development of products and processes, see [1].

In quality assurance agreements for the assurance of delivery quality by suppliers, an FMEA is often mandatory. For example, a process FMEA is required to be carried out according to the latest state-of-the-art technical requirements, [6]. The results of an empirical study show that FMEAs are hardly ever used in project management for quality planning and assurance or for risk management, see [2].

For the assurance of the smooth execution of the processes of a packing centre implementing controlled processes, a risk analysis was carried out with the application of an FMEA in the early planning phase of the project, see [9]. In this way, possible failures and their causes, potential effects as well as measures to be implemented for the avoidance and detection of such failures, can be analysed from the aspect of failure mode factors, which included man, machine, method, material and environment.

The FMEA is performed in 5 steps by a team comprising of members from all areas under the guidance of an experienced presenter. The 5 steps are as follows:

- Representation of the system structures (hierarchical process structure),
- Representation of the functions and function structures (process flow),
- Failure analysis (possible failures, failure causes and failure mode),
- Risk assessment with respect to the severity of the failure mode as well as to the occurrence potential or detection potential of the occurred failure and its cause,
- Optimisation implementation. This involves the specification of the dead-lines and persons responsible, coordination of the corrective measures (process sheets and operating instructions etc.).

The potential failures can be subdivided into 2groups during the risk assessment:

- Refrain failures (omission of required activities, refrain from ignorance etc.),

- Execution errors (mix up, unsatisfactory checks of the attribute, scan double etc.).

The environment is also taken into consideration. In this context, it is the ergonomic conditions in particular, such as illumination, noise level, temperature etc. that can have an influence on the performance and motivation of the employees in a positive or in a negative regard. These conditions have been well-executed in the packaging plant, where much attention has been paid to avoiding the occurrence of refraining and executing errors on the part of the employees during the various manual tasks.

In the case of this project, the possible risk of errors occurring during a variety of manual tasks could be reduced with the aid of remedy or avoidance measures. This mainly involved the provision of descriptions on how to carry out the individual processes (work instructions, descriptions of operational sequences, company rulings, maintenance timetables and programming SAP). An early preparation of these process descriptions is recommendable as they can then also be used for the training of the employees. If they are compiled simultaneously with the development of the process, they represent an up-to-date document of the process flow. The processes and the execution of the processes by the employees should be checked at regular intervals in order to indicate where any improvements could be made.

An accurately timed use of a risk analysis is recommendable from both a technical and a business management planning perspective. Many functions are similar and can be transferred to other applications. In addition to a well-timed implementation of the FMEA, it is essential that the involvement of the operator is also favorable in terms of scheduling. At the start-up of the production, preventative measures are more difficult to set up. However, the FMEA can be used as a basis for follow-up planning from both a technical and a business management standpoint and can be continued by the operator as a method for the continuous improvement process after the start-up and for the stabilization phase.

Risk analysis with FMEA provides an early indication of the existence of potential failures and risks in the front-end of the process, thus allowing countermeasures to be already started in the early planning phase of this project. In this way, the well-controlled execution of processes is guaranteed.

3 Sustainability in the Suppy Chain

3.1 High Standards for Suppliers and Logistics

As of spring 2003, the domestic and international purchasing conditions of the Company contain exact guidelines on environmental responsibility. They obligate suppliers to design the related components as per the state-of-the-art technology so that emissions are reduced during the production, usage and recycling stages. When manufacturing each component, energy and raw materials are to be used efficiently. For this reason, each partner is urged to draw up a certified environmental management system according to the established standards ISO 14001 or EMAS II. Alternatively, smaller suppliers may furnish proof of individual management systems and confirmation that they have systematised environmental protection in their production. Aside from environmental responsibility, the Company also requires from its suppliers and service providers that they assume social responsibility.

The purchasing conditions are binding for all existing and new suppliers to the Company. The selection of the suppliers is tasked to a multi-disciplinary team, which is located in the central office in Germany. Experts from the purchasing, logistics, development and quality management areas evaluate the concepts suggested by the suppliers, not only in terms of the cost and quality aspects but also in view of the social and environmental risks. The selection of suppliers also includes an evaluation of the concepts suggested against the backdrop of the protection of resources. Criteria for this include the weight of the components or the resulting mechanical frictional losses with drive components.

3.2 Suppliers Selection According to Sustainability Criteria

New suppliers are tested using a "Questionnaire for supplier selection", which also poses questions on the social and ecological performance of the supplier. Attendant to the product design process, environmental questions on the planned production process of the new parts are taken into account in conjunction with a risk management assessment of purchased parts from the existing suppliers. Aside from checking environmental management certificates, the Company requires its suppliers to provide extensive data on resource consumption, the contents used and their risk potential. Using this data, it is possible to create environmental performance evaluations for specific parts and processes, identify situations where there is any room for improvement, and to obligate suppliers to implement an environmentally optimised design and production for new components.

Should any infringements against the criteria that have been agreed upon, be detected, then the experts responsible for environmental protection, recycling and purchasing from the Company will, together with the supplier, first attempt to find the reasons for these irregularities. Should the supplier fail to implement satisfactory measures, an escalation process is triggered, which may lead to a change of supplier.

In this manner, the manufacturer commits its direct suppliers (first-tier suppliers) to conform to reliable and uniform environmental protection and social standards. At the same time, the Company expects from its suppliers, a corresponding examination of those suppliers with whom the manufacturer has no direct business relationship (sub-contractors). When submitting an offer, each new supplier must therefore confirm that sub-contractors are checked regularly for compliance with quality, environmental and social standards and, as a result, that the risks of its own supply chain can be reliably controlled.

Especially in the emerging markets, where environmental protection efforts trickle down only slowly to medium and small suppliers, the Company supports its suppliers in establishing environmentally friendly production methods. Since 2000, the South African plant has, by means of a coaching programme, informed it suppliers on the environmental protection standards in force and the economic advantages, which arise from environmentally responsible production. The result: the percentage of suppliers with a certified environmental management system increased from about 10% in 2000 to 93 % at the end of 2006.

To maintain this status at the suppliers, the product and process auditors from the South African plant regularly inspect the environmental management systems and facilities of all suppliers of major components. The objective is to ensure a constantly high environmental standard at the suppliers in the face of continually emerging new suppliers and expiring certificates.

When embarking upon new projects, the Company also examines the social and environmental standards of possible partners in order to ensure that the standards are observed throughout the value added chain. An example: the engine plant in Austria, which produces around 750,000 engines a year, conducted a competitive enquiry among suppliers worldwide as part of the development of a new four-cylinder diesel engine. Forty-seven potential suppliers returned their completed "Sustainability questionnaire". Unlike the national and international survey of suppliers, this broader survey also included companies that had not worked for the Company before. The suppliers provided information on their economic data and on whether they supported international initiatives to protect human rights and safeguard labour and social standards, such as the Global Compact. The Company also enquired about the status of environmental management in each company. Not only the application of an internationally valid environmental management system was decisive, but also the use of environmentally compatible production methods, such as design for recycling, or of life cycle assessment case studies.

The results showed that all the companies surveyed have an environmental management system. And nearly all the potential suppliers take account of standards for environment-oriented product development. Three-quarters of the suppliers who took part are governed by fixed social standards, such as a code of conduct or a corporate ethics charter. The potential suppliers also claim adherence to environmental and social standards along their value added chain. Thus, around 85 percent of the companies demand that their sub-suppliers meet corresponding environmental and social standards. Together with other criteria, the Company used all these facts and figures to select suitable partners.

4 Conclusions

Companies assume responsibility for their economic success as well as for the environment and society, because long-term economic success can only be achieved by those companies that take both the interests of people and the needs of the environment into account, i.e. companies that operate sustainably. For the Company, sustainability management means using resources efficiently and sparingly, recognizing and minimising risks, acting in a socially responsible manner and thus enhancing the Company's reputation. In doing so, both the management and employees constantly strive to improve on their achievements.

Here, it is evident that the Company equates an increased transportation capacity with a continually decreasing ecological impact. This reduction is made possible by numerous individual coordinated measures. One important measure is the minimisation of the material transportation. The sustainability in the supply chain is achieved by the careful selection of the suppliers and the maintenance of high standards for suppliers and logistics. This selection of the suppliers is evaluated by the Company's interdisciplinary team, which evaluates the concepts suggested by the suppliers and considers the cost and quality aspects as well as the social and environmental criteria and risks. Economy and ecology are inseparable, i.e. they are intrinsically tied together, see [5].

Sustainable logistics plays an important part in the corporate sustainability strategy. The Company and Toyota are the industrial leaders by a considerable margin. Both companies consistently create positive sustainable value over the entire period under review, and use their economic, environmental and social resources in a value-creating way. In other words, they use these resources more efficiently than their industry peers, see. [7]. Now is the time to act – towards creating Sustainable Business Cultures, see [5].

In general, supply chains were not built with environmental requirements in mind. The high transportation volume, the complex supplier and production network and the high emissions of noxious substances from transportation, require new environmental friendly solutions. To improve supply chains with environmental requirements in mind more work and new solutions are therefore necessary for the planning of logistics systems and for the early consideration of requirements including risk analysis.

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Systems Concurrent Engineering of an Electrical Ground Support Equipment for an On-Board Computer

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Abstract. This paper presents a systems concurrent engineering approach for the development of an electrical ground support equipment (EGSE) for a satellite on-board computer. Traditional approaches focuses on the product, development organization and the product concepts of operation (CONOPS). In those approaches the overall view of the inherent complexity in the development of a product, its life cycle processes and their performing organizations are not taken into consideration. The systems concurrent engineering performs stakeholder analysis, requirements analysis, functional analysis and implementation architecture analysis, simultaneously, for the product, its life cycle processes and their performing organization. From the analysis, requirements and attributes are captured for the product and its life cycle processes organizations and the relationship among them are identified. Conclusions are that impact, traceability and hierarchy links promote the anticipation of life cycle process requirements to the early stages of systems architecting. Late changes are avoided, development costs are dramatically reduced while satisfaction of stakeholders over product life cycle is increased.

Keywords. Systems concurrent engineering, systems engineering, concurrent engineering, complex product, integrated product development.

1 Introduction

All equipment to be used in the space segment should pass through a series of environmental and functional tests, in different development steps of a sattelite. For carrying out functional tests, it is necessary to use an auxiliary equipment called Electrical Ground Support Equipment – EGSE. The EGSE emulates input and output loads to a given equipment under test. For a satellite On-Board Computer (OBC) testing, all telecommands and telemetries, all signals from and to

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the OBC must be emulated and monitored by an EGSE. The OBC EGSE emulates of the OBC satellite in orbit operation, during satellite assembly, integration and testing (AIT) activities providing a reference to the expected behaviour of the OBC under test. This paper aims to present a systems concurrent engineering approach for the development of an OBC EGSE. The approach is different from traditional systems engineering approach because it anticipates to the early stages of system architecting the product life cycle process requirements. It proposes to simultaneously develop, from the outset, the product and its life cycle processes performing organizations.

The paper is organized as following: Section 2 presents the traditional systems engineering and concurrent engineering approaches. Section 3 presents the systems concurrent engineering approach framework and method. Section 4 presents the models derived for the OBC EGSE using the approach. Section 5 discusses the advantages and opportunities for improving the proposed approach. Section 6 concludes this paper.

2 Traditional systems engineering and concurrent engineering

Space products are complex [9]. They are multidisciplinary products, they must cope with extreme environmental conditions over their life cycle (vibration, temperature ranging from -196 Celsius to 150 Celsius in vacuum), they must undergo very strict assembly, integration and testing (AIT) procedures. AIT organizations are worth the order of hundred million dollars. Two ton satellites may take the order of 18 months just for the AIT process. There are many opportunities to improve productivity over satellite life cycle if a concurrent engineering approach takes place from the beginning of the satellite architecting stage.

Traditional systems engineering approaches do not provide an overall view of the system during its various life cycle processes. They focus on an operational product development starting from product concept of operations. They also focus on the development organization that must be put in place in order to assure that the product meets its operational requirements [2,3,6,8]. A product has life cycle processes other than operations and it must be recognized from the outset in order to promote gains in productivity in the product development organization, by the avoidance of late changes, and in other product life cycle process organizations, as the product will be developed taking into consideration their requirements. Life cycle process organizations themselves can be developed simultaneously to product development, when they are part of the scope of the whole product development effort. For example the NASA systems engineering handbook [8] states that systems engineering focuses in the development and the realization of a final product. Modern commercial standards, such as EIA 632 [2], state that systems engineering focuses on the operations product and on capturing requirements for the other product life cycle processes. In other words, these requirements are captured not to impact product development. The product will be systems engineered with operations in mind. When its architecture (and maybe detailed design) is defined, then life cycle processes requirements are captured to be implemented in life cycle process performing organizations. This paper proposes a method to take into consideration the impact of these organizations on the product during the product architecting process. Conceptually, concurrent engineering acknowledges benefits of anticipating life cycle process requirements to the early stages of product development. For space products, these early stages are the system architecting phases. A systems approach requires life cycle process requirements to be balanced in the beginning of the product development process. Concurrent engineering, however, in practice, treats life cycle processes separately and optimizes product design seeking each life cycle process productivity increase. For example, DFA optimizes for assemblability, QFD, for customer satisfaction, DFI, for inspectability, and so on. Also, concurrent engineering is, in practice, applied to parts design and not to systems composed of many integrated parts [5]. This paper proposes how the concurrent engineering concept can be used for systems engineering.

3 The systems concurrent engineering approach

Hitchins [4] states that complexity can be understood by what he calls complexity factors. They are variety, connectedness and disorder. Variety accounts for the number of different elements you have in a set. Regarding products, variety refers, for example, to the number of different parts a product may have, number of different functions it accomplishes, number of different requirements categories it is supposed to meet, number of different stakeholders it should satisfy. Connectedness refers to the relationships among elements. For example, how parts interact, how functions affect one another, how requirements conflict to each other, how value flow among stakeholders. Disorder refers to the level of tangling of those relationships. For example, is there a structure pattern of deploying stakeholder requirements through functional concept up to implementation architecture?

Figure 1 presents a framework to address complexity in product development – the total view framework evolved from Loureiro [7]. It has three dimensions. Each dimension addresses one of the complexity factors mentioned above. The analysis dimension addresses the variety factor. Along the analysis dimension, it is deployed what must be analysed in order to develop a complex product. A systems engineering process consists of stakeholder analysis, requirements analysis, functional analysis and implementation or physical analysis. The integration dimension addresses the connectedness factor. It defines what must be integrated along an integrated product development process: product elements and organization elements. Organization here refers to the organizations that perform product life cycle processes. Product elements and organization elements are the system elements. The structure dimension addresses the disorder factor. According to Alexander [1] all structures evolve into a hierarchy. System breakdown structures are also represented in hierarchies.

Figure 2 provides an overview of a method within the total view framework. The method is called concurrent structured analysis method evolved from Loureiro [7]. Stakeholder analysis, requirements analysis, functional analysis and implementation (or physical) analysis is performed, simultaneously, for the product under development and its life cycle process performing organizations. The analysis processes are performed at each layer of the system breakdown structure. For example, if a car is the product under development, the analysis processes are performed at the car layer, at the powertrain layer, at the engine layer and so on.

Figure 3 details the concurrent structured analysis method showing how to incorporate the concurrent engineering concept in the systems engineering process:

Step 1: Identify the product mission, the product life cycle processes and their scenarios and, the scope of the development effort. Product mission refers to the product purpose or reason of being. Life cycle process scenarios are the alternatives in each process (for example, preventive or corrective maintenance) or the decomposition of a process (for example, advanced technology development, process engineering as components of the development process). The scope of the development effort consists of the life cycle processes or their scenarios that the development organization is also responsible for accomplishing. For example, EMBRAER is responsible for developing aircraft but is also responsible for providing maintenance services.

Step 2: Identify product stakeholders and their concerns for each product life cycle process scenario. Product stakeholders are the people who affect or are affected by the product during its life cycle. Product stakeholders are identified per life cycle process scenario. Identify organization stakeholders and their concerns for each process within the scope of the development effort. Organization stakeholders are the people who affect or are affected by the business of the organization in question. Organization stakeholders are identified per life cycle process scenario within the scope of the development effort. From stakeholder concerns, stakeholder requirements are identified and measures of effectiveness (MoEs) are derived. MoEs must measure how the system meets the stakeholder requirements. From stakeholder requirements, functions, performance and conditions are identified. The definition of what functions the system will perform, how well the system is going to perform such functions and under which conditions comprise the requirements analysis process. Requirement analysis transform stakeholder requirements into system requirements. System requirements will be met not only by product elements but also by organization elements.

Step 3: Identify functional context for product at each life cycle process scenario and for organization at each life cycle process scenario within the scope of the development effort. Functional context defines the function performed by the system element and identifies the elements in the environment of the system. The environment of the system contains the elements outside the system function scope and that exchanges material, information and energy flows with the system. Those flows define logical interface requirements. Environment elements may have different relevant states. Sets of environment element states are called circumstances. The system must have different modes depending on the circumstances. Behaviour modelling is required to show under which conditions system mode and system state transition occurs. Functions are identified per mode. Functions are identified from outside in by identifying which responses the system is supposed to give to deal with each stimulus provided by the environment elements. For each function, performance requirements are identified. Circumstances, flows between the system and the environment and function failures are sources of hazards. Risk analysis is performed on each identified potential hazard and exception handling functions are also identified at this stage.

Step 4: Identify implementation architecture context for product at each life cycle process scenario and for organization at each life cycle process scenario within the scope of the development effort. Physical connections between the system and the environment elements define the physical external interface requirements. Physical parts are identified. Physical internal interfaces are defined by architecture connections and architecture flows among those parts. Allocation matrix relates physical parts and physical interfaces to the functions and functional flows.

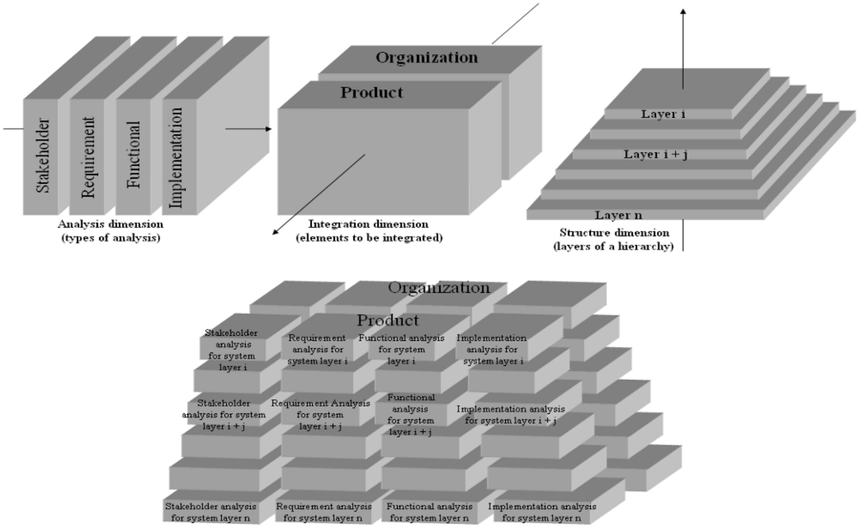

Figure 1. A framework to address complexity in complex product development – the total view framework

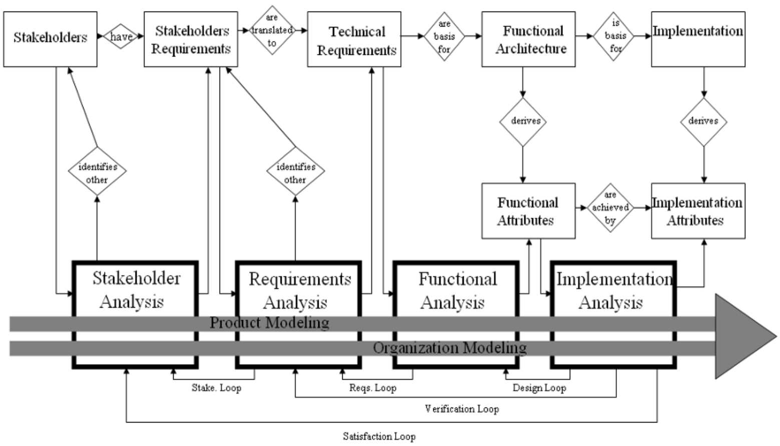

Figure 2. A method within the total view framework – the concurrent structured analysis method

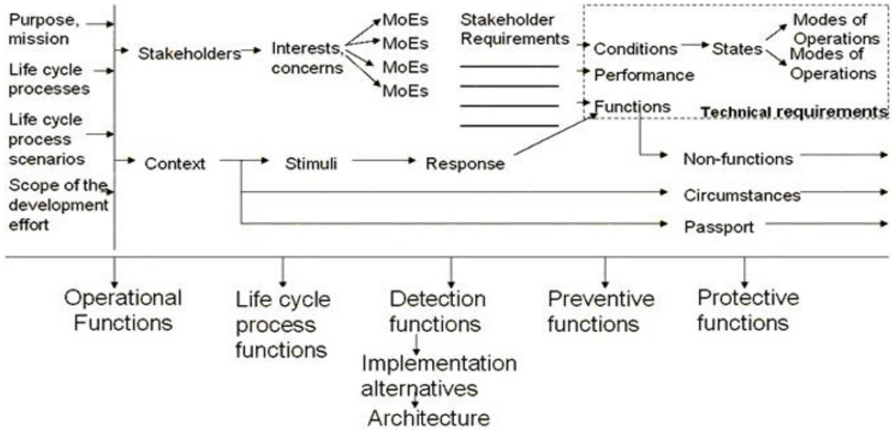

Figure 3. The system concurrent engineering method in detail

4 The OBC EGSE system concurrent engineering

This section illustrates the steps listed in Section 3 highlighting where the proposed approach is different from traditional approaches. The proposed approach is stakeholder driven whereas traditional approaches are customer or user driven. In the various steps listed in Section 3, analysis are performed for each life cycle process scenario, simultaneously, for product and organization. Traditional approaches focus on product operation and development organization. Figure 4 presents the life cycle processes and scenarios of a satellite OBC EGSE. Development process is decomposed in scenarios presented in boxes 15, 16 and 17 in Figure 4.

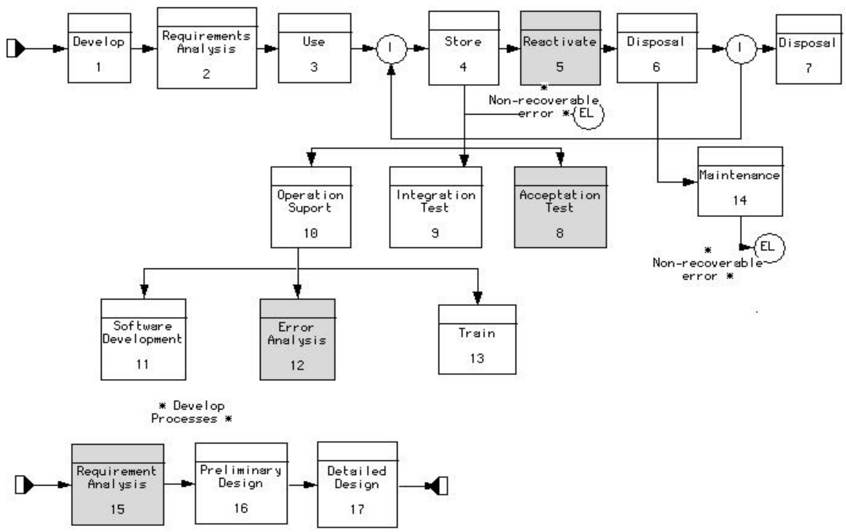

Figure 4. Life cycle processes and scenarios

The processes highlighted in grey in Figure 4 are the ones for which the stakeholder analysis, requirements analysis, functional analysis and implementation architecture analysis will be exemplified. In practice steps 1 to 4 in Section 3 must be run for all life cycle process scenarios. Figures 6 to 16 just exemplify the steps for some selected processes.
Figure 5 presents the life cycle processes that are within the scope of development effort. The organization that develops the OBC EGSE is also responsible for the use, storage, reactivation and disposal of the OBC EGSE.

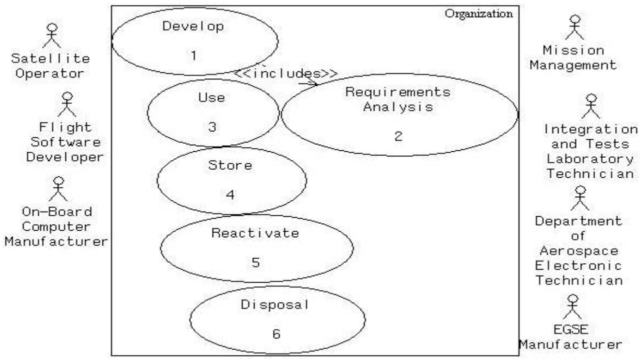

Figure 5. Scope of the development effort and organization stakeholder identification

Figures 6 and 7 exemplify the identification of organization stakeholders for two life cycle process scenarios: 'requirements analysis' and 'store'. The 'requirements analysis' scenario belongs to the development life cycle process and the 'store' process is not a product development process but is within the scope of the development effort. This is to show that it is necessary and possible to develop from the outset all processes within the scope of development effort, even though not all of them are product development processes. This innovates the traditional focus on systems engineering the product. This approach recognizes that the system solution is not only made of product elements but also of organization elements. Figures 6 and 7 also capture the stakeholder concerns represented by the connections between the stakeholders and the central bubble (containing life cycle process or scenario).

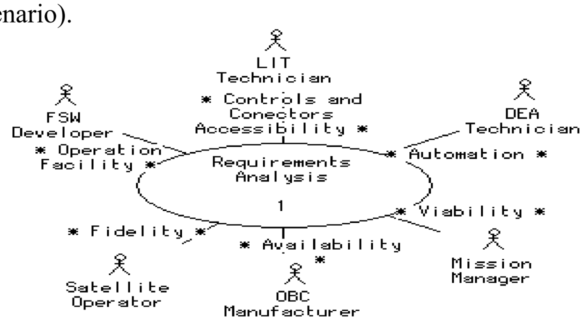

Figure 6. Organization stakeholders and their 'concerns' for the requirements analysis scenario

Figure 7. Organization stakeholders and their concerns for the 'Store' life cycle process

Figures 8 and 9 presents the product stakeholders identified and their concerns for two other life cycle process scenarios (OBC acceptance test and Error Analysis). OBC acceptance tests are one of the use scenarios of the EGSE. Error analysis is one of the scenarios of operations support. From stakeholder concerns, stakeholder requirements are identified and measures of effectiveness (MoEs) are derived. From stakeholder requirements, functions, performance and conditions are identified. Requirement analysis transforms stakeholder requirements into system requirements. System requirements will be met not only by product elements but also by organization elements.

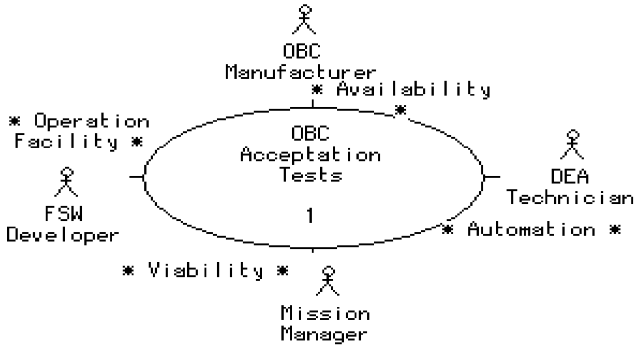

Figure 8. Product stakeholders and their concerns for the 'OBC acceptance test' scenario

Figure 9. Product stakeholders and their concerns for the 'Error Analysis' process scenario

Figures 10 and 11 depict the organization functional context for two life cycle process scenarios: 'requirements analysis' (a development scenario) and 'store' (a non-development scenario). In Figures 10 and 11, the links between the 'central bubble' and the elements in the organization environment at that scenario are identified. These links show the flows of information (in this case) between the environment and the system.

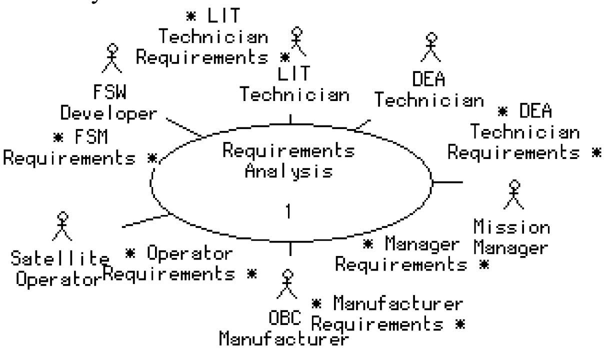

Figure 10. Organization functional context for the 'Reqirements Analysis' process scenario

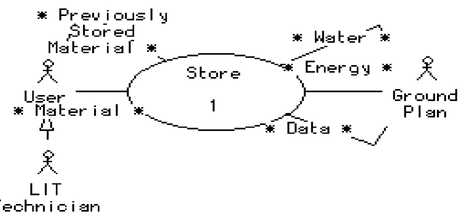

Figure 11. Organization functional context for the 'Store' process scenario

Figures 12 and 13 depict the product during 'OBC acceptance testing' and 'EGSE operation' in the central bubble and the elements in the environment during those processes. Links between product and environment are energy, material and information flows.

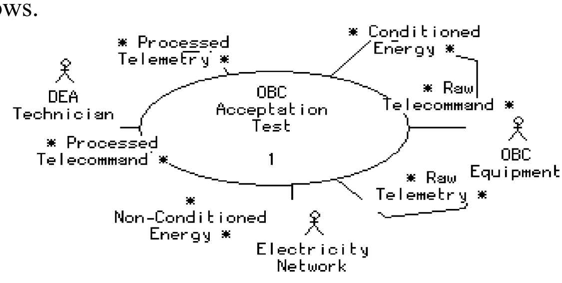

Figure 12. Product functional context for the 'OBC acceptance test' process scenario

Figure 13 also presents, besides each element in the environment, some of their potential states. For example, for the 'electricity network' potential states are 'nominal', 'peak power' or 'lack of energy'. The composition with states of other elements in the environment results in the potential circumstances a system must cope with. The system must have different modes depending on the circumstances. Behaviour modelling is required to show under which conditions system mode and system state transition occurs. Functions are identified per mode. Functions are identified from outside in by identifying which responses the system is supposed to give to deal with each stimulus provided by the environment elements. For each function, performance requirements are identified. Circumstances, flows between the system and the environment and function failures are sources of hazards. Risk analysis is performed on each identified potential hazard and exception handling functions are also identified at this stage.

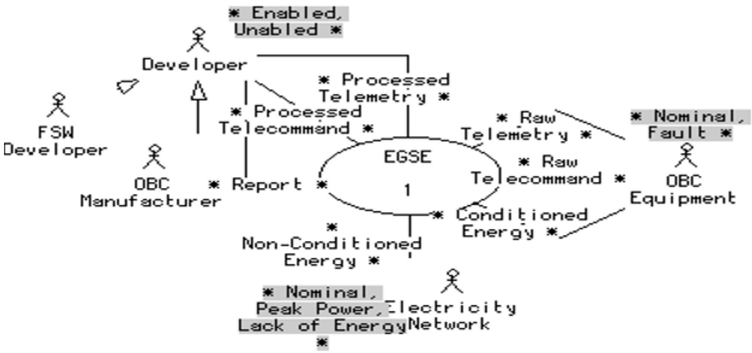

Figure 13. Product functional context for the 'operations' process and circumstances identified

Figure 14 presents the external physical connections between the 'store' organization and the elements in its environment.

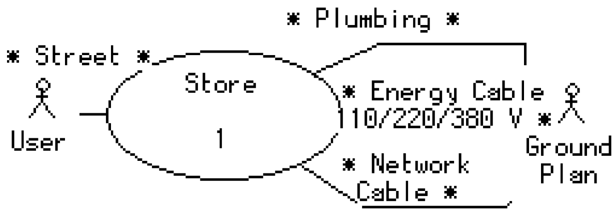

Figure 14. Organization implementation architecture context during the 'store' process and external physical interfaces identified

Figure 15 presents a decomposition of the 'store' organization into its internal elements and also shows the internal physical interfaces among internal elements. Figure 16 shows the product EGSE and its external physical interfaces with the elements in the environment, during EGSE use process. Figure 17 decomposes the product EGSE into its constituent parts. EGSE internal physical interfaces among its parts are also depicted in Figure 17.

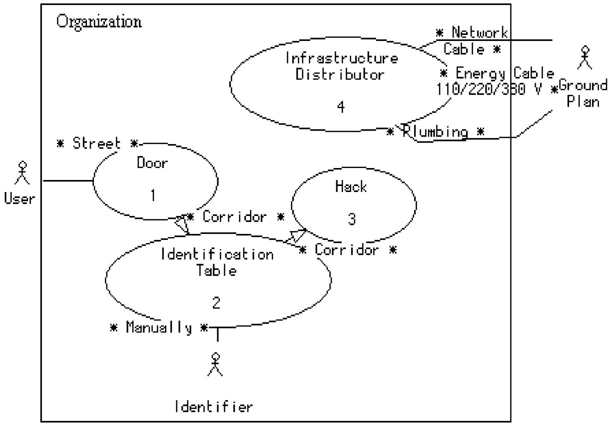

Figure 15. Organization implementation architecture with internal elements and internal physical interfaces for the 'store' process

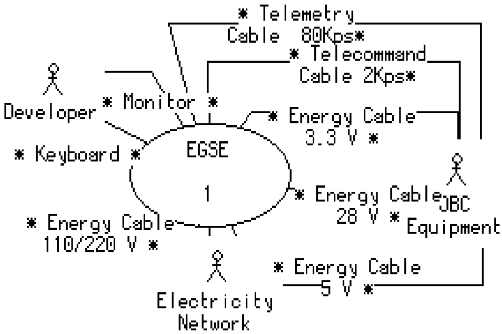

Figure 16. Product implementation architecture context during the 'operation' process and external physical interfaces identified

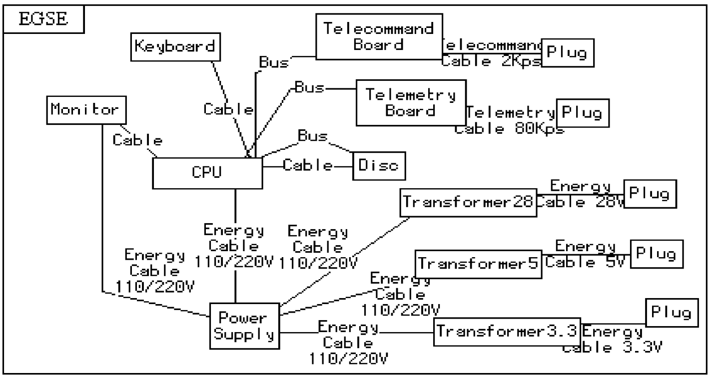

Figure 17. Product implementation architecture decomposition with internal physical interfaces

An allocation matrix relates physical parts and physical interfaces to the functions and functional flows. For example, from the functional decomposition of the context diagram in Figure 13, functions can be allocated to the parts identified in Figure 17. This allocation is depicted on an, so called, allocation matrix.

5 Discussion

This sections highlights the differences between traditional and proposed approaches. Complex products such as space products or space product support equipment such as the OBC EGSE analyzed in this paper have many stakeholders. It is not possible to consider only customer or user as stakeholders of interests, like in the traditional approaches. Stakeholders related to all product life cycle process must be taken into consideration from the outset of the system architecting process. The proposed approach accomplishes it. (see Steps 1 and 2 in Section 3).

Traditional systems engineering approaches perform functional context analysis only during product operations (the so called CONOPS or concept of operations) and for product development organization processes. However, a system solution is comprised of product and organization elements and many enabling elements must be also developed for mission success. These elements are only identified if context for each life cycle process scenario is performed. Therefore, the proposed approach covers the overall product life cycle, not only operations and development. (see Step 3 in Section 3). By considering product life cycle processes from the beginning of the system architecting process and from the top level context diagrams to be decomposed in lower level functions and lower level physical architectures, the concurrent engineering concept is implemented within the systems engineering process. This fulfills the framework proposed in Figure 1.

The proposed approach allows requirements from the whole product life cycle to be anticipated to the early stages of a system architecting process. Stakeholder requirements are captured for the whole product life cycle process. Functions, performance, conditions, circumstances, modes and exception functions are captured for the whole product life cycle process. External physical and logical interfaces and internal physical and logical interfaces are identified for the whole product life cycle process. The system solution here is composed of product and organization elements. The product interaction with other system elements is identified in the beginning of the system architecting process. This promotes dramatic gains in productivity during product development and during product life cycle. System quality increases. Product changes are avoided. Changes cost and time are eliminated.

6 Conclusion

This paper presented a system concurrent engineering approach for a satellite OBC EGSE. The proposed approach addressed the deficiencies of traditional methods, such as, product focus, operation and development focus, and part focus.

The paper described the approach as a way to perform stakeholder analysis, requirements analysis, functional analysis and implementation architecture, simultaneously, for the product and organization elements of a system at every layer of the system breakdown structure. This is necessary to address all complexity factors that are inherent to complex product development. Conclusions are that impact, traceability and hierarchy links promote the anticipation of life cycle process requirements to the early stages of systems architecting. Late changes are avoided, development costs are dramatically reduced while satisfaction of stakeholders over product life cycle is increased.

7 Acknowledgement

The authors would like to thank CAPES (Coordination for Supporting and Development Superior Education Personnel, www.capes.br) for Jonas Bianchini Fulindi scholarship. The authors would like to thank INPE (the Brazilian Institute for Space Research, www.inpe.br) for the post graduate course and the case study opportunity. The authors would like to thank IAE (Aeronautics and Space Institute, www.iae.cta.br) and 3SL (www.threesl.co.uk) for providing Cradle, the systems engineering environment software used for the development of this work.

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Systems Concurrent Engineering of a Turbo-generator

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Abstract. This paper presents a systems concurrent engineering approach for the development of a turbo-generator. Traditional approaches focus on the product, development organization and the product concepts of operation (CONOPS). In those approaches the overall view of the inherent complexity in the development of a product, its life cycle processes and their performing organizations are not taken into consideration. The systems concurrent engineering performs stakeholder analysis, requirements analysis, functional analysis and implementation architecture analysis, simultaneously, for the product, its life cycle processes and their performing organization. From the analysis, requirements and attributes are captured for the product and its life cycle processes organizations and the relationship among them are identified. Conclusions are that impact, traceability and hierarchy links promote the anticipation of life cycle process requirements to the early stages of systems architecting. Late changes are avoided, development costs are dramatically reduced while satisfaction of stakeholders over product life cycle is increased.

Keywords. Systems concurrent engineering, systems engineering, concurrent engineering, complex product, integrated product development.

1 Introduction

Turbo-generator is a device that converts kinetic energy into electrical energy. Today more and more importance is given to clean and renewable fuels, which do not harm the environment. Taking this into account, the turbo-generator described in this paper is an equipment that provides electric energy in different power levels using a gas turbine. The gas turbine uses clean and sustainable fuels that do not harm the environment.

Several components are part of a turbo-generator, among them we highlight the compressor, combustion chamber, turbines, ducts input and output, skid, electric generators, fuel pumps, control panels, etc.

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This paper aims to present a systems concurrent engineering approach for the development of a turbo-generator. The approach is different from traditional systems engineering approach because it anticipates to the early stages of system architecting the product life cycle process requirements. It proposes to simultaneously develop, from the outset, the product and its life cycle processes performing organizations.

The paper is organized as following: Section 2 presents the traditional systems engineering and concurrent engineering approaches. Section 3 presents the systems concurrent engineering approach framework and method. Section 4 presents the models derived for the turbo-generator using the approach. Section 5 discusses the advantages and opportunities for improving the proposed approach. Section 6 concludes this paper.

2 Traditional systems engineering and concurrent engineering

Energy generating products are complex. They are multidisciplinary products, they must cope with extreme environmental conditions over their life cycle (vibration, high temperatures, powder), they must undergo very strict calibration and tuning procedures. Development organizations are worth the order of hundred million dollars. There are many opportunities to improve productivity over energy generating product life cycle if a concurrent engineering approach takes place from the beginning of the product architecting stage.

Traditional systems engineering approaches do not provide an overall view of the system during its various life cycle processes. They focus on an operational product development starting from product concept of operations. They also focus on the development organization that must be put in place in order to assure that the product meets its operational requirements [2,3,6,8]. A product has life cycle processes other than operations and it must be recognized from the outset in order to promote gains in productivity in the product development organization, by the avoidance of late changes, and in other product life cycle process organizations, as the product will be developed taking into consideration their requirements. Life cycle process organizations themselves can be developed simultaneously to product development, when they are part of the scope of the whole product development effort.

For example the NASA systems engineering handbook [8] states that systems engineering focuses in the development and the realization of a final product. Modern commercial standards, such as EIA 632 [2], state that systems engineering focuses on the operations product and on capturing requirements for the other product life cycle processes. In other words, these requirements are captured not to impact product development. The product will be systems engineered with operations in mind. When its architecture (and maybe detailed design) is defined, then life cycle processes requirements are captured to be implemented in life cycle process performing organizations. This paper proposes a method to take into consideration the impact of these organizations on the product during the product architecting process. Conceptually, concurrent engineering acknowledges benefits of anticipating life cycle process requirements to the early stages of product development. For space products, these early stages are the system architecting phases. A systems approach requires life cycle process requirements to be balanced in the beginning of the product development process.

Concurrent engineering, however, in practice, treats life cycle processes separately and optimizes product design seeking each life cycle process productivity increase. For example, DFA optimizes for assemblability, QFD, for customer satisfaction, DFI, for inspectability, and so on. Also, concurrent engineering is, in practice, applied to parts design and not to systems composed of many integrated parts [5]. This paper proposes how the concurrent engineering concept can be used for systems engineering.

3 The systems concurrent engineering approach

Hitchins [4] states that complexity can be understood by what he calls complexity factors. They are variety, connectedness and disorder. Variety accounts for the number of different elements you have in a set. Regarding products, variety refers, for example, to the number of different parts a product may have, number of different functions it accomplishes, number of different requirements categories it is supposed to meet, number of different stakeholders it should satisfy. Connectedness refers to the relationships among elements. For example, how parts interact, how functions affect one another, how requirements conflict to each other, how value flow among stakeholders. Disorder refers to the level of tangling of those relationships. For example, is there a structure pattern of deploying stakeholder requirements through functional concept up to implementation architecture?

Figure 1 presents a framework to address complexity in product development – the total view framework evolved from Loureiro [7]. It has three dimensions. Each dimension addresses one of the complexity factors mentioned above. The analysis dimension addresses the variety factor. Along the analysis dimension, it is deployed what must be analysed in order to develop a complex product. A systems engineering process consists of stakeholder analysis, requirements analysis, functional analysis and implementation or physical analysis. The integration dimension addresses the connectedness factor. It defines what must be integrated along an integrated product development process: product elements and organization elements. Organization here refers to the organizations that perform product life cycle processes. Product elements and organization elements are the system elements. The structure dimension addresses the disorder factor. According to Alexander [1] all structures evolve into a hierarchy. System breakdown structures are also represented in hierarchies.

Figure 2 provides an overview of a method within the total view framework. The method is called concurrent structured analysis method evolved from Loureiro [7]. Stakeholder analysis, requirements analysis, functional analysis and implementation (or physical) analysis is performed, simultaneously, for the product under development and its life cycle process performing organizations. The analysis processes are performed at each layer of the system breakdown structure.

For example, if a car is the product under development, the analysis processes are performed at the car layer, at the powertrain layer, at the engine layer and so on.

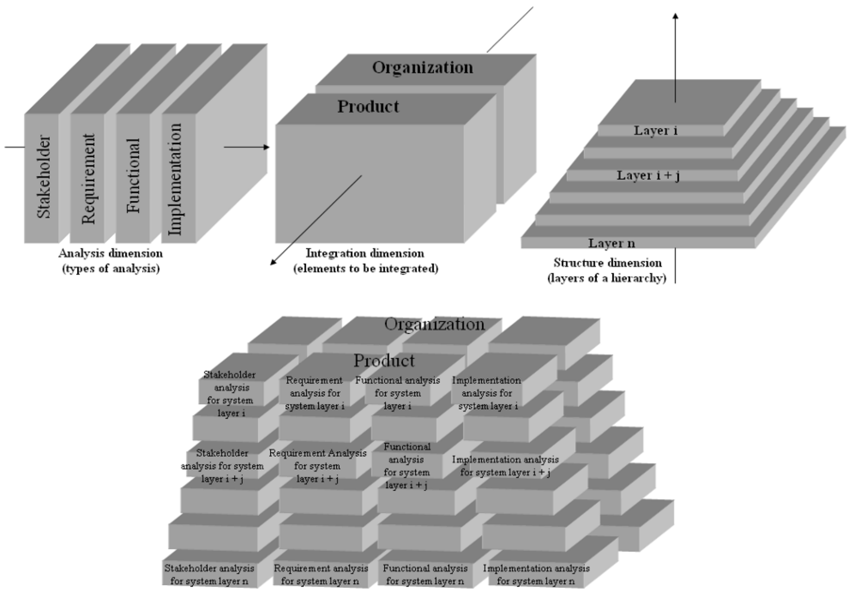

Figure 1. A framework to address complexity in complex product development – the total view framework

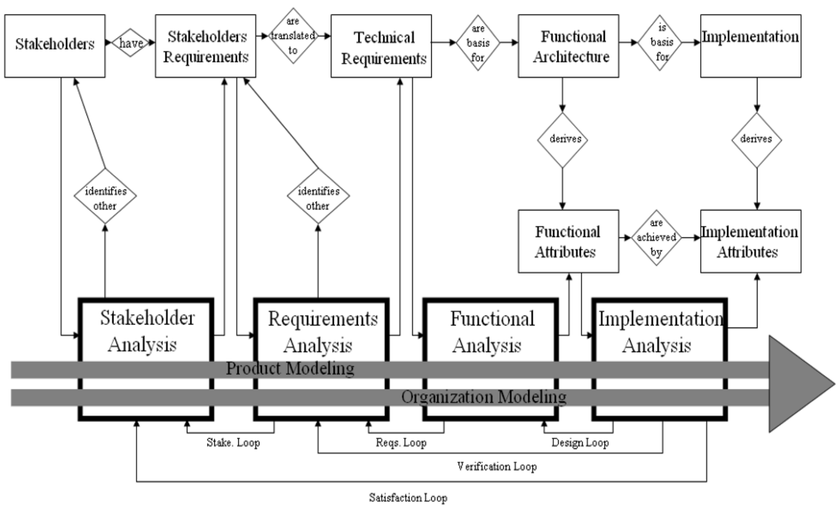

Figure 2. A method within the total view framework – the concurrent structured analysis method

Figure 3 details the concurrent structured analysis method showing how to incorporate the concurrent engineering concept in the systems engineering process:

Step 1: Identify the product mission, the product life cycle processes and their scenarios and, the scope of the development effort. Product mission refers to the product purpose or reason of being. Life cycle process scenarios are the alternatives in each process (for example, preventive or corrective maintenance) or the decomposition of a process (for example, advanced technology development, process engineering as components of the development process). The scope of the development effort consists of the life cycle processes or their scenarios that the development organization is also responsible for accomplishing. For example, EMBRAER is responsible for developing aircraft but is also responsible for providing maintenance services.

Step 2: Identify product stakeholders and their concerns for each product life cycle process scenario. Product stakeholders are the people who affect or are affected by the product during its life cycle. Product stakeholders are identified per life cycle process scenario. Identify organization stakeholders and their concerns for each process within the scope of the development effort. Organization stakeholders are the people who affect or are affected by the business of the organization in question. Organization stakeholders are identified per life cycle process scenario within the scope of the development effort. From stakeholder concerns, stakeholder requirements are identified and measures of effectiveness (MoEs) are derived. MoEs must measure how the system meets the stakeholder requirements. From stakeholder requirements, functions, performance and conditions are identified. The definition of what functions the system will perform, how well the system is going to perform such functions and under which conditions comprise the requirements analysis process. Requirement analysis transforms stakeholder requirements into system requirements. System requirements will be met not only by product elements but also by organization elements.

Step 3: Identify functional context for product at each life cycle process scenario and for organization at each life cycle process scenario within the scope of the development effort. Functional context defines the function performed by the system element and identifies the elements in the environment of the system. The environment of the system contains the elements outside the system function scope and that exchanges material, information and energy flows with the system. Those flows define logical interface requirements. Environment elements may have different relevant states. Sets of environment element states are called circumstances. The system must have different modes depending on the circumstances. Behaviour modelling is required to show under which conditions system mode and system state transition occurs. Functions are identified per mode. Functions are identified from outside in by identifying which responses the system is supposed to give to deal with each stimulus provided by the environment elements. For each function, performance requirements are identified. Circumstances, flows between the system and the environment and function failures are sources of hazards. Risk analysis is performed on each identified potential hazard and exception handling functions are also identified at this stage.

Step 4: Identify implementation architecture context for product at each lifecycle process scenario and for organization at each life cycle process scenario within the scope of the development effort. Physical connections between the system and the environment elements define the physical external interface requirements. Physical parts are identified. Physical internal interfaces are defined by architecture connections and architecture flows among those parts. Allocation matrix relates physical parts and physical interfaces to the functions and functional flows.

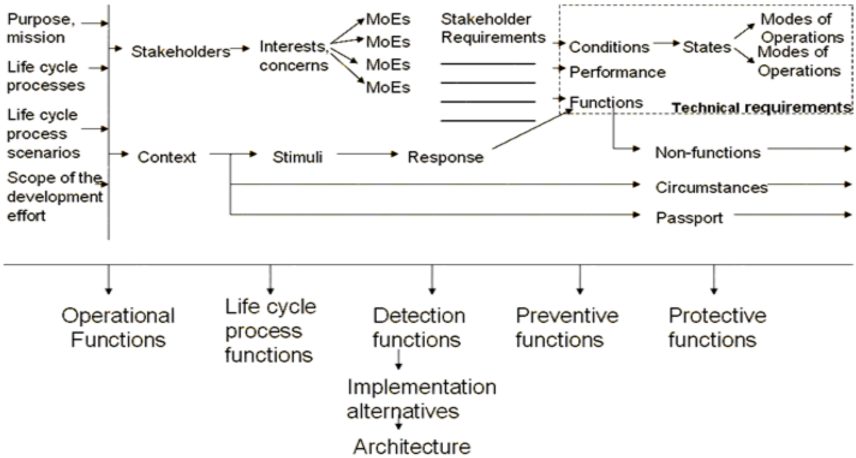

Figure 3. The system concurrent engineering method in detail

4 The turbo-generator system concurrent engineering

This section illustrates the steps listed in Section 3 highlighting where the proposed approach is different from traditional approaches. The proposed approach is stakeholder driven whereas traditional approaches are customer or user driven. In the various steps listed in Section 3, analysis are performed for each life cycle process scenario, simultaneously, for product and organization. Traditional approaches focus on product operation and development organization.

Figure 4 presents the life cycle process and the scenarios of a turbo-generator. Life cycle process is described and under of each life cycle process the scenarios are pointed by arrows. The processes 'development', 'manufacturing and assembly', 'operation', 'maintenance' and 'sales' are the ones for which the stakeholder analysis, functional analysis and implementation architecture analysis will be exemplified. Section 3 must be run for all life cycle process scenarios. Figures 5 to 13 just exemplify the steps for some selected processes.

Figure 5 and 6 presents the product stakeholders identified and their concerns for two life cycle process: 'development' and 'manufacturing and assembly'. From stakeholders concerns, stakeholder requirements are identified and measures of effectiveness (MoEs) are derived. From stakeholders requirements, functions, performance and conditions are identified. Requirements analysis transforms

stakeholder requirements into system requirements. System requirements will be met not only by product elements but also by organization elements.
Figure 7 exemplifies the identification of organization stakeholders for the process: ‘development and services’. In this case all processes are supported by the organization in the scope of the development effort. Figure 7 exemplifies the identification of organization stakeholders, this is to show that it is necessary and possible to develop from the outset all processes within the scope of development effort, even though not all of them are product development processes. This innovates the traditional focus on systems engineering the product. This approach recognizes that the system solution is not only made of product elements but also of organization elements. Figure 7 also captures the stakeholders and the central bubble containing life cycle process. In the arrows connected with the central bubble is describe their ‘concerns’.

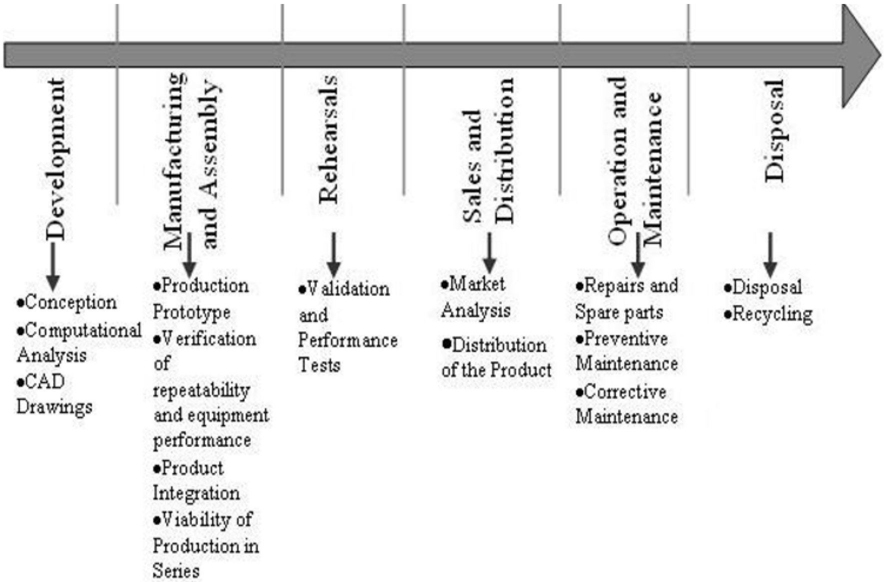

Figure 4. Life cycle processes and scenarios

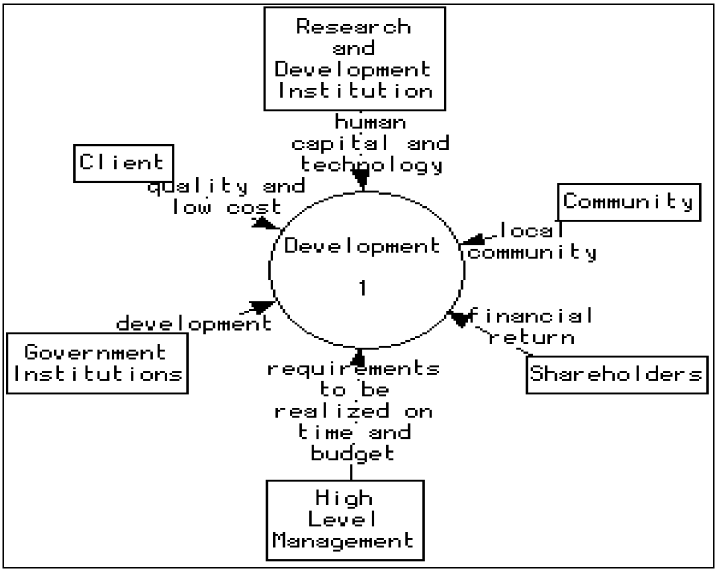

Figure 5. Product stakeholders and their concerns for the development analysis

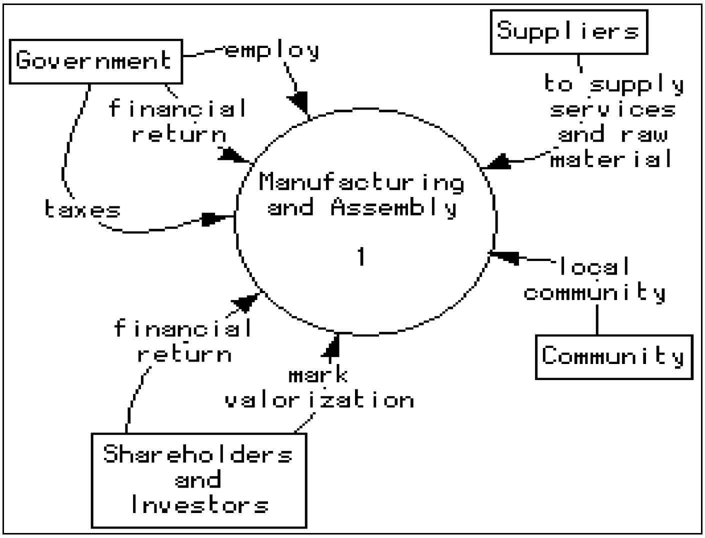

Figure 6. Product stakeholders and their concerns for the 'manufacture and assembly'life cycle process

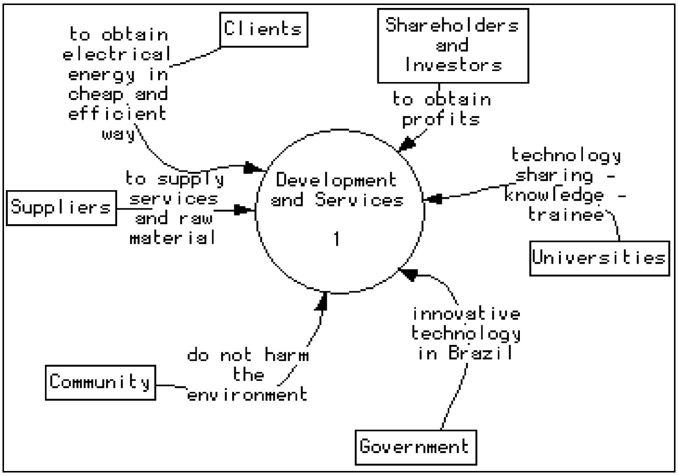

Figure 7. Organization stakeholders and their concerns for the 'development and services'

Figures 8 and 9 depict the product during 'operation' and 'maintenance' in the central bubble and the elements in the environment during those processes. Links between product and environment are energy, material and information flows. Besides each element in the environment, is necessary to identify some of their potential states. In Figure 8, for example, for the 'operator' potential states could be an operator enabled or unable to realize their actions. The composition with states of other elements in the environment results in the potential circumstances a system must cope with.

The system must have different modes depending on the circumstances. Behaviour modeling is required to show under which conditions system mode and system state transition occurs. Functions are identified per mode. Functions are identified from outside in by identifying which responses the system is supposed to give to deal with each stimulus provide by the environment elements. For each function, performance requirements are identified. Circumstances, flows between the system and the environment and function failures are sources of hazards. Risk analysis is performed on each identified potential hazard and exception handling functions are also identified at this stage.

Figures 10 and 11 depict the organization functional context for two life cycle process: 'development' and 'sales'. In Figures 10 and 11, the links between the central bubble and the elements in the organization environment are identified. The links show the flows of information and materials, an example of the material flow is identified in Figure 11 between the 'sales' process depicted in the central bubble and the 'expedition' as element of the environment, the material is the product transported.

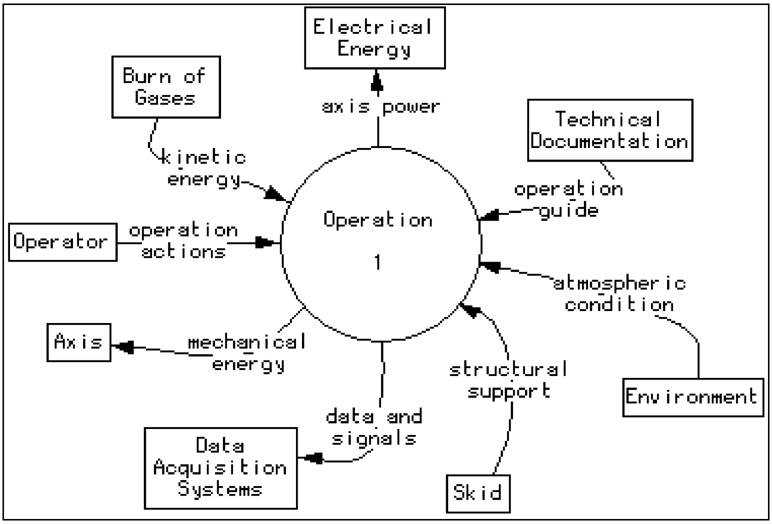

Figure 8. Product functional context for the 'operation' process

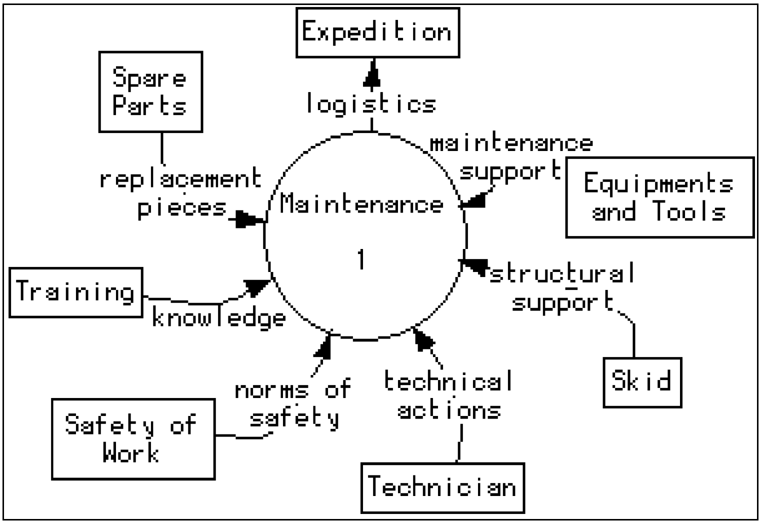

Figure 9. Product functional context for the 'maintenance' process

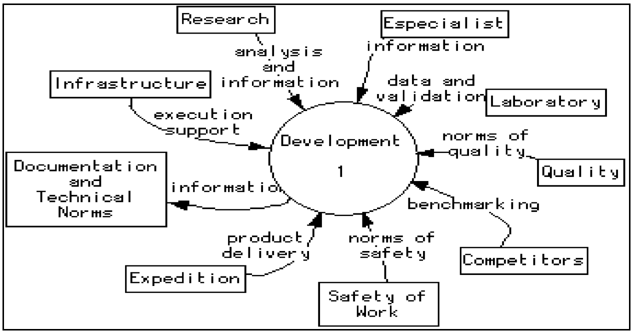

Figure 10. Organization functional context for the 'development' process

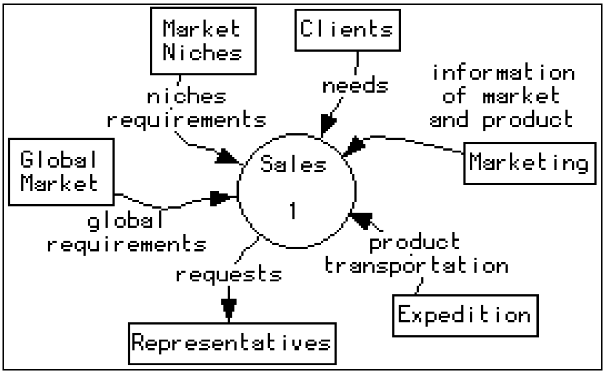

Figure 11. Organization functional context for the 'sales' process

Figure 12 decomposes the turbo-generator into its constituent parts. The turbo-generator internal physical interfaces among its parts are also depicted.

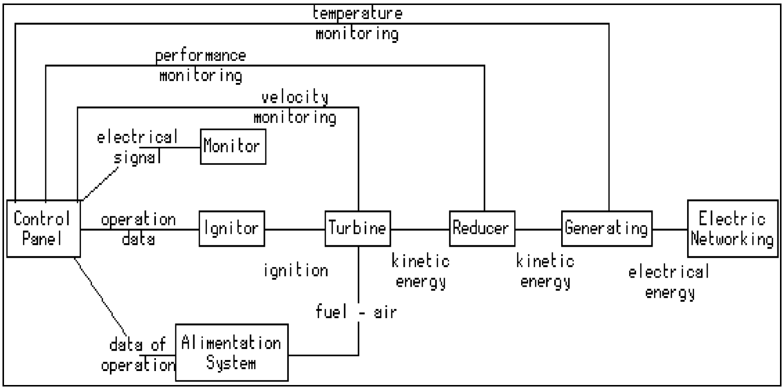

Figure 12. Product implementation architecture context and its flows

Figure 13 shows the internal elements and identify their internal physical interfaces.

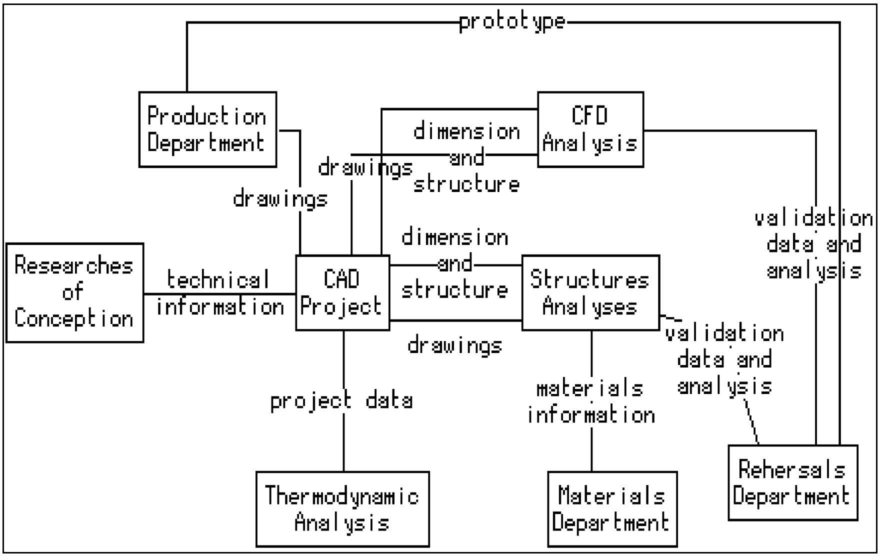

Figure 13. Organization implementation architecture context and internal physical interfaces identified

5 Discussion

This sections highlights the differences between traditional and proposed approaches.

The complex product analyzed in this paper has many stakeholders. It is not possible to consider only customer or user as stakeholders of interests, like in the traditional approaches. Stakeholders related to all product life cycle process must be taken into consideration from the outset of the system architecting process. The proposed approach accomplishes it. (see Steps 1 and 2 in Section 3)

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By considering product life cycle processes from the beginning of the system architecting process and from the top level context diagrams to be decomposed in lower level functions and lower level physical architectures, the concurrent engineering concept is implemented within the systems engineering process. This fulfills the framework proposed in Figure 1.

The proposed approach allows requirements from the whole product life cycle to be anticipated to the early stages of a system architecting process. Stakeholder requirements are captured for the whole product life cycle process. Functions, performance, conditions, circumstances, modes and exception functions are captured for the whole product life cycle process. External physical and logical interfaces and internal physical and logical interfaces are identified for the whole product life cycle process. The system solution here is composed of product and organization elements. The product interaction with other system elements is identified in the beginning of the system architecting process. This promotes dramatic gains in productivity during product development and during product life cycle. System quality increases. Product changes are avoided. Changes cost and time are eliminated.

6 Conclusion

This paper presented a system concurrent engineering approach of a turbo-generator. The proposed approach addressed the deficiencies of traditional methods, such as, product focus, operation and development focus, and part focus.

The paper described the approach as a way to perform stakeholder analysis, requirements analysis, functional analysis and implementation architecture, simultaneously, for the product and organization elements of a system at every layer of the system breakdown structure. This is necessary to address all complexity factors that are inherent to complex product development. Conclusions are that impact, traceability and hierarchy links promote the anticipation of life cycle process requirements to the early stages of systems architecting. Late changes are avoided, development costs are dramatically reduced while satisfaction of stakeholders over product life cycle is increased.

7 Acknowledgement

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Systems Concurrent Engineering of an Electric Bike

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[c,d,e]Post graduate students at Technological Insitute of Aeronautics - ITA.

Abstract. This paper presents a systems concurrent engineering approach for the development of an electric bike. Traditional approaches focuses on the product, development organization and the product concepts of operation (CONOPS). In those approaches the overall view of the inherent complexity in the development of a product, its life cycle processes and their performing organizations are not taken into consideration. The systems concurrent engineering performs stakeholder analysis, requirements analysis, functional analysis and implementation architecture analysis, simultaneously, for the product, its life cycle processes and their performing organization. From the analysis, requirements and attributes are captured for the product and its life cycle processes organizations and the relationship among them are identified. Conclusions are that impact, traceability and hierarchy links promote the anticipation of life cycle process requirements to the early stages of systems architecting. Late changes are avoided, development costs are dramatically reduced while satisfaction of stakeholders over product life cycle is increased.

Keywords. Systems concurrent engineering, systems engineering, concurrent engineering, integrated product development.

1 Introduction

Electric bike industry has been having a growing demand. Due to health and environment issues, consumers have chosen configurable bicycles where they can add value by acquiring accessories. Development activities for two-wheel transport systems are made in various national and international industries, as well as their components and accessories. The products are intended primarily for leisure and carrying small loads. However, R & D is needed in order to engineer a system with specific customers (of various ages and different purchasing power) needs.

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The paper is organized as following: Section 2 presents the traditional systems engineering and concurrent engineering approaches. Section 3 presents the systems concurrent engineering approach framework and method. Section 4 presents the models derived for the electric bike using the approach. Section 5 discusses the advantages and opportunities for improving the proposed approach. Section 6 concludes this paper.

2 Traditional systems engineering and concurrent engineering

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Also, concurrent engineering is, in practice, applied to parts design and not to systems composed of many integrated parts [5]. This paper proposes how the concurrent engineering concept can be used for systems engineering.

3 The systems concurrent engineering approach

Hitchins [4] states that complexity can be understood by what he calls complexity factors. They are variety, connectedness and disorder. Variety accounts for the number of different elements you have in a set. Regarding products, variety refers, for example, to the number of different parts a product may have, number of different functions it accomplishes, number of different requirements categories it is supposed to meet, number of different stakeholders it should satisfy. Connectedness refers to the relationships among elements. For example, how parts interact, how functions affect one another, how requirements conflict to each other, how value flow among stakeholders. Disorder refers to the level of tangling of those relationships. For example, is there a structure pattern of deploying stakeholder requirements through functional concept up to implementation architecture?

Figure 1 presents a framework to address complexity in product development – the total view framework evolved from Loureiro [7]. It has three dimensions. Each dimension addresses one of the complexity factors mentioned above. The analysis dimension addresses the variety factor. Along the analysis dimension, it is deployed what must be analysed in order to develop a complex product. A systems engineering process consists of stakeholder analysis, requirements analysis, functional analysis and implementation or physical analysis. The integration dimension addresses the connectedness factor. It defines what must be integrated along an integrated product development process: product elements and organization elements. Organization here refers to the organizations that perform product life cycle processes. Product elements and organization elements are the system elements. The structure dimension addresses the disorder factor. According to Alexander [1] all structures evolve into an hierarchy. System breakdown structures are also represented in hierarchies.

Figure 2 provides an overview of a method within the total view framework. The method is called concurrent structured analysis method evolved from Loureiro [7]. Stakeholder analysis, requirements analysis, functional analysis and implementation (or physical) analysis is performed, simultaneously, for the product under development and its life cycle process performing organizations. The analysis processes are performed at each layer of the system breakdown structure. For example, if a car is the product under development, the analysis processes are performed at the car layer, at the powertrain layer, at the engine layer and so on.

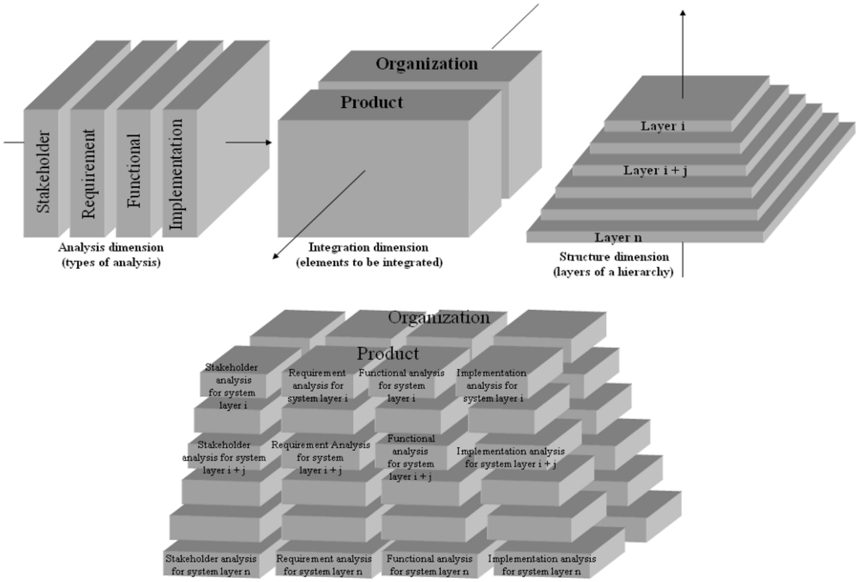

Figure 1. A framework to address complexity in complex product development – the total view framework

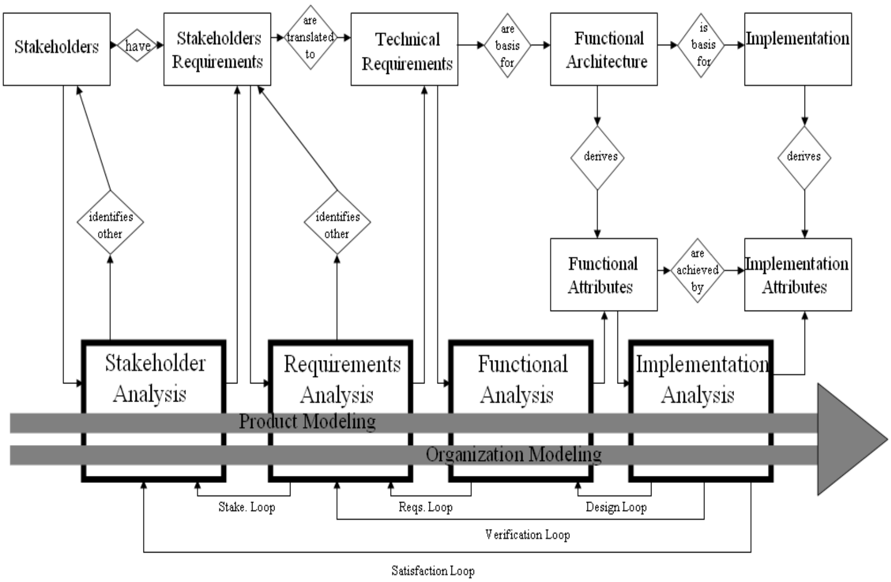

Figure 2. A method within the total view framework – the concurrent structured analysis method

Figure 3 details the concurrent structured analysis method showing how to incorporate the concurrent engineering concept in the systems engineering process:

Step 1: Identify the product mission, the product life cycle processes and their scenarios and, the scope of the development effort. Product mission refers to the product purpose or reason of being. Life cycle process scenarios are the alternatives in each process (for example, preventive or corrective maintenance) or the decomposition of a process (for example, advanced technology development, process engineering as components of the development process). The scope of the development effort consists of the life cycle processes or their scenarios that the development organization is also responsible for accomplishing. For example, EMBRAER is responsible for developing aircraft but is also responsible for providing maintenance services.

Step 2: Identify product stakeholders and their concerns for each product life cycle process scenario. Product stakeholders are the people who affect or are affected by the product during its life cycle. Product stakeholders are identified per life cycle process scenario. Identify organization stakeholders and their concerns for each process within the scope of the development effort. Organization stakeholders are the people who affect or are affected by the business of the organization in question. Organization stakeholders are identified per life cycle process scenario within the scope of the development effort. From stakeholder concerns, stakeholder requirements are identified and measures of effectiveness (MoEs) are derived. MoEs must measure how the system meets the stakeholder requirements. From stakeholder requirements, functions, performance and conditions are identified. The definition of what functions the system will perform, how well the system is going to perform such functions and under which conditions comprise the requirements analysis process. Requirement analysis transforms stakeholder requirements into system requirements. System requirements will be met not only by product elements but also by organization elements.

Step 3: Identify functional context for product at each life cycle process scenario and for organization at each life cycle process scenario within the scope of the development effort. Functional context defines the function performed by the system element and identifies the elements in the environment of the system. The environment of the system contains the elements outside the system function scope and that exchanges material, information and energy flows with the system. Those flows define logical interface requirements. Environment elements may have different relevant states. Sets of environment element states are called circumstances. The system must have different modes depending on the circumstances. Behaviour modelling is required to show under which conditions system mode and system state transition occurs. Functions are identified per mode. Functions are identified from outside in by identifying which responses the system is supposed to give to deal with each stimulus provided by the environment elements. For each function, performance requirements are identified. Circumstances, flows between the system and the environment and function failures are sources of hazards. Risk analysis is performed on each identified potential hazard and exception handling functions are also identified at this stage.

Step 4: Identify implementation architecture context for product at each life cycle process scenario and for organization at each life cycle process scenario within the scope of the development effort. Physical connections between the system and the environment elements define the physical external interface requirements. Physical parts are identified. Physical internal interfaces are defined by architecture connections and architecture flows among those parts. Allocation matrix relates physical parts and physical interfaces to the functions and functional flows.

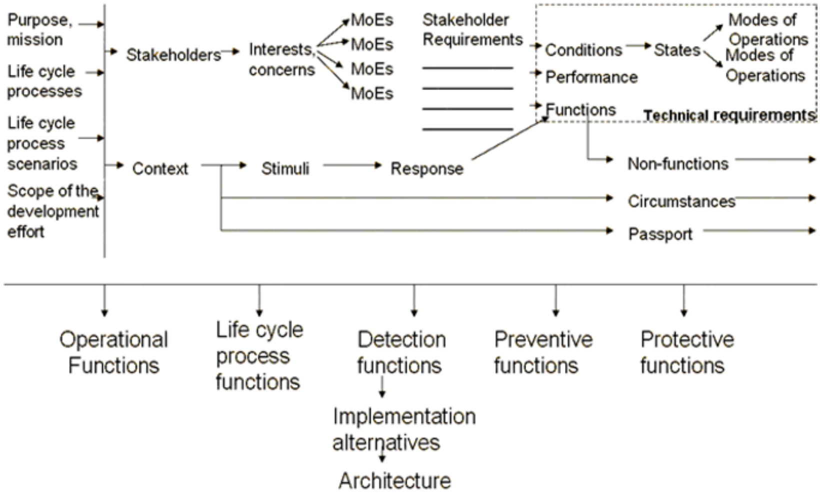

Figure 3. The system concurrent engineering method in detail

4 The electric bike system concurrent engineering

This section illustrates the steps listed in Section 3 highlighting where the proposed approach is different from traditional approaches. The proposed approach is stakeholder driven whereas traditional approaches are customer or user driven. In the various steps listed in Section 3, analysis are performed for each life cycle process scenario, simultaneously, for product and organization. Traditional approaches focus on product operation and development organization.

Figure 4 presents the life cycle processes to conduct the product project. The processes ‘operation’, ‘production’, ‘development’ and ‘maintenance’ are the ones for which the stakeholders analysis, functional analysis and implementation architecture analysis will be exemplified. Section 3 must be run for all life cycle process scenarios. Figures 5 to 14 just exemplify the steps for some selected processes.

Figure 5 and 6 presents the product stakeholders identified for two life cycle process: ‘operation’ and ‘production’. From stakeholders concerns, stakeholder requirements are identified and measures of effectiveness (MoEs) are derived. From stakeholders requirements, functions, performance and conditions are identified. Requirements analysis transforms stakeholder requirements into system requirements. System requirements will be met not only by product elements but also by organization elements.

Figures 7 and 8 exemplify the identification of organization stakeholders for the processes: 'development' and 'maintenance'. The processes in the scope of development effort supported by the organization are: market studies, business plan, conception, detailed project, prototype project, qualification and tests, production in series and distribution. It shows that is necessary and possible to develop from the outset all processes within the scope of development effort. This innovates the traditional focus on the product. This approach recognizes that the system solution is not only made of product elements but also of organization elements. Figures 7 and 8 capture the stakeholders and the central bubble containing life cycle process.

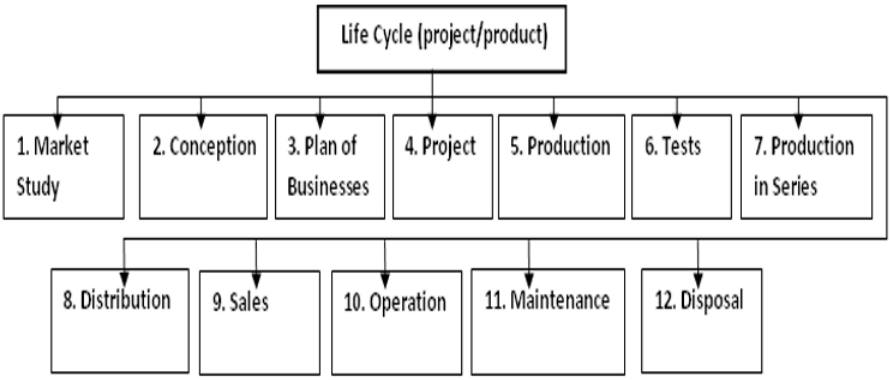

Figure 4. Life Cycle

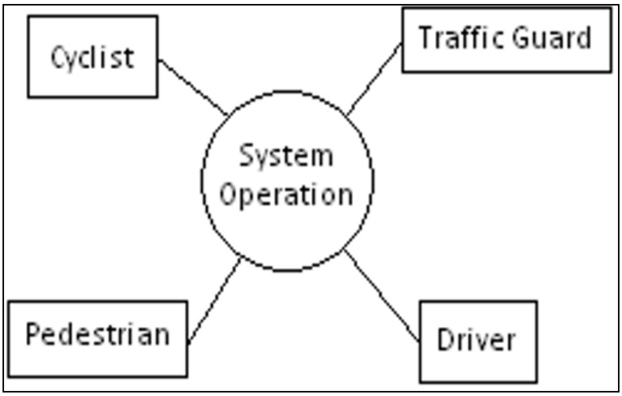

Figure 5. Product stakeholders for the system operation

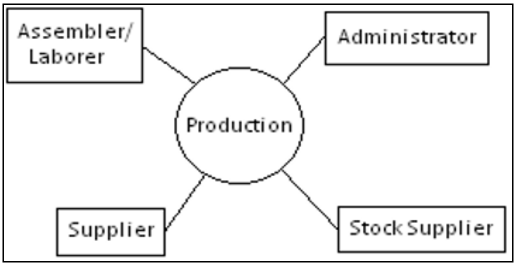

Figure 6. Product stakeholders for the 'production'

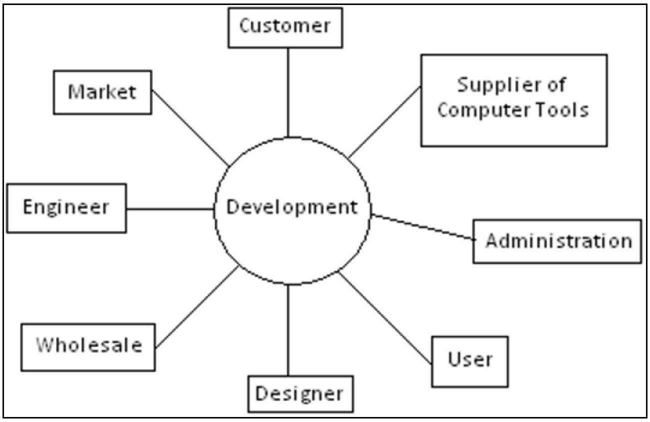

Figure 7. Organization stakeholders and their concerns for the 'development' process

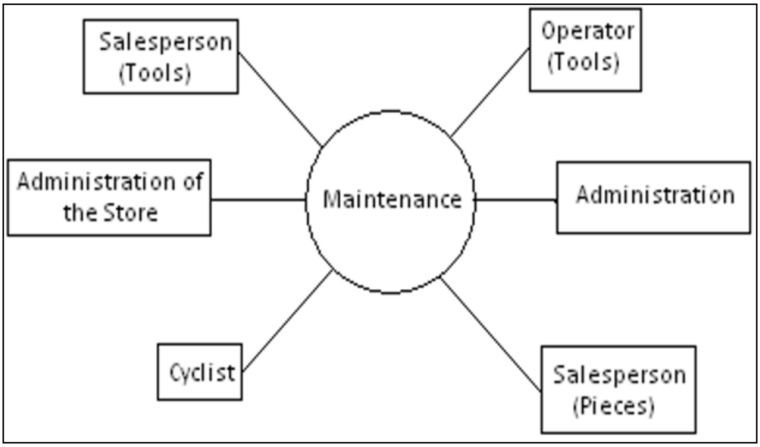

Figure 8. Organization stakeholders and their concerns for the 'maintenance'

Figures 9 and 10 depict the product during ‘operation’ and ‘manufacture’ in the central bubble and the elements in the environment during those processes. Links between product and environment are energy, material and information flows. Besides each element in the environment, is necessary to identify some of their potential states. In Figure 9 for example for the ‘loader of energy’ potential states could be lack of energy or in nominal. The composition with states of other elements in the environment results in the potential circumstances a system must cope with.

The system must have different modes depending on the circumstances. Behaviour modelling is required to show under which conditions system mode and system state transition occurs. Functions are identified per mode. Functions are identified from outside in by identifying which responses the system is supposed to give to deal with each stimulus provide by the environment elements. For each function, performance requirements are identified. Circumstances, flows between the system and the environment and function failures are sources of hazards. Risk analysis is performed on each identified potential hazard and exception handling functions are also identified at this stage.

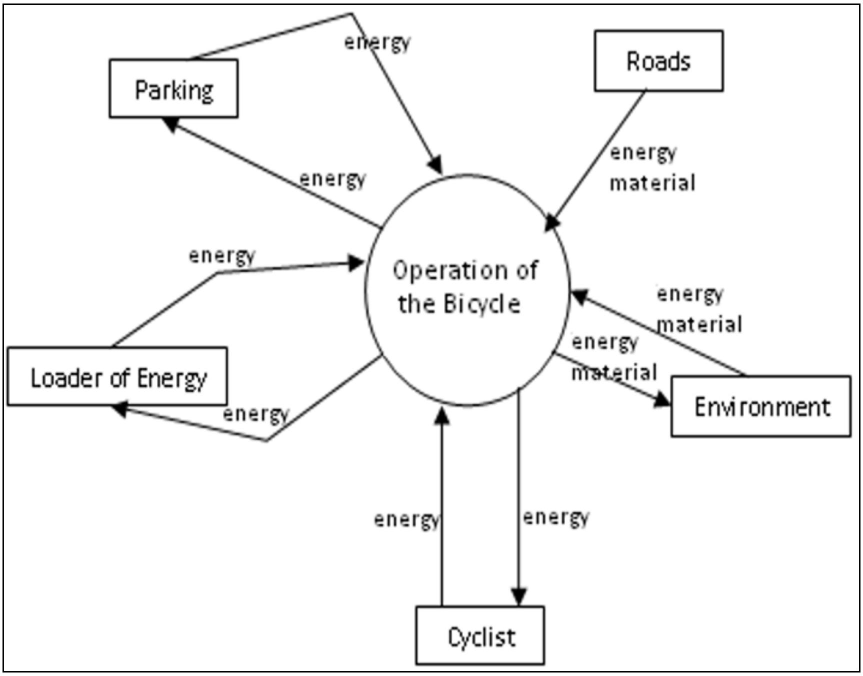

Figure 9. Product functional context for the ‘operation of the bicycle’ process

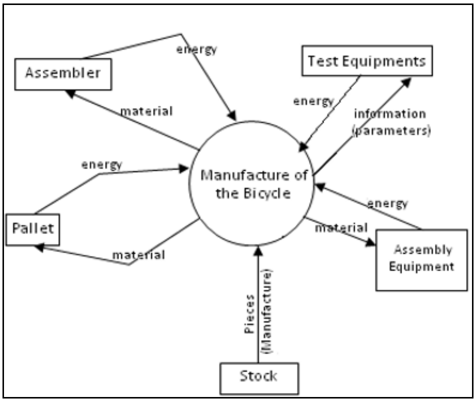

Figure 10. Product functional context for the 'maintenance of the bicycle' process

Figures 11 and 12 depict the organization functional context for two life cycle process: 'development' and 'maintenance'. The links between the central bubble and the elements in the organization environment are identified. The links show the flows of information, material and energy.

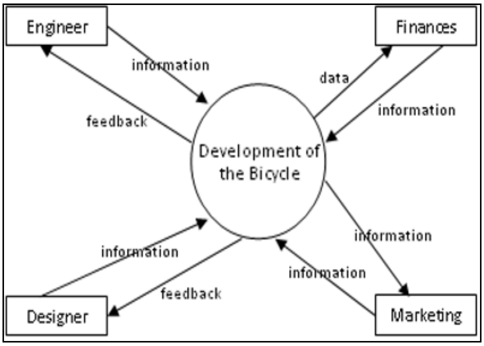

Figure 11. Organizational functional context for the 'development of the bicycle' process

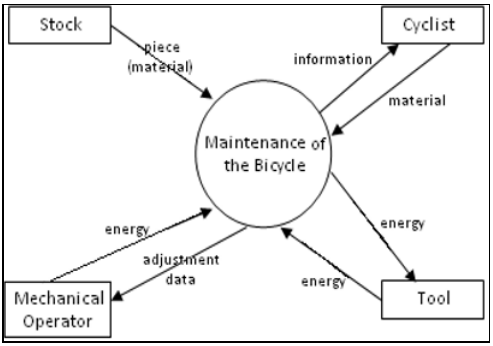

Figure 12. Organizational functional context for the 'maintenance'

Figures 13 and 14 illustrate the product physical interfaces and the organization physical interfaces respectively. Figure 13 identifies the interaction with the elements in the environment and the internal elements of product. Figure 14 shows the interaction of the organization elements with the external physical interfaces identified.

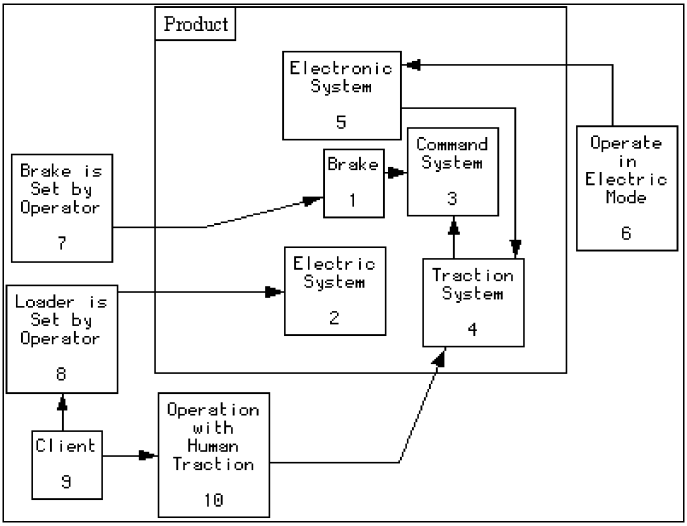

Figure 13. Product physical interfaces

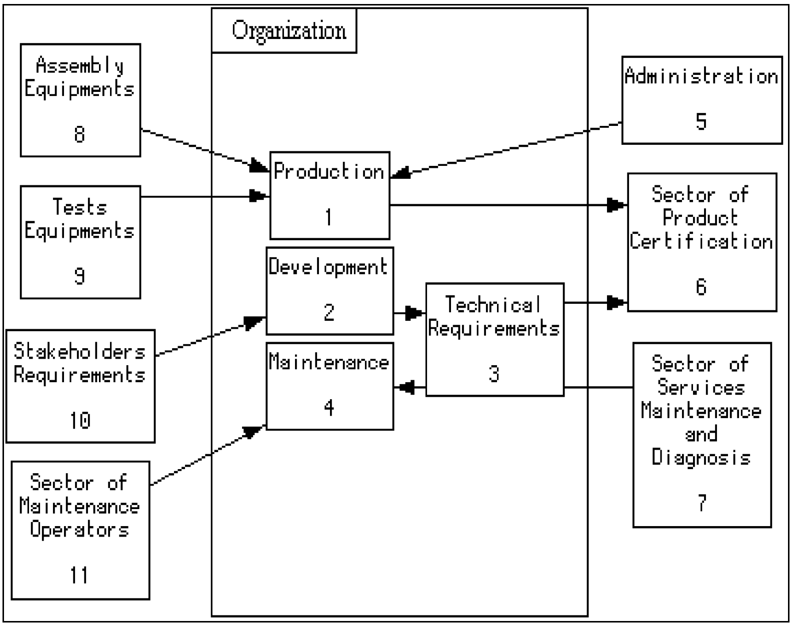

Figure 14. Organization physical interfaces

5 Discussion

This sections highlights the differences between traditional and proposed approaches.

It is not possible to consider only customer or user as stakeholders of interests, like in the traditional approaches. Stakeholders related to all product life cycle process must be taken into consideration from the outset of the system architecting process. The proposed approach accomplishes it. (see Steps 1 and 2 in Section 3).

Traditional systems engineering approaches perform functional context analysis only during product operations (the so called CONOPS or concept of operations) and for product development organization processes. However, a system solution is comprised of product and organization elements and many enabling elements must be also developed for mission success. These elements are only identified if context for each life cycle process scenario is performed. Therefore, the proposed approach covers the overall product life cycle, not only operations and development. (see Step 3 in Section 3).

By considering product life cycle processes from the beginning of the system architecting process and from the top level context diagrams to be decomposed in lower level functions and lower level physical architectures, the concurrent engineering concept is implemented within the systems engineering process. This fulfills the framework proposed in Figure 1.

The proposed approach allows requirements from the whole product life cycle to be anticipated to the early stages of a system architecting process. Stakeholder requirements are captured for the whole product life cycle process. Functions, performance, conditions, circumstances, modes and exception functions are captured for the whole product life cycle process. External physical and logical interfaces and internal physical and logical interfaces are identified for the whole product life cycle process. The system solution here is composed of product and organization elements. The product interaction with other system elements is identified in the beginning of the system architecting process. This promotes dramatic gains in productivity during product development and during product life cycle. System quality increases. Product changes are avoided. Changes cost and time are eliminated.

6 Conclusion

This paper presented a system concurrent engineering approach for an electric bike. The proposed approach addressed the deficiencies of traditional methods, such as, product focus, operation and development focus, and part focus. The paper described the approach as a way to perform stakeholder analysis, requirements analysis, functional analysis and implementation architecture, simultaneously, for the product and organization elements of a system at every layer of the system breakdown structure. This is necessary to address all complexity factors that are inherent to complex product development. Conclusions are that impact, traceability and hierarchy links promote the anticipation of life cycle process requirements to the early stages of systems architecting. Late changes are avoided, development costs are dramatically reduced while satisfaction of stakeholders over product life cycle is increased.

7 Acknowledgement

The authors would like to thank CAPES (Coordination for Supporting and Development Superior Education Personnel, www.capes.br) for Jonas Bianchini Fulindi scholarship. The authors would like to thank ITA (the Technological Institute of Aeronautics, www.ita.br) for the post graduate course opportunity. The authors would like to thank IAE (Aeronautics and Space Institute, www.iae.cta.br) and 3SL (www.threesl.co.uk) for providing Cradle, the systems engineering environment software used for the development of this work.

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Systems Concurrent Engineering for the Conception of a Hybrid Vehicle

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[c,d,e,f]Post graduate students at Technological Insitute of Aeronautics - ITA.

Abstract. This paper presents a systems concurrent engineering approach for the conception of a hybrid vehicle. Traditional approaches focuses on the product, development organization and the product concepts of operation (CONOPS). In those approaches the overall view of the inherent complexity in the development of a product, its life cycle processes and their performing organizations are not taken into consideration. The systems concurrent engineering performs stakeholder analysis, requirements analysis, functional analysis and implementation architecture analysis, simultaneously, for the product, its life cycle processes and their performing organization. From the analysis, requirements and attributes are captured for the product and its life cycle processes organizations and the relationship among them are identified. Conclusions are that impact, traceability and hierarchy links promote the anticipation of life cycle process requirements to the early stages of systems architecting. Late changes are avoided, development costs are dramatically reduced while satisfaction of stakeholders over product life cycle is increased.

Keywords. Systems concurrent engineering, systems engineering, concurrent engineering, complex product, integrated product development.

1 Introduction

Hybrid systems incorporate two sources of energy in a single vehicle, combining an internal combustion engine and an electric motor. In the hybrid vehicles currently on the market, the internal combustion engine can directly trigger the wheels or an electric generator to charge a battery that feeds an electric motor.

This paper aims to present a systems concurrent engineering approach for the conception of a hybrid vehicle. The approach is different from traditional systems engineering approach because it anticipates to the early stages of system

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architecting the product life cycle process requirements. It proposes to simultaneously develop, from the outset, the product and its life cycle processes performing organizations.

The paper is organized as following: Section 2 presents the traditional systems engineering and concurrent engineering approaches. Section 3 presents the systems concurrent engineering approach framework and method. Section 4 presents the models derived for the hybrid vehicle using the approach. Section 5 discusses the advantages and opportunities for improving the proposed approach. Section 6 concludes this paper.

2 Traditional systems engineering and concurrent engineering

Automotive products are complex. They are multidisciplinary products, they must cope with extreme environmental conditions over their life cycle (vibration, temperature range, altitude range, electromagnetic interference and compatibility), they must undergo very strict calibration and tuning procedures. Automotive development organizations are worth the order of billion dollars. A car may take from a year to four years to develop. There are many opportunities to improve productivity over a car life cycle if a concurrent engineering approach takes place from the beginning of the car architecting stage.

Traditional systems engineering approaches do not provide an overall view of the system during its various life cycle processes. They focus on an operational product development starting from product concept of operations. They also focus on the development organization that must be put in place in order to assure that the product meets its operational requirements [2,3,6,8]. A product has life cycle processes other than operations and it must be recognized from the outset in order to promote gains in productivity in the product development organization, by the avoidance of late changes, and in other product life cycle process organizations, as the product will be developed taking into consideration their requirements. Life cycle process organizations themselves can be developed simultaneously to product development, when they are part of the scope of the whole product development effort.

For example the NASA systems engineering handbook [8] states that systems engineering focuses in the development and the realization of a final product. Modern commercial standards, such as EIA 632 [2], state that systems engineering focuses on the operations product and on capturing requirements for the other product life cycle processes. In other words, these requirements are captured not to impact product development. The product will be systems engineered with operations in mind. When its architecture (and maybe detailed design) is defined, then life cycle processes requirements are captured to be implemented in life cycle process performing organizations. This paper proposes a method to take into consideration the impact of these organizations on the product during the product architecting process.

Conceptually, concurrent engineering acknowledges benefits of anticipating life cycle process requirements to the early stages of product development. For space products, these early stages are the system architecting phases. A systems approach requires life cycle process requirements to be balanced in the beginning of the product development process. Concurrent engineering, however, in practice, treats life cycle processes separately and optimizes product design seeking each life cycle process productivity increase. For example, DFA optimizes for assemblability, QFD, for customer satisfaction, DFI, for inspectability, and so on. Also, concurrent engineering is, in practice, applied to parts design and not to systems composed of many integrated parts [5]. This paper proposes how the concurrent engineering concept can be used for systems engineering.

3 The systems concurrent engineering approach

Hitchins [4] states that complexity can be understood by what he calls complexity factors. They are variety, connectedness and disorder. Variety accounts for the number of different elements you have in a set. Regarding products, variety refers, for example, to the number of different parts a product may have, number of different functions it accomplishes, number of different requirements categories it is supposed to meet, number of different stakeholders it should satisfy. Connectedness refers to the relationships among elements. For example, how parts interact, how functions affect one another, how requirements conflict to each other, how value flow among stakeholders. Disorder refers to the level of tangling of those relationships. For example, is there a structure pattern of deploying stakeholder requirements through functional concept up to implementation architecture?

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Figure 2 provides an overview of a method within the total view framework. The method is called concurrent structured analysis method evolved from Loureiro [7]. Stakeholder analysis, requirements analysis, functional analysis and implementation (or physical) analysis is performed, simultaneously, for the product under development and its life cycle process performing organizations. The analysis processes are performed at each layer of the system breakdown structure. For example, if a car is the product under development, the analysis processes are performed at the car layer, at the powertrain layer, at the engine layer and so on.

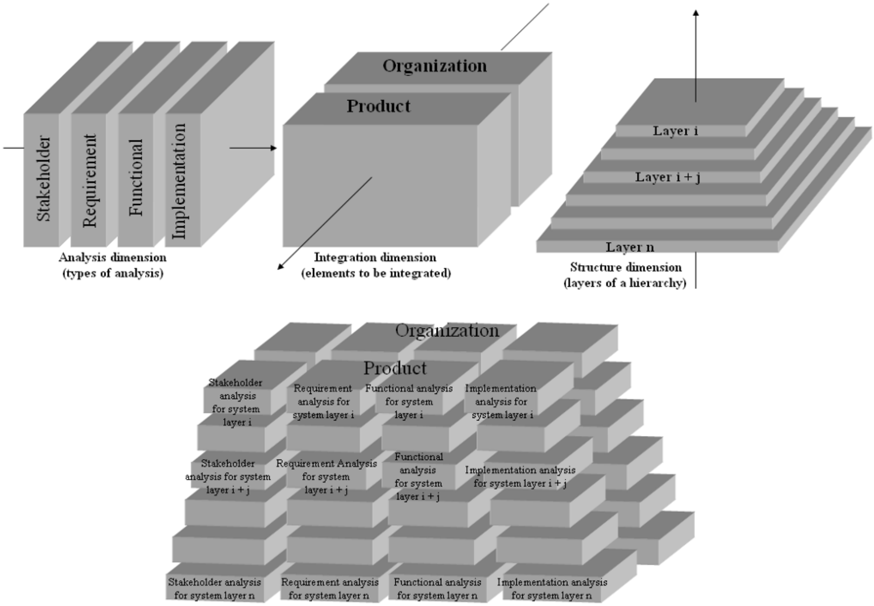

Figure 1. A framework to address complexity in complex product development – the total view framework

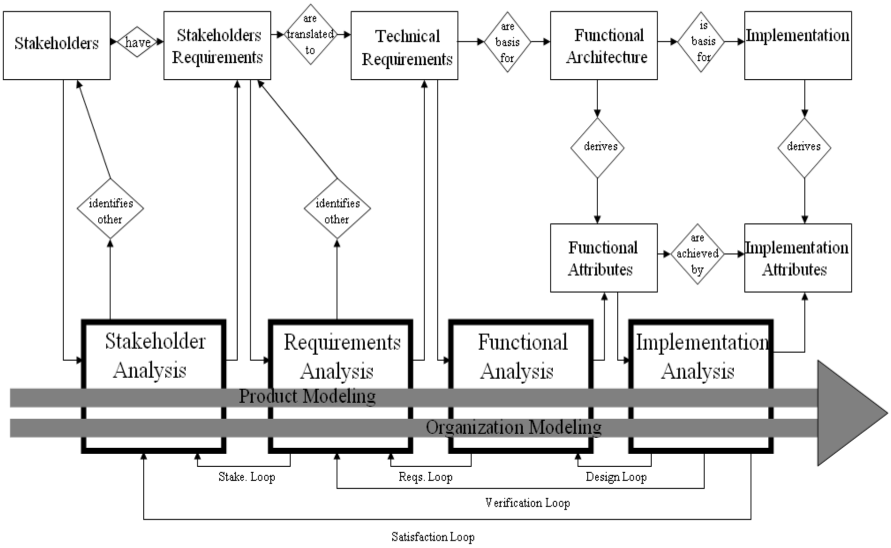

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Figure 3 details the concurrent structured analysis method showing how to incorporate the concurrent engineering concept in the systems engineering process:

Step 1: Identify the product mission, the product life cycle processes and their scenarios and, the scope of the development effort. Product mission refers to the product purpose or reason of being. Life cycle process scenarios are the alternatives in each process (for example, preventive or corrective maintenance) or the decomposition of a process (for example, advanced technology development, process engineering as components of the development process). The scope of the development effort consists of the life cycle processes or their scenarios that the development organization is also responsible for accomplishing. For example, EMBRAER is responsible for developing aircraft but is also responsible for providing maintenance services.

Step 2: Identify product stakeholders and their concerns for each product life cycle process scenario. Product stakeholders are the people who affect or are affected by the product during its life cycle. Product stakeholders are identified per life cycle process scenario. Identify organization stakeholders and their concerns for each process within the scope of the development effort. Organization stakeholders are the people who affect or are affected by the business of the organization in question. Organization stakeholders are identified per life cycle process scenario within the scope of the development effort. From stakeholder concerns, stakeholder requirements are identified and measures of effectiveness (MoEs) are derived. MoEs must measure how the system meets the stakeholder requirements. From stakeholder requirements, functions, performance and conditions are identified. The definition of what functions the system will perform, how well the system is going to perform such functions and under which conditions comprise the requirements analysis process. Requirement analysis transforms stakeholder requirements into system requirements. System requirements will be met not only by product elements but also by organization elements.

Step 3: Identify functional context for product at each life cycle process scenario and for organization at each life cycle process scenario within the scope of the development effort. Functional context defines the function performed by the system element and identifies the elements in the environment of the system. The environment of the system contains the elements outside the system function scope and that exchanges material, information and energy flows with the system. Those flows define logical interface requirements. Environment elements may have different relevant states. Sets of environment element states are called circumstances. The system must have different modes depending on the circumstances. Behaviour modelling is required to show under which conditions system mode and system state transition occurs. Functions are identified per mode. Functions are identified from outside in by identifying which responses the system is supposed to give to deal with each stimulus provided by the environment elements. For each function, performance requirements are identified. Circumstances, flows between the system and the environment and function failures are sources of hazards. Risk analyses are performed on each identified potential hazard and exception handling functions are also identified at this stage.

Step 4: Identify implementation architecture context for product at each life cycle process scenario and for organization at each life cycle process scenario within the scope of the development effort. Physical connections between the system and the environment elements define the physical external interface requirements. Physical parts are identified. Physical internal interfaces are defined by architecture connections and architecture flows among those parts. Allocation matrix relates physical parts and physical interfaces to the functions and functional flows.

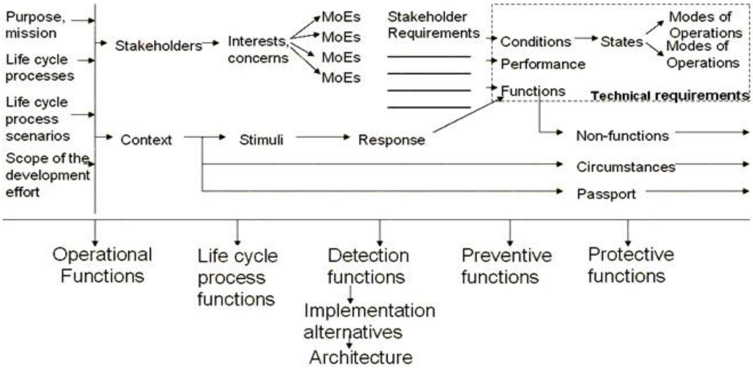

Figure 3. The system concurrent engineering method in detail

4 The hybrid vehicle system concurrent engineering

This section illustrates the steps listed in Section 3 highlighting where the proposed approach is different from traditional approaches. The proposed approach is stakeholder driven whereas traditional approaches are customer or user driven. In the various steps listed in Section 3, analysis are performed for each life cycle process scenario, simultaneously, for product and organization. Traditional approaches focus on product operation and development organization. Table 1 presents the life cycle processes and scenarios of a hybrid vehicle. To the processes 'conception', 'system assembly', 'acceleration' and 'maintenance' are considered the cells highlighted in grey as the scope of development effort.

Table 1. Life cycle processes and scenarios

Processes	Organization Processes		Processes of Product Life Cycle	
	Development	Manufacturing and Assembly	Operation	Support to Operation
Scenarios	Conception	System Assembly	Initialization	Provisioning
	Detailed Project	Manufacturing of the Structure	Neutral	Check-up
	Components Project	Components Supplying	Acceleration	Maintenance
	Prototype	Acceptation Tests	Low Velocity	Towing
	Tests		High Velocity	Repair
	Processes of Engineering		Waiting	

The processes of the life cycle are the ones for which the stakeholder analysis, requirements analysis, functional analysis and implementation architecture analysis will be exemplified. In practise steps 1 to 4 in Section 3 must be run for all life cycle process scenarios. Figures 4 to 13 just exemplify the steps for some selected processes.

Figures 4 and 5 exemplify the identification of organization stakeholders for two life cycle processes: ‘development’ and ‘manufacturing and assembly’. The scenarios belongs to the scope of the development effort. This is to show that it is necessary and possible to develop from the outset all processes within the scope of development effort. This innovates the traditional focus on systems engineering the product. This approach recognizes that the system solution is not only made of product elements but also of organization elements. Figures 4 and 5 also captures the stakeholder concerns represented by the connections between the stakeholders and the central bubble, containing the process of the life cicle.

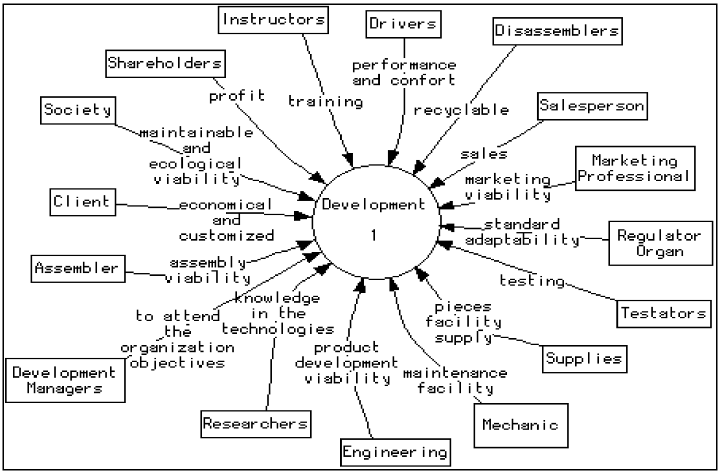

Figure 4. Stakeholders and their concerns for the development analysis

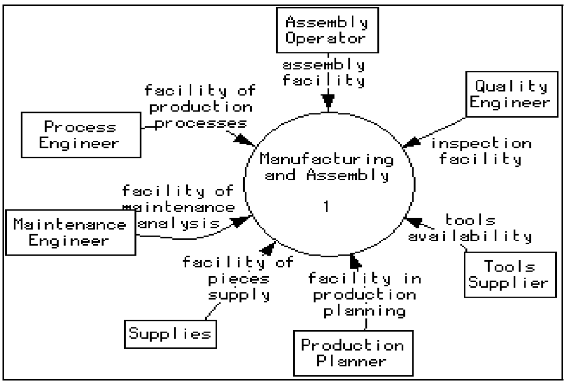

Figure 5. Stakeholders and their concerns for the ‘manufacturing and assembly’ life cycle process

Figures 6 and 7 presents the product stakeholders identified and their concerns for two other life cycle processes: 'operation' and 'support to operation'. From stakeholder concerns, stakeholder requirements are identified and measures of effectiveness (MoEs) are derived. From stakeholder requirements, functions, performance and conditions are identified. Requirement analysis transforms stakeholder requirements into system requirements. System requirements will be met not only by product elements but also by organization elements.

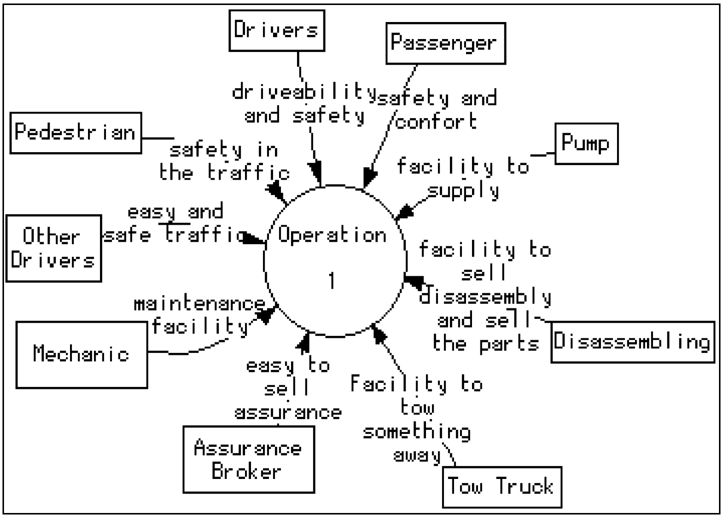

Figure 6. Product stakeholders and their concerns for the 'operation' process

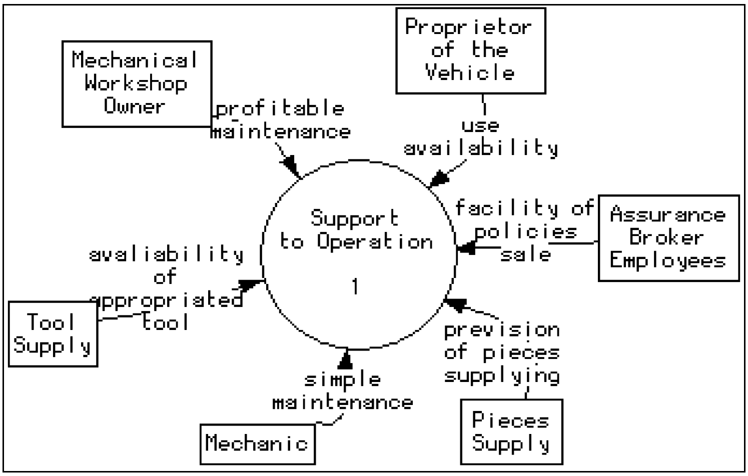

Figure 7. Product stakeholders and their concerns for the 'support to operation' process

Figures 8 and 9 depict the organization functional context for two life cycle process scenarios: ‘conception’ and ‘assembly’. The links between the central bubble and the elements in the organization environment at that scenario are identified. These links show the flows of information (in this case), material and energy between the environment and the system.

Figures 10 and 11 depict the product during ‘providing acceleration’ and ‘vehicle in maintenance’ in the central bubble and the elements in the environment during those processes. Links between product and environment are energy, material and information flows. Besides each element in the environment, some of their potential states is necessary to be identified. In Figure 10 for example, for the ‘alimentation system’ potential states could be empty. The composition with states of other elements in the environment results in the potential circumstances a system must cope with.

The system must have different modes depending on the circumstances. Behaviour modelling is required to show under which conditions system mode and system state transition occurs. Functions are identified per mode. Functions are identified from outside in by identifying which responses the system is supposed to give to deal with each stimulus provided by the environmental elements. For each function, performance requirements are identified. Circumstances, flows between the system and the environment and function failures are sources of hazards. Risk analysis is performed on each identified potential hazard and exception handling functions are also identified at this stage.

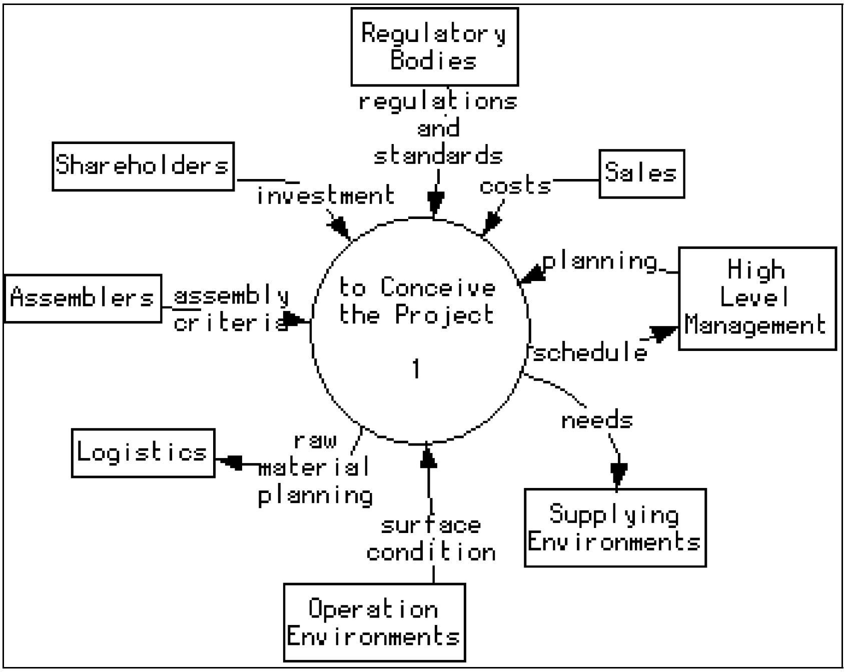

Figure 8. Organization functional interfaces analysis for the ‘to conceive the project’ scenario

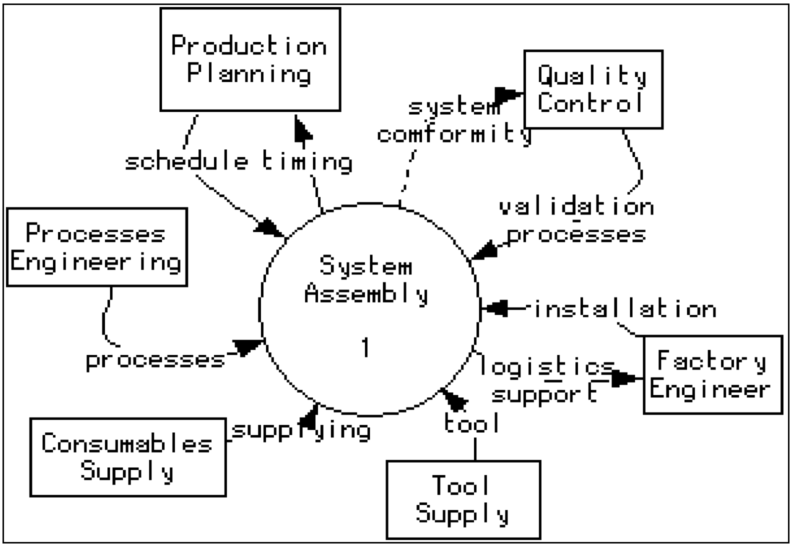

Figure 9. Organization functional interfaces analysis for the 'systems assembly' process scenario

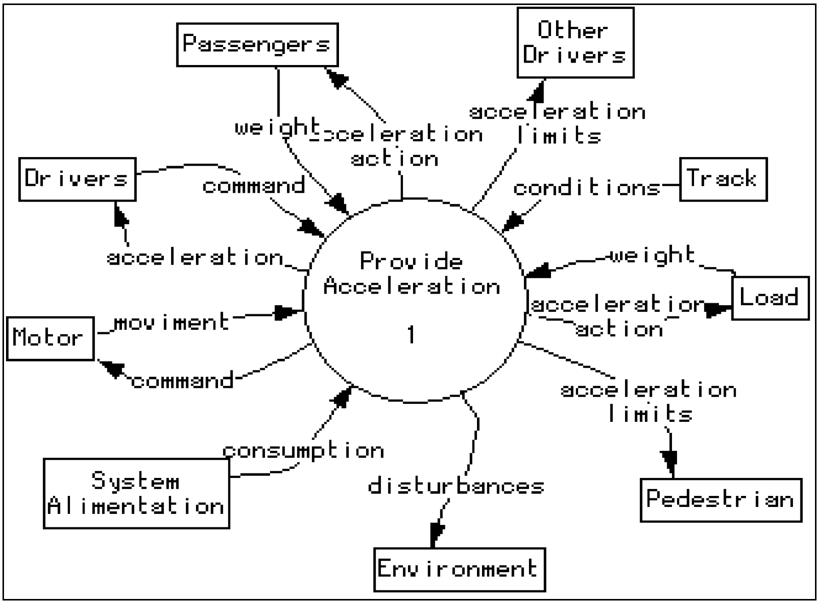

Figure 10. Product functional context for the 'provide acceleration' process scenario

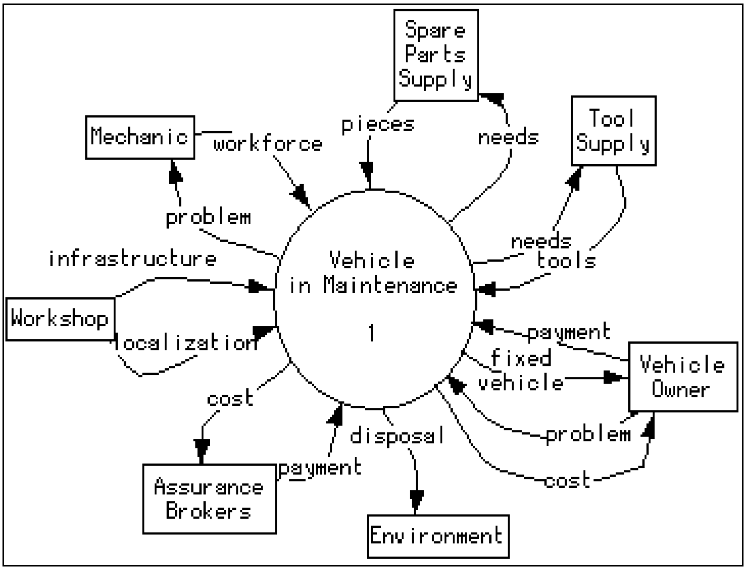

Figure 11. Product functional context for the 'vehicle in maintenance' process

Figure 12 presents the external physical connections and its flows between the elements of the environment and the 'acceleration system'.

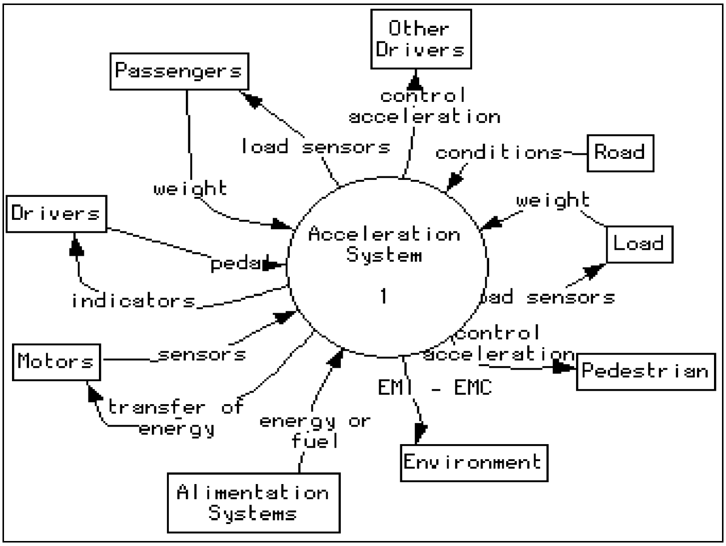

Figure 12. Physical analysis context and external physical interfaces for the 'acceleration system' process

5 Discussion

This sections highlights the differences between traditional and proposed approaches. Complex products such as hybrid vehicle analyzed in this paper have many stakeholders. It is not possible to consider only customer or user as stakeholders of interests, like in the traditional approaches. Stakeholders related to all product life cycle process must be taken into consideration from the outset of the system architecting process. The proposed approach accomplishes it. (see Steps 1 and 2 in Section 3). Traditional systems engineering approaches perform functional context analysis only during product operations (the so called CONOPS or concept of operations) and for product development organization processes. However, a system solution is comprised of product and organization elements and many enabling elements must be also developed for mission success. These elements are only identified if context for each life cycle process scenario is performed. Therefore, the proposed approach covers the overall product life cycle, not only operations and development. (see Step 3 in Section 3). By considering product life cycle processes from the beginning of the system architecting process and from the top level context diagrams to be decomposed in lower level functions and lower level physical architectures, the concurrent engineering concept is implemented within the systems engineering process. This fulfills the framework proposed in Figure 1. The proposed approach allows requirements from the whole product life cycle to be anticipated to the early stages of a system architecting process. Stakeholder requirements are captured for the whole product life cycle process. Functions, performance, conditions, circumstances, modes and exception functions are captured for the whole product life cycle process. External physical and logical interfaces and internal physical and logical interfaces are identified for the whole product life cycle process. The system solution here is composed of product and organization elements. The product interaction with other system elements is identified in the beginning of the system architecting process. This promotes dramatic gains in productivity during product development and during product life cycle. System quality increases. Product changes are avoided. Changes cost and time are eliminated.

6 Conclusion

This paper presented a system concurrent engineering approach for the conception of a hybrid vehicle. The proposed approach addressed the deficiencies of traditional methods, such as, product focus, operation and development focus, and part focus. The paper described the approach as a way to perform stakeholder analysis, requirements analysis, functional analysis and implementation architecture, simultaneously, for the product and organization elements of a system at every layer of the system breakdown structure. This is necessary to address all complexity factors that are inherent to complex product development. Conclusions are that impact, traceability and hierarchy links promote the anticipation of life cycle process requirements to the early stages of systems architecting. Late changes are avoided, development costs are dramatically reduced while satisfaction of stakeholders over product life cycle is increased.

7 Acknowledgement

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Systems Concurrent Engineering to Develop a Green Car

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Abstract. This paper presents a systems concurrent engineering approach to develop a green car. Traditional approaches focuses on the product, development organization and the product concepts of operation (CONOPS). In those approaches the overall view of the inherent complexity in the development of a product, its life cycle processes and their performing organizations are not taken into consideration. The systems concurrent engineering performs stakeholder analysis, requirements analysis, functional analysis and implementation architecture analysis, simultaneously, for the product, its life cycle processes and their performing organization. From the analysis, requirements and attributes are captured for the product and its life cycle processes organizations and the relationship among them are identified. Conclusions are that impact, traceability and hierarchy links promote the anticipation of life cycle process requirements to the early stages of systems architecting. Late changes are avoided, development costs are dramatically reduced while satisfaction of stakeholders over product life cycle is increased.

Keywords. Systems concurrent engineering, systems engineering, concurrent engineering, complex product, integrated product development.

1 Introduction

In the automotive industry, a project of a new vehicle requires a huge workload of man-years of engineering work. Driving this type of project becomes much more difficult if the engineering approach used does not consider the systems in their totality. Before the introduction of technical systems engineering, the design of a new model of car required several prototypes. The integration of various systems of the vehicle occurred in a costly and time-consuming successive approximations made based on those prototypes.

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This paper aims to present a systems concurrent engineering approach for the development of a green car. The approach is different from traditional systems engineering approach because it anticipates to the early stages of system architecting the product life cycle process requirements. It proposes to simultaneously develop, from the outset, the product and its life cycle processes performing organizations.

The paper is organized as following: Section 2 presents the traditional systems engineering and concurrent engineering approaches. Section 3 presents the systems concurrent engineering approach framework and method. Section 4 presents the models derived for the green car using the approach. Section 5 discusses the advantages and opportunities for improving the proposed approach. Section 6 concludes this paper.

2 Traditional systems engineering and concurrent engineering

Automotive products are complex. They are multidisciplinary products, they must cope with extreme environmental conditions over their life cycle (vibration, temperature range, altitude range, electromagnetic interference and compatibility), they must undergo very strict calibration and tuning procedures. Automotive development organizations are worth the order of billion dollars. A car may take from a year to four years to develop. There are many opportunities to improve productivity over a car life cycle if a concurrent engineering approach takes place from the beginning of the car architecting stage.

Traditional systems engineering approaches do not provide an overall view of the system during its various life cycle processes. They focus on an operational product development starting from product concept of operations. They also focus on the development organization that must be put in place in order to assure that the product meets its operational requirements [2,3,6,8]. A product has life cycle processes other than operations and it must be recognized from the outset in order to promote gains in productivity in the product development organization, by the avoidance of late changes, and in other product life cycle process organizations, as the product will be developed taking into consideration their requirements. Life cycle process organizations themselves can be developed simultaneously to product development, when they are part of the scope of the whole product development effort.

For example the NASA systems engineering handbook [8] states that systems engineering focuses in the development and the realization of a final product. Modern commercial standards, such as EIA 632 [2], state that systems engineering focuses on the operations product and on capturing requirements for the other product life cycle processes. In other words, these requirements are captured not to impact product development. The product will be systems engineered with operations in mind. When its architecture (and maybe detailed design) is defined, then life cycle processes requirements are captured to be implemented in life cycle process performing organizations. This paper proposes a method to take into consideration the impact of these organizations on the product during the product architecting process.

Conceptually, concurrent engineering acknowledges benefits of anticipating life cycle process requirements to the early stages of product development. For space products, these early stages are the system architecting phases. A systems approach requires life cycle process requirements to be balanced in the beginning of the product development process. Concurrent engineering, however, in practice, treats life cycle processes separately and optimizes product design seeking each life cycle process productivity increase. For example, DFA optimizes for assemblability, QFD, for customer satisfaction, DFI, for inspectability, and so on. Also, concurrent engineering is, in practice, applied to parts design and not to systems composed of many integrated parts [5]. This paper proposes how the concurrent engineering concept can be used for systems engineering.

3 The systems concurrent engineering approach

Hitchins [4] states that complexity can be understood by what he calls complexity factors. They are variety, connectedness and disorder. Variety accounts for the number of different elements you have in a set. Regarding products, variety refers, for example, to the number of different parts a product may have, number of different functions it accomplishes, number of different requirements categories it is supposed to meet, number of different stakeholders it should satisfy. Connectedness refers to the relationships among elements. For example, how parts interact, how functions affect one another, how requirements conflict to each other, how value flow among stakeholders. Disorder refers to the level of tangling of those relationships. For example, is there a structure pattern of deploying stakeholder requirements through functional concept up to implementation architecture?

Figure 1 presents a framework to address complexity in product development – the total view framework evolved from Loureiro [7]. It has three dimensions. Each dimension addresses one of the complexity factors mentioned above. The analysis dimension addresses the variety factor. Along the analysis dimension, it is deployed what must be analysed in order to develop a complex product. A systems engineering process consists of stakeholder analysis, requirements analysis, functional analysis and implementation or physical analysis. The integration dimension addresses the connectedness factor. It defines what must be integrated along an integrated product development process: product elements and organization elements. Organization here refers to the organizations that perform product life cycle processes. Product elements and organization elements are the system elements. The structure dimension addresses the disorder factor. According to Alexander [1] all structures evolve into an hierarchy. System breakdown structures are also represented in hierarchies.

Figure 2 provides an overview of a method within the total view framework. The method is called concurrent structured analysis method evolved from Loureiro [7]. Stakeholder analysis, requirements analysis, functional analysis and implementation (or physical) analysis is performed, simultaneously, for the product under development and its life cycle process performing organizations. The analysis processes are performed at each layer of the system breakdown structure.

For example, if a car is the product under development, the analysis processes are performed at the car layer, at the powertrain layer, at the engine layer and so on.

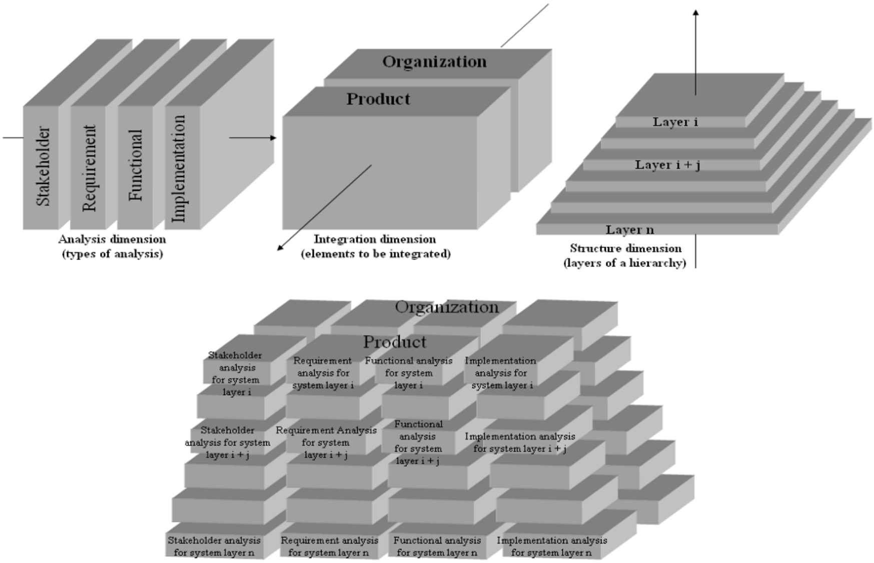

Figure 1. A framework to address complexity in complex product development – the total view framework

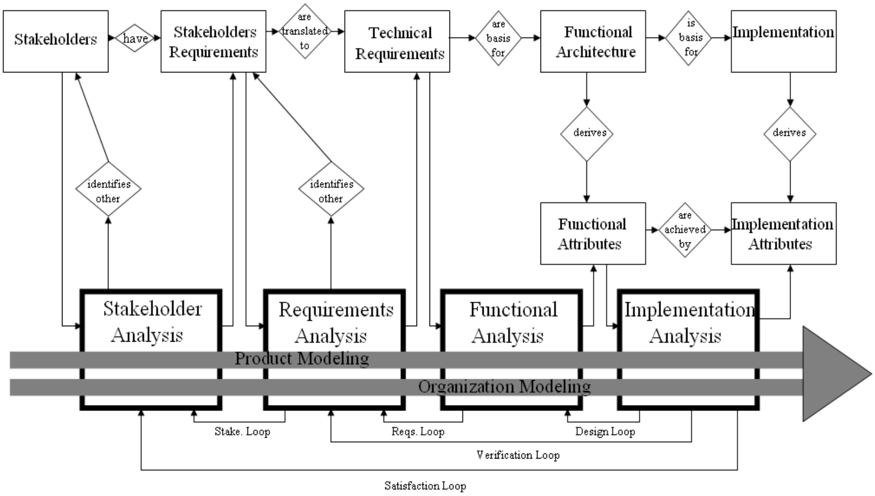

Figure 2. A method within the total view framework – the concurrent structured analysis method

Figure 3 details the concurrent structured analysis method showing how to incorporate the concurrent engineering concept in the systems engineering process:

Step 1: Identify the product mission, the product life cycle processes and their scenarios and, the scope of the development effort. Product mission refers to the product purpose or reason of being. Life cycle process scenarios are the alternatives in each process (for example, preventive or corrective maintenance) or the decomposition of a process (for example, advanced technology development, process engineering as components of the development process). The scope of the development effort consists of the life cycle processes or their scenarios that the development organization is also responsible for accomplishing. For example, EMBRAER is responsible for developing aircraft but is also responsible for providing maintenance services.

Step 2: Identify product stakeholders and their concerns for each product life cycle process scenario. Product stakeholders are the people who affect or are affected by the product during its life cycle. Product stakeholders are identified per life cycle process scenario. Identify organization stakeholders and their concerns for each process within the scope of the development effort. Organization stakeholders are the people who affect or are affected by the business of the organization in question. Organization stakeholders are identified per life cycle process scenario within the scope of the development effort. From stakeholder concerns, stakeholder requirements are identified and measures of effectiveness (MoEs) are derived. MoEs must measure how the system meets the stakeholder requirements. From stakeholder requirements, functions, performance and conditions are identified. The definition of what functions the system will perform, how well the system is going to perform such functions and under which conditions comprise the requirements analysis process. Requirement analysis transforms stakeholder requirements into system requirements. System requirements will be met not only by product elements but also by organization elements.

Step 3: Identify functional context for product at each life cycle process scenario and for organization at each life cycle process scenario within the scope of the development effort. Functional context defines the function performed by the system element and identifies the elements in the environment of the system. The environment of the system contains the elements outside the system function scope and that exchanges material, information and energy flows with the system. Those flows define logical interface requirements. Environment elements may have different relevant states. Sets of environment element states are called circumstances. The system must have different modes depending on the circumstances. Behaviour modelling is required to show under which conditions system mode and system state transition occurs. Functions are identified per mode. Functions are identified from outside in by identifying which responses the system is supposed to give to deal with each stimulus provided by the environment elements. For each function, performance requirements are identified. Circumstances, flows between the system and the environment and function failures are sources of hazards. Risk analysis is performed on each identified potential hazard and exception handling functions are also identified at this stage.

Step 4: Identify implementation architecture context for product at each life cycle process scenario and for organization at each life cycle process scenario within the scope of the development effort. Physical connections between the system and the environment elements define the physical external interface requirements. Physical parts are identified. Physical internal interfaces are defined by architecture connections and architecture flows among those parts. Allocation matrix relates physical parts and physical interfaces to the functions and functional flows.

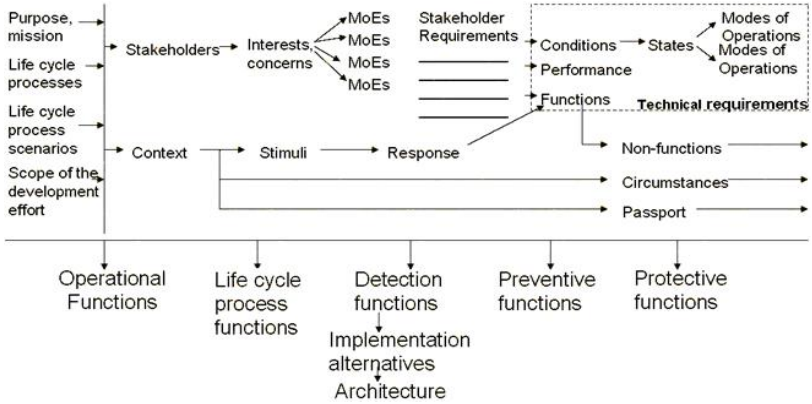

Figure 3. The system concurrent engineering method in detail

4 The green car system concurrent engineering

This section illustrates the steps listed in Section 3 highlighting where the proposed approach is different from traditional approaches. The proposed approach is stakeholder driven whereas traditional approaches are customer or user driven. In the various steps listed in Section 3, analysis are performed for each life cycle process scenario, simultaneously, for product and organization. Traditional approaches focus on product operation and development organization.

Table 1 presents the life cycle processes and scenarios of a green car. The processes 'development', 'sales', 'operation' and 'disposal' are highlighted in grey. The processes highlighted in grey are the ones for which the stakeholder analysis, requirements analysis, functional analysis and implementation architecture analysis will be exemplified. In practise steps 1 to 4 in Section 3 must be run for all life cycle process scenarios. Figures 4 to 13 just exemplify the steps for some selected processes.

Table 1. Life cycle processes and scenarios

Organization	Development	Conception	Advanced Drawing	Components Drawing	Tests and Adjusts
	Sales	Logistics Planning	Deliveries	-	-
Product	Operation	Start Wait	Low Velocity	High Velocity	Collision
	Disposal	Disassembly	-	Conditioning	Repair

Figures 4 and 5 exemplify the identification of organization stakeholders for two life cycle process scenarios: ‘conception’ and ‘deliveries’. The ‘conception’ scenario belongs to the development life cycle process and the ‘deliveries’ belongs to the sales process. The ‘conception’ and the ‘deliveries’ is within the scope of the development effort. This is to show that it is necessary and possible to develop from the outset all processes within the scope of development effort. This innovates the traditional focus on systems engineering the product. This approach recognizes that the system solution is not only made of product elements but also of organization elements. Figures 4 and 5 also capture the stakeholder concerns represented by the connections between the stakeholders and the central bubble, containing life cycle scenario.

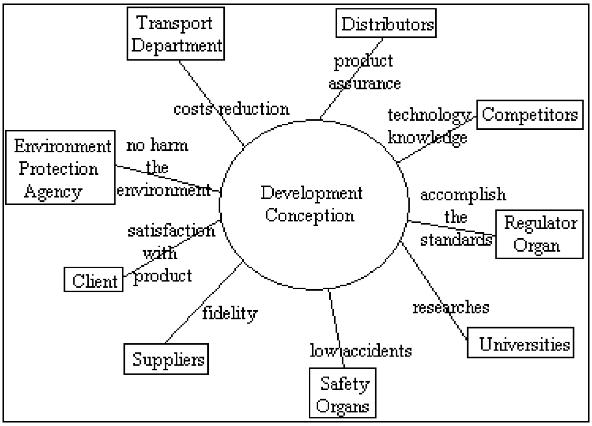

Figure 4. Organization stakeholders and their concerns for the ‘development conception’ analysis scenario

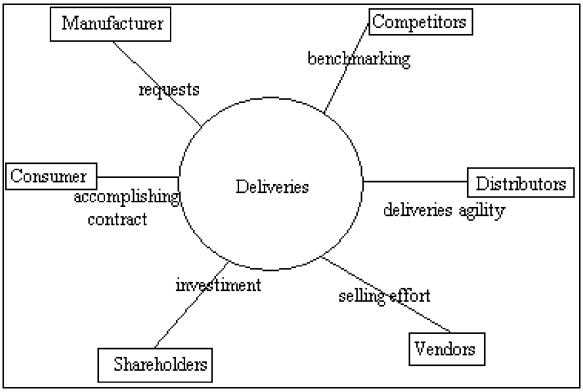

Figure 5. Organization stakeholders and their concerns for the ‘deliveries’ life cycle process scenario

Figures 6 and 7 present the product stakeholders identified and their concerns for two other life cycle process scenarios: ‘high speed’ and ‘disassembly’. ‘High speed’ is one of the operation scenarios of the green car. ‘Disassembly’ is one of the scenarios of the disposal. From stakeholders concerns, stakeholder requirements are identified and measures of effectiveness (MoEs) are derived. From stakeholder requirements, functions, performance and conditions are identified. Requirement analysis transforms stakeholder requirements into system requirements. System requirements will be met no only by product elements but also by organization elements.

Figures 8 and 9 depict the product during ‘high speed’ and ‘disassembly’ in the central bubble and the elements in the environment during those processes. Links between product and environment are energy, material and information flows. Besides each element in the environment, some of their potential states is necessary to be identified. In Figure 8 for example, for the ‘alimentation system’ potential states could be ‘empty’. The composition with states of other elements in the environment results in the potential circumstances a system must cope with.

The system must have different modes depending on the circumstances. Behaviour modelling is required to show under which conditions system mode and system state transition occurs. Functions are identified per mode. Functions are identified from outside in by identifying which responses the system is supposed to give to deal with each stimulus provided by the environment elements. For each function, performance requirements are identified. Circumstances, flows between the system and the environment and function failures are sources of hazards. Risk analysis is performed on each identified potential hazard and exception handling functions are also identified at this stage.

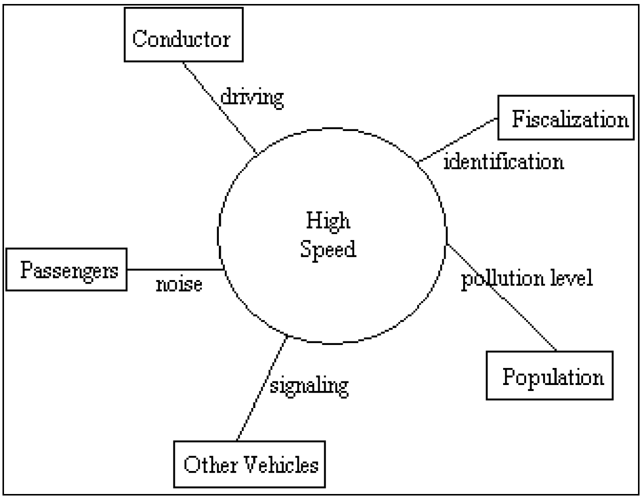

Figure 6. Product stakeholders and their concerns for the ‘high speed’ process scenario

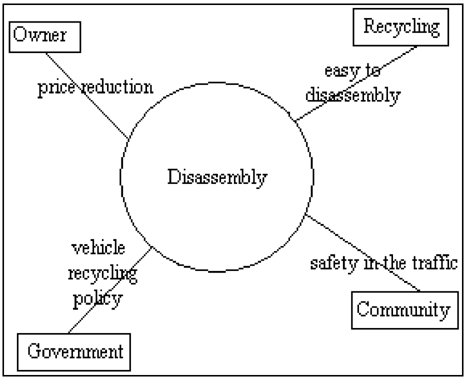

Figure 7. Product stakeholders and their concerns for the ‘disassembly’ process scenario

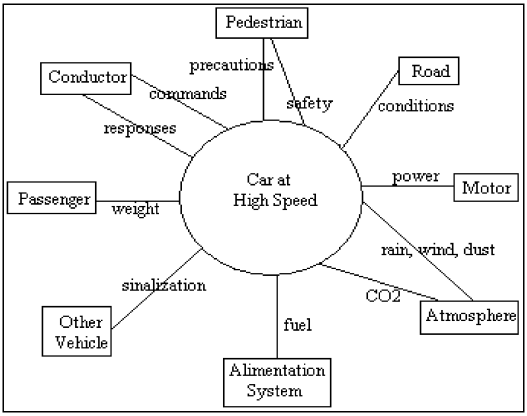

Figure 8. Product functional context for the ‘car at high speed’ process scenario

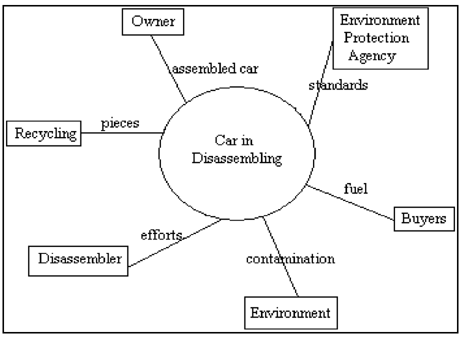

Figure 9. Product functional context for the ‘car in disassembling’ process scenario

Figures 10 and 11 depict the organization functional context for two life cycle process scenarios: 'conception' and 'deliverables'. The links between the central bubble and the elements in the organization environment at that scenario are identified. These links show the flows of information, material and energy between the environment and the system. Figure 12 presents the product physical interfaces. It identifies the interfaces between elements in the environment of operation and the elements that compose the product for this scenario. It shows the relationship of the parts.

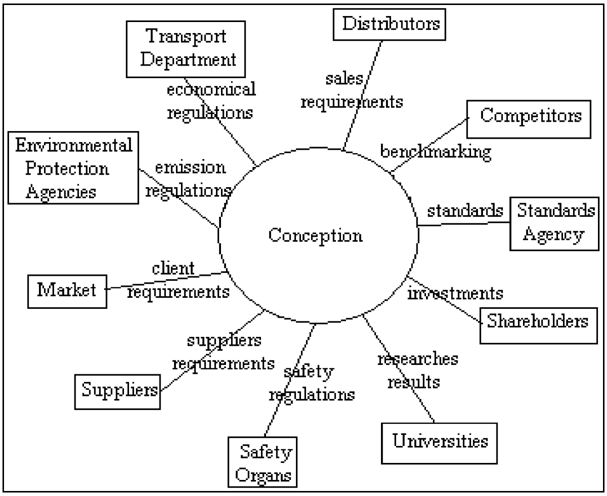

Figure 10. Organization functional context for the 'conception' process scenario

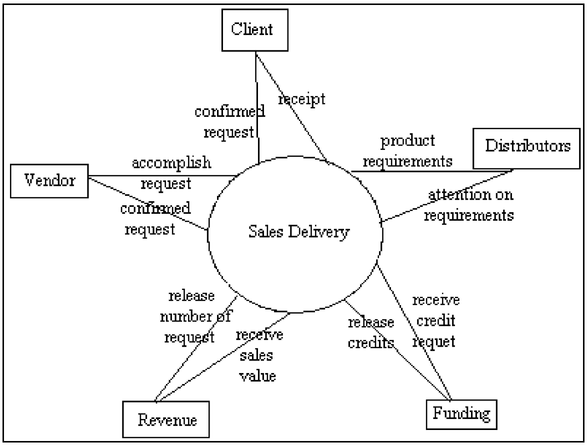

Figure 11. Organization functional context for the 'sales delivery' process

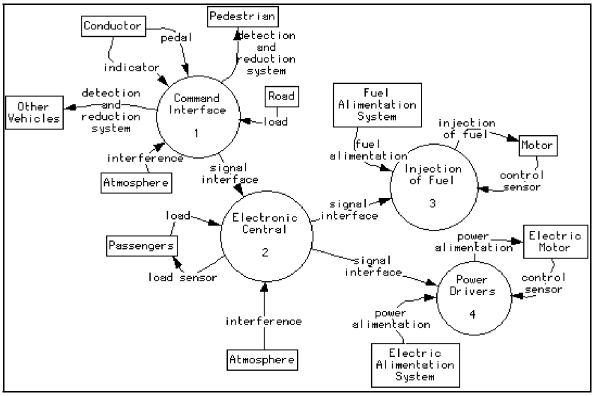

Figure 12. Product physical interfaces

5 Discussion

This sections highlights the differences between traditional and proposed approaches. Complex products such as the green car analyzed in this paper have many stakeholders. It is not possible to consider only customer or user as stakeholders of interests, like in the traditional approaches. Stakeholders related to all product life cycle process must be taken into consideration from the outset of the system architecting process. The proposed approach accomplishes it. (see Steps 1 and 2 in Section 3). Traditional systems engineering approaches perform functional context analysis only during product operations (the so called CONOPS or concept of operations) and for product development organization processes. However, a system solution is comprised of product and organization elements and many enabling elements must be also developed for mission success. These elements are only identified if context for each life cycle process scenario is performed. Therefore, the proposed approach covers the overall product life cycle, not only operations and development. (see Step 3 in Section 3). By considering product life cycle processes from the beginning of the system architecting process and from the top level context diagrams to be decomposed in lower level functions and lower level physical architectures, the concurrent engineering concept is implemented within the systems engineering process. This fulfills the framework proposed in Figure 1. The proposed approach allows requirements from the whole product life cycle to be anticipated to the early stages of a system architecting process. Stakeholder requirements are captured for the whole product life cycle process. Functions, performance, conditions, circumstances, modes and exception functions are captured for the whole product life cycle process. External physical and logical interfaces and internal physical and logical interfaces are identified for the whole product life cycle process. The system solution here is composed of product and organization elements. The product interaction with other system elements is identified in the beginning of the system architecting process. This promotes dramatic gains in productivity during product development and during product life cycle. System quality increases. Product changes are avoided. Changes cost and time are eliminated.

6 Conclusion

This paper presented a system concurrent engineering approach to develop a green car. The proposed approach addressed the deficiencies of traditional methods, such as, product focus, operation and development focus, and part focus. The paper described the approach as a way to perform stakeholder analysis, requirements analysis, functional analysis and implementation architecture, simultaneously, for the product and organization elements of a system at every layer of the system breakdown structure. This is necessary to address all complexity factors that are inherent to complex product development. Conclusions are that impact, traceability and hierarchy links promote the anticipation of life cycle process requirements to the early stages of systems architecting. Late changes are avoided, development costs are dramatically reduced while satisfaction of stakeholders over product life cycle is increased.

7 Acknowledgement

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Implementation Concept of a Versioning Approach for Civil Engineering Process Models

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Abstract. Civil engineering processes are characterized by the specific peculiarity that they need to be designed individually for each project. A modelling technique has been developed at TU Berlin that is suitable to support the design of these processes. In this approach, the process is regarded as a result of a computation which requires specific user input. Project independent and project dependent information is necessary as user input. Thus, objects from different sources specified by different users form a model. Models which have been specified by different users need to be merged. Effects of subsequent modifications need to be determined. This collaborative mode of working requires a specific versioning. In this paper an implementation concept of a versioning approach is presented supporting collaboration in civil engineering process modelling. The versioning approach is based on objects administrated in sets.

Keywords. Process Modelling, Civil Engineering Processes, Versioning, Auditing

1 Introduction

Civil engineering processes can cover thousands of activities. They require an extensive preparation phase where in detail guidelines for the planned project are worked out. In planning processes, for instance, ten thousands of documents, technical drawings and reports are planned to be worked out; and construction processes can cover several thousands of components that are erected, installed, modified or demolished during a project.

Our modelling approach is based on triples to describe planning or construction tasks. A planning task consists of an activity that is executed on a specific document where the document achieves a specific state at the end of the execution of that activity; and a construction task consists of an activity that is executed on a specific building component where the component achieves a specific state at the end of the execution of that activity. The tasks are generated from project independent process templates [1,2]; and as a consequence of this modelling

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approach, the specification of a planning process model starts with the specification of the documents that need to be worked out during the project and the specification of a construction process model starts with the specification of the building components.

On an abstract level, we are dealing with objects which bind other objects. The objects are administrated in sets. A suitable approach is necessary to support collaborative work in a distributed environment based on objects administrated in sets. Models which have been specified by different users need to be merged. Effects of subsequent modifications need to be determined automatically.

Such an approach has not been implemented as yet. Versioning is a common problem to many disciplines in computer science. Engineering and software environments that have an iterative and tentative nature apply versioning concepts to enable distributed cooperation by tracking the evolution of progressive stages of data [3]. Two different concepts are distinguished in literature to manage the cooperation: optimistic and pessimistic concurrency control [4]. An optimistic approach allows parallel manipulation of shared data. Multiple project participants download data and may modify the same data at the same time. Modified data has to be uploaded and compared, conflicting changes need to be resolved, and finally a merged, consistent version is stored in the shared data storage. In contrast, a pessimistic approach only allows sequential modifications realized by a locking mechanism. Data in use is set to a read only access mode to avoid concurrent modifications following the lock-modify-unlock paradigm. Due to our requirements, we need to support the optimistic approach.

A further distinction of versioning concepts can be undertaken by categorizing into state-based and operation-based approaches [5]. State-based approaches only store identified states of a model. Differences between two states are derived by comparing two different states. Change-based approaches record the changes. Either an initial state of a model is stored and the recorded operations transform the initial state into a succeeding state or the actual state of a model is stored and the recorded states allow returning to previous states. A comparison between state-based and operation-based change tracking has been examined by [6]. In our approach, we make use of the state-based approach.

In the area of source code versioning, a multitude of version control systems (VCSs), alternately known as revision control systems (RCSs), have been proposed. Examples based on a client-server architecture are CVS [7] or SVN [8] and examples based on a distributed peer-to-peer approach are Git [9] and Mercurial [10]. Standard VCSs for code versioning usually work on file-level in an optimistic way and perform the conflict detection by line-oriented text comparison algorithms. In our approach, these concepts are used to version objects.

Amongst others, graph-like data structures occur in object-oriented environments, in the area of software configuration management (SCM). In the area of SCM [11] developed a unified versioning approach through feature logic called Version Set Model. Version sets denote versions, components, and configurations by feature terms. Feature terms consist of a conjunction of (feature: value)-pairs, where each feature represents an attribute of an object. Feature values include literals, variables, and (nested) feature terms. Boolean set operations intersection, union, and complement are used to construct feature terms.

Beer et al. [12] present a system architecture for net-distributed applications in civil engineering that integrates a persistence interface for versioned object models, focussing the needs in the area of civil and building engineering. The versioning concept distinguishes between application specific information which is kept in the object model of an application in form of attributes to objects and application independent information which is kept and maintained in elements with specific features [13-15]. This separation allows to uniform information. The object versioning is realized on the basis of a binding and versioning graph. Objects are stored as files using a SVN as VCS [16]. Elements are stored in an additional database. Feature Logic is used on the basis of the element database in the sense of set algebra to provide a selection mechanism overcoming the limits of individual application models [17].

[18] and [19] describe a versioning approach that tracks the evolution of an application model on object level. Each object is versioned, spanning a version graph. References between objects are considered as bindings, spanning a binding graph. The binding graph is used to ensure model consistency. Based on the concept of version graphs and binding graphs [20] developed a set-based approach that does not address objects individually, but sets of objects. The aim of this approach is to reduced complexity while selecting a valid model. The modified approach was first presented in the context of planning processes and has been adapted to construction processes [21].

The versioning concept that is described in this paper substantiates the set-based versioning approach mentioned in the last paragraph. A detailed view is presented to point out the set-based approach in the context of selecting consistent model units for concurrent modification and the versioning mechanism when writing back the modified data into a shared database.

2 Objects and Sets of Objects

The modelling technique is designed to compute schedules for planning and construction processes from user input. It is stored as information in objects with different meanings, e.g. structuring tree nodes to describe for instance the locations in a planned building or building components. Different objects with the same meaning are administrated in sets. Types of different sets are prescribed from the modelling technique.

In our approach, objects keep their identity once they have been instantiated. Objects can have attributes. We distinguish the identity of an object from the values of the attributes. An object is modified if at least one attribute is modified. Attributes can be of native data types such as integer values or strings; and objects can have references to other objects. References between objects describe that information from an object is used as a basis for another object. We use the term binding to describe such relationships: Consider two objects A and B. Object A binds object B if object B is based on information of object A. Bindings are represented by references. Object B references object A.

Figure 1 shows an example with two different types of objects: objects of the type location and objects of the type component. Locations are used to structure components. A component object references a location object. As a consequence, a location binds a component.

In figure 1, a scenario is presented where in a first step a location object has been instantiated. In a second step, a component object has been instantiated that references the location object; and in a third step, the location object has been modified.

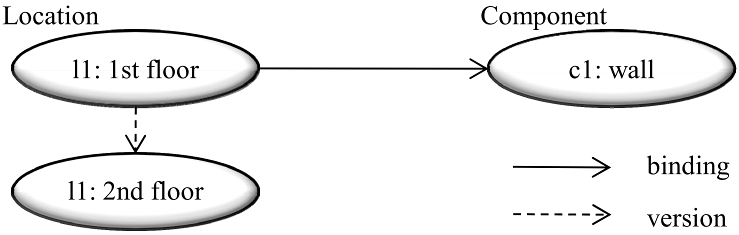

Figure 1 Working with Bound and Versioned Objects

We are convinced that functionality is necessary in the area of modelling civil engineering processes to show the consequences of modifications to the user. In the example shown in figure 1, the user has to be informed that component c1 might become invalid; and the user has to decide whether he wants that c1 now refers to l1 with the new name “2nd floor”.

The example in figure 1 shows a binding and a versioning relation on object level. On a more abstract level, the concept of binding and versioning relations can be used to describe dependencies between sets of objects. I.e. as part of a model, there is a set of location objects and a set of component objects (see figure 2). If there is a component that is bound by a location on object level then the set of components is considered to be bound by the set of locations on model level. Modifications to any object of the set of locations result in the creation of a new version of that set. As the previous version of the set of locations was bound, an update on the set of components is required to ensure model consistency. The result of the update is a new version of the set of components and a new binding relation.

This approach does not version a model as a whole but it acts on the assumption that a model consists of identifiable parts respectively sets of objects. Each set of objects is versioned. Thus, a model that describes a complete project consists of a number of versioned sets. If objects of one set are related to objects of another set, these sets are considered to be bound. A binding represents a constraint. A valid model can be obtained by selecting a number of versioned sets for which all bindings are considered, in other words for which there is no conflict in the set of constraints.

The objective of the presented approach is to support the collaboration of multiple project participants. Depending on the role and the intended work, specific parts of the model are affected. A participant shall be able to identify specific sets of objects in identifiable versions and shall be supported by domain logic to ensure consistency in the selected sets.

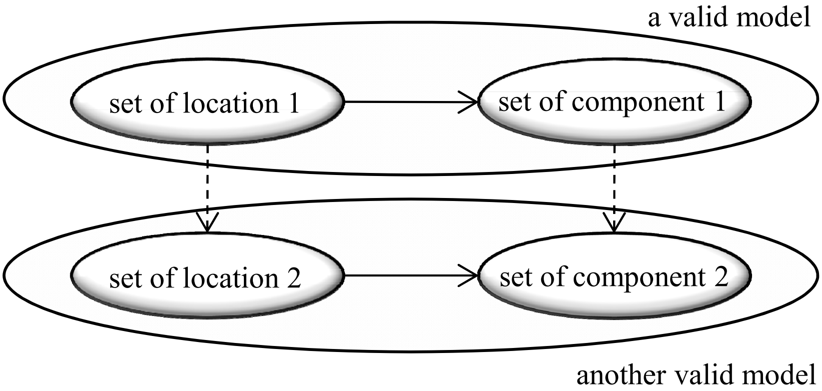

Figure 2 Working with Bound and Versioned Sets of Objects

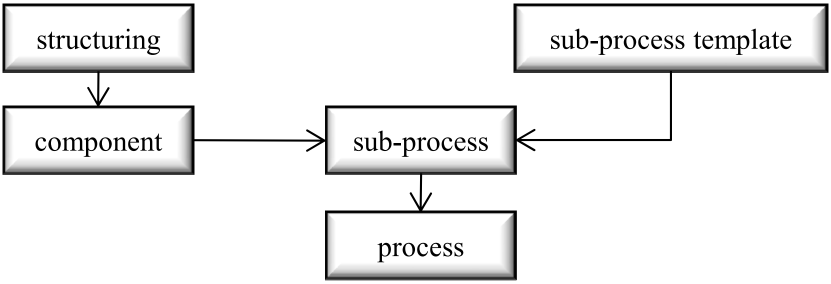

Figure 3 Relevant Classes of our Model

Figure 3 shows typical types of objects that are relevant for our domain model. Objects of these types are maintained in versioned sets. The relations presented indicate possible bindings. To receive a complete and consistent model, a single version of each set shown in figure 3 needs to be identified. Only in the case that the bindings are considered, the selection represents a valid model.

3 Versioning Objects

Objects within and beyond the scope of an application have to be distingushed. Data bases use primary keys to identify objects. In object-oriented programming there are different kinds of object equality: Objects can be identical or equal. In Java identity of objects is determined by their location in the memory. Equality is determined by calling the method equals any objects takes hold of. Equality therefore depends on the implementation of equals.

In our application, we decided to distinguish objects by an identifier that is attached as an attribute to any object. The identifier is an instance of the type

UUID (Universally Unique Identifier). The method equals is implemented as such, that equality is determined by that identifier.

Using relational data bases is a suitable way for persisting data. To store objects into relational data bases, they usually need to be decomposed into their different properties. Since data base communication is not native to programming languages, an additional layer, a so called persistence layer needs to be implemented for that purpose.

To reduce implementation effort concerning persisting objects to das, within the last years different frameworks have been set up to provide object relational mapping (ORM) to data bases. ORM supports programmers with automated persistence of objects to the tables of a relational data base. A popular open source framework that provides ORM for Java applications is Hibernate [4]. Within our application, we use Hibernate to persist specified data.

To include Hibernate into an application, the framework has to be supported with information by the programmer: the main purpose is to define the mapping of objects to the table of a data base. This can be done by using annotations. Annotations provide the possibility to add metadata to source code. The usage of annotations is supported by Java since Java 1.5. For mapping definitions, the Enterprise Java Beans API [22] and additionally to that Hibernate itself provide special annotations.

In an application, objects are created, changed and deleted. Persistence mechanisms ensure the storage and retrieval of these objects. Information about the objects' history is not stored.

An approach to preserve the history of an object has to be implemented. The Hibernate core implementation consists of a model of events and listeners [4]. For instance, if an object shall be persisted to the data base, an event is triggered. That event is handed to listeners.

A framework that enables persisting objects' lifecycles is Envers [23], which will be a native part of Hibernate 3.5. Within Envers object versioning is called auditing. There are custom implementations of listeners provided by the framework. The listeners have to be registered within Hibernate. As a result, object auditing will be enabled.

As a result, the combination of Hibernate and Envers enables object auditing. For each audited object, additional lifecycle information will be persisted to the data base as object history based on revision numbers.

4 Working with Sets of Versioned Objects

The main reason for the development of a versioning concept is to support the collaboration of multiple project participants. Different participants with different roles contribute to a common project model from different locations.

In our approach (see Figure 4), we distinguish functionality for process modelling from functionality to administrate different sets of objects. Process modelling takes place locally on the basis of a single model. A remote data base is used to store the models returned by participants from their local environments.

Local work and working on the remote data base require a different understanding of the term model.

As a policy, we introduce a model object to work with objects. A model object comprises objects in such a way that a user specific unit of work is addressed. The model classes are prescribed by the modeling approach. Each model object can be regarded as a set of versioned objects. Locally, model objects are treated as described in section 3. Working on the remote data base requires different model objects.

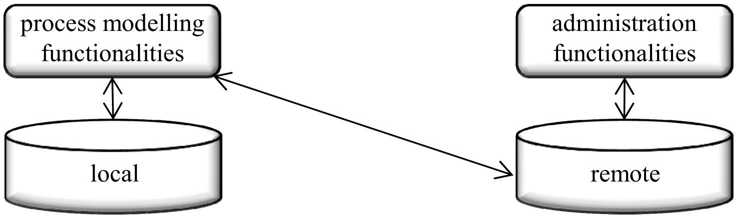

Figure 4 Functionalities and Data Bases

Each time when a local model is returned to the remote data base it is divided into sets of objects. Each set contains objects of the same type. Binding relations are created for these sets. Instead of storing the model as a whole, the objects of the model, the sets, and the binding relations are stored. Each object is treated as described in section 3. Each set is added to a type specific versioning graph. The binding relations are added to an overall binding graph.

The result of this is that many different model states can be extracted from the remote data base by evaluating bindings. Each combination of versioned sets represents a valid model. Standard algorithms from graph theory i.e. path algebra are used to determine the sets of a valid model.

The approach changes the way, project participants collaborate today. The following scenario describes how modifications are executed and propagated to the collaborative project model. Scenario: (1) Selection, (2) Process Modelling, (3) Merge.

(1) Download a number of versioned sets from the remote environment: A project participant connects to a central repository that hosts the collaborative project model. Depending on the role and the intended work, the types of effected sets are identified automatically. Each set can exist in a number of different versions. The participant needs to explicitly choose a specific version for each type. Program logic ensures coherence between the selected sets. The choice is checked out to the local environment of the participant and stored in a local database.

(2) Modify the objects and their relations in the local environment: Inside the locale environment of the participant a local copy is created for each downloaded versioned set. Based on the downloaded sets, a single and coherent model is created. Modifications are executed on the local model in a detached mode, i.e. there is no connection to the remote server. At the end of each session modifications are stored in the local database only (long transaction). A local persistence layer is required for this purpose.

(3) Submit changes to the remote environment and support the merging: Once a participant decides to submit the changes, a new connection to the remote repository server is established. A merge mechanism is required that allows to work with versioned objects respectively versioned sets. Concurrent modifications by different participants on equal types of sets result in the creation of new versions of those sets.

The program logic that manages the versioning when submitting the changes to the remote server is provided by the client. The server is a classical data base management system.

5 Conclusions and Outlook

The approach presented in this paper has been developed to support distributed work on civil engineering processes. We are convinced that traditional process modelling in civil engineering must be replaced by approaches where the process itself is regarded as a result. Processes in civil engineering reach a complexity where the design of the process must be supported by computational methods. The objective is to guarantee completeness and correctness of these processes.

Such computational methods require specific modes of working where different users can contribute to a single process. As a consequence, different versions of the same process model must be administrated; and merge functionalities are necessary to guarantee consistency in process models. The implementation of the presented approach is under progress. Case studies will be the next steps in our research to demonstrate the benefit of the versioning approach.

6 Acknowledgements

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Numerical Simulations of the Microscale Material Phenomena Based on Cellular Automata Framework and Workflow Idea

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Abstract. The multiscale modelling of material behaviour during processes of heating and cooling or under loading conditions is highly sophisticated numerical problem. It requires many advanced algorithms solving a thermo-mechanical issues in macro scale as well as algorithms simulating undergoing processes of microstructure evolution e.g. recrystallization, phase transformation or fracture occurring in micro and nano scales. These phenomena are closely coupled and depends on each other. To properly illustrate this behaviour the numerical algorithms have to be also arranged together in various configurations e.g. simultaneously, sequentially, iteratively or conditionally. This eventually leads to complex numerical solutions. Coupling various micro scale evolution models always presents difficulties and requires a high-level framework responsible for exchange of data through programming interfaces. A static component diagram and reverse engineering is not sufficient to satisfy requirements of such advanced approaches. Therefore, Authors decided to apply the dynamic workflow idea into the microstructure evolution simulations. The dynamic workflow supports design of complex algorithm with flexible data flow and reusable components. The computer program implemented on the basis of the Windows Workflow Foundation and results obtained from simulations are presented in the paper.

Keywords. Multiscale modelling, digital material representation, workflow, cellular automata

1 Introduction

The development of reliable material models for metal forming simulations has been in interest of scientists for a number of years. A series of deterministic models, based either on closed form equations describing the flow stress dependence on external variables [4], or on differential equations describing the evolution of internal variables [3] have been published in the scientific literature. These models are commonly used in simulations for the majority of metal forming processes and give reasonably accurate results. These models fail, however, to

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describe the material behaviour when some special conditions of deformation occur, e.g. fast changes in the deformation conditions or a strong tendency to strain localization. The main problem is to realistically describe the phenomena occurring in materials at lower length scales under the above complex conditions of deformation and to incorporate this into the continuum based approaches. Beyond this, accounting for the influence of such phenomena as cracks, shear bands, Luders bands at the macro scale and such discontinuities as micro shear bands, grain boundaries, phase boundaries at the micro scale, become necessary when the model aims to predict the properties of the final products. Finally, several of these phenomena are stochastic in nature and their realistic description by deterministic models may be limited.

Thus, the search for models that account more accurately for micro scale and even nano scale phenomena has been the objective of research during last two or even three decades. The improvements in the experimental techniques are the major factors stimulating this research. New experimental techniques have made it possible to visualize physical processes and to measure relevant parameters at fine scales (e.g. atomic force microscopy (AFM), nano indentation tests, computer tomography, electron back scattered diffraction (EBSD) etc). The knowledge obtained about mechanisms of deformation from these experiments has been recently combined with the idea of multi scale modelling of materials to develop models with new predictive capabilities.

The main objective of this paper is focused on development of advanced micro scale models being the crucial part of complex multiscale solution. The basic interest is put on support of design of mentioned micro scale models, which are composed of elementary algorithms implemented using the cellular automata (CA) framework. This support is realized by application of workflow idea and implementation of two separated computer programs dedicated two design and usage of micro scale models. The following sections present the idea of multiscale modelling, proposed CA framework and applied workflow solution. The results obtained for simulation of recrystallization and phase transformation phenomena are presented as well.

2 Multiscale Modelling

2.1 Idea

The methods, which cope with the multi scale material phenomena are usually classified into two groups: upscaling methods and concurrent multi scale computing [2]. In the upscaling class of methods, constitutive models at higher scales are constructed from observations and models at lower, more elementary scales. The idea of the representative volume element is employed here. By a sophisticated interaction between experimental observations at different scales and numerical solutions of constitutive models at increasingly larger scales, physically based models and their parameters can be derived at the macro scale [1]. The methods of computational homogenisation, e.g. [7], are considered to belong to this group of methods.

In the concurrent multi scale computing one strives to solve the problem simultaneously at several scales by an a priori decomposition. The two-scale methods, whereby the decomposition is made into coarse scale and fine scale, have been considered so far.

Both groups of methods have been intuitively used for decades [8]. Recent years have, however, witnessed the rapid development of the multi scale methods in various areas of science. Applications to deformation processes are particularly frequent. Various discrete methods have been applied to describe material behaviour at the micro and/or nano scales, e.g. cellular automata (CA), molecular dynamics (MD), Monte Carlo (MC) methods. In this work the CA methodology was applied and the presented micro scale models were implemented on the basis of the CA framework developed by Authors. The short description of the framework is included in the next section.

2.2 CA framework

The main motivation for development of the CA framework was lack of the universal programming framework able to support creation of a CA algorithms. All existing solutions have several disadvantages. Firstly, they are dedicated to specific problems like traffic simulation [5] or event forecasting [6] and are inaccessible for external users that are interested in implementation of their own algorithms. Secondly, available CA frameworks are characterized by low runtime efficiency. That is due to a large number of cells e.g. CA space with dimension 200 in 3D requires 8E+6 cells and in case of 300 it is already 27E+6. Thus, simulation of huge number of cells is time, CPU and memory consuming. When a single cell consists only one variable of integer type (4 baits) the mentioned spaces already require 32MB and 108MB of memory respectively. Obviously, more sophisticated models require more variables, that represent various microstructure data/features and are used in the CA rules. In that case even more than gigabytes of RAM memory are required. These advanced CA models and algorithms force implementation of optimized codes regarding parallelization, efficient usage of cache memory and finally employment of specialized data structures. The solution proposed in this framework satisfies all these needs and allows to perform parallel computations only in the CPU cache which significantly speed up the calculation process. In conventional approach with the RAM memory even the parallelization based on the OpenMP approach still results in deterioration of the final performance. This is caused by the loss of time during communication between multi-core CPU and shared RAM memory, which use the same data bus. In the modified approach the crucial factor influencing the efficiency of the CA framework is proper design of the code and division of the information sizes. The use of data divided into small pieces required by CPU cache allowed to improve the efficiency even by 6-7 times.

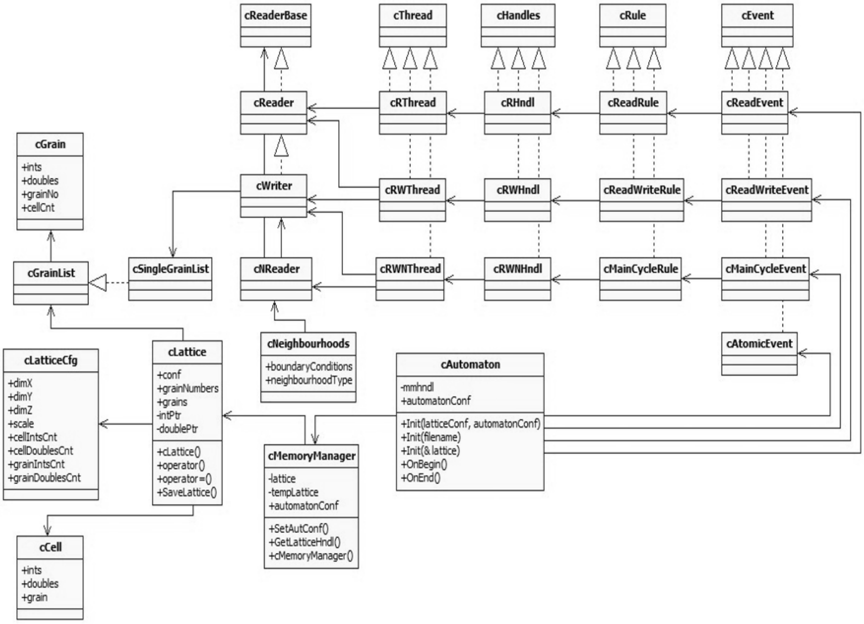

Figure 1. Class diagram of CA framework.

The developed architecture of the Cellular Automata framework consists of the two several major classes (Figure 1), while two of them i.e. cLattice (cLatticeCfg), cAutomaton are the most important. Additional components responsible mainly for data storing and configuration purposes are implemented in form handlers and references. The first mentioned class is used to store all the data related to CA space like dimensions or cells' pointers. It also provides a simple interface that is used by a particular automaton. The main objective of the cAutomaton class is to facilitate creation of individually designed CA algorithms. Therefore, the cAutomaton is responsible for abstract representation of automata and aggregates information about neighbours, configuration parameters, calculations data and two cellular spaces. One of this spaces is modified during the calculation of the transition rules, while the second one remains unchanged and provide data from the previous time step. The most crucial part during creation of a new CA algorithm is focused on implementation of three main cAutomaton methods providing the following functionality: automaton configuration, implementation of a transition rules and boundary conditions, description of neighbourhood.

The various algorithms that are used to describe material phenomena at micro scale., e.g. dynamic recrystallization, austenite-ferrite transformation, cracking, were implemented on the basis of proposed framework and tested with different parameters. These algorithms work with satisfactory quality, however they have to be combined together in one sophisticated model to illustrate complexity of material with high reliability. The combination of such algorithms is supported by the workflow idea and is described in the next section.

3 Workflow Solution

3.1 Idea

The manual combination of algorithms is extremely difficult because of high heterogeneity of in-house source codes as well as differences in input parameters description, results, CA space configuration, etc. Even if the elementary algorithms are implemented on the basis of the CA framework, each algorithm can be created in non-standardized way, which does not facilitate further compilation of different algorithms in one complex model. Thus, Authors decided to apply the workflow idea. The basis of this approach were developed by Taylor in the beginning of 19th century as part of the business and management science, aiming at optimization of enterprises' various activities. During next years the concept of workflow evolved and was introduced into computer science[2]. Currently it is being developed by different software vendors. The workflow idea is applied in this work as a computer support for the design of complex micro scale material models (Figure 2).

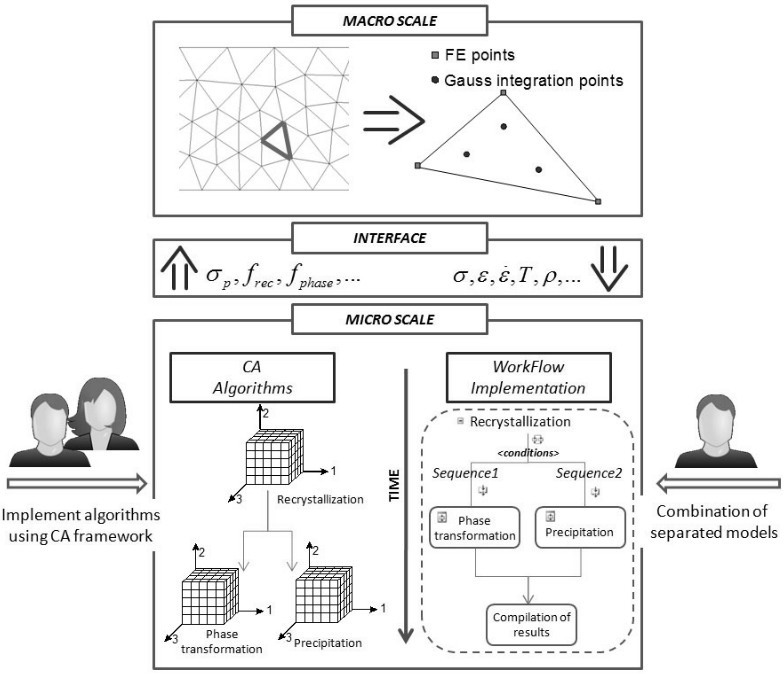

Figure 2. Main idea of workflow included in multiscale modelling.

The whole approach is composed of combined numerical models working in macro and micro scale. The interface between them is responsible for exchange of

[2] http://home.agh.edu.pl/~lrauch/tmp/workflow_links.html - set of links to web sites

data from macro to micro scale including e.g. strain, stress, temperatures, dislocation density as well as from micro to macro scale, including the response from designed models. Due to the standardization and flexibility provided by workflows, the conceptual design of complex model (Figure 2 on the left at micro scale) can be easily mapped onto the workflows (Figure 2 on the right at micro scale) and compiled as one computer program.

3.2 Implementation Details

The workflow was implemented using the Windows Workflow Foundation (WWF – http://msdn.microsoft.com/en-us/netframework/aa663328.aspx) supported by Microsoft. The computer system proposed in this paper includes two separated application i.e. workflow designer and workflow runner. The functionality of latter one offers the possibility of usage of the designed material model on the basis of .NET framework, MS Workflow Services and MS Workflow Engine. However, the workflow designer is the main part of the created system. Crucial components of this software (Figure 3) are responsible for workflow presentation (*WorkflowView*), saving, loading (*WorkflowLoader*) and design (*DesignerSurface*).

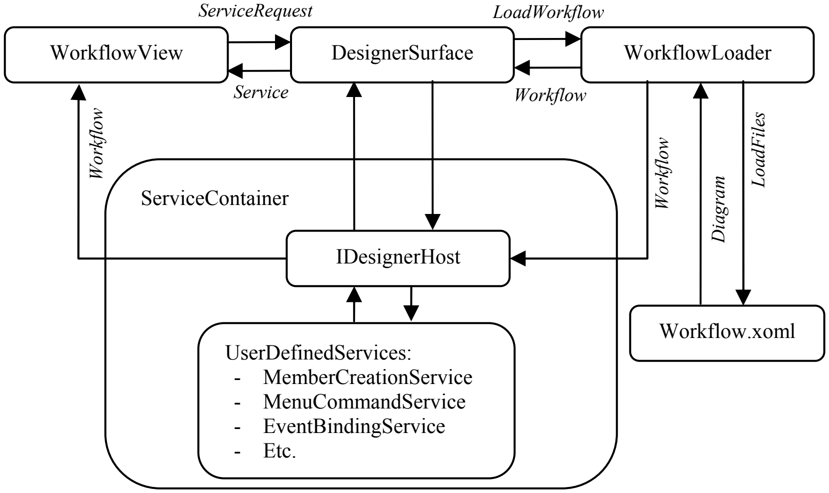

Figure 3. Main components of workflow designer software.

The user interface is directly connected to WorkflowView component, which receives information about workflow and services from two sources i.e. DesignerSurface component and IDesignerHost interface. The latter interface is used to connect services implemented by user to currently designed workflow. The final workflow is compiled as dynamically linked library (dll) and passed to workflow runner software, where user sets the input parameters and analyzes obtained results.

4 Results

The deformation of a two phase material is analyzed in the work to show the basic idea of the numerical simulations based on the workflow approach. First the developed CA model for dynamic recrystalization is used to describe material behaviour during hot deformation conditions. Then the resultant austenite microstructure is used as input during CA austenite-ferrite phase transformation simulations. That way a realistic description of material behaviour during cooling processes can be obtained. Each CA cell is described by several state and internal variables in order to properly describe behaviour of the material. The transition rules describing microstructure evolution are designed to replicate experimental observations of mechanisms responsible for particular processes. In the present work the final product of the phase transformation is a ferrite-martensite microstructure. Details of the model can be found in [9].

The obtained two phase microstructure (Figure 4a) is then used in this work as input for simulation of the inhomogeneities occurring during plastic deformation. Based on this input regarding topology and properties, the generation of the homogenous triangular mesh is performed in the commercial FE software Forge2. Each finite element within this mesh takes its properties from the underlying two phase microstructure. The sample was subjected to the plain strain compression test (Figure 4b,c).

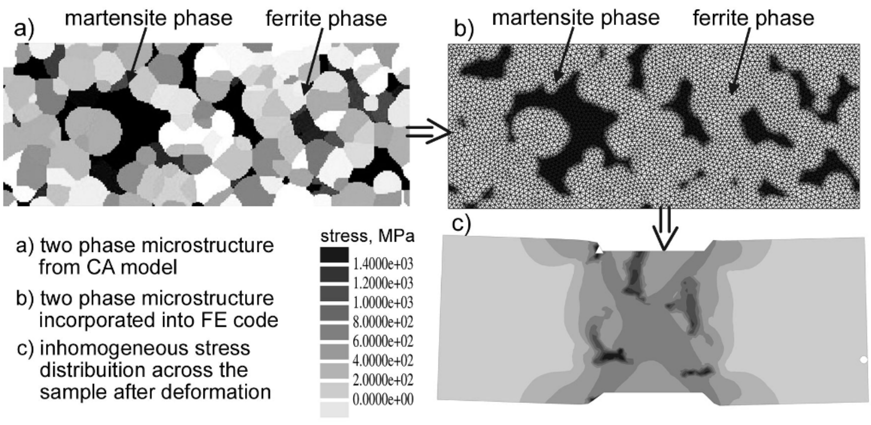

Figure 4. Results obtained from CA model and foregoing numerical simulations of plain strain compression test. Sample size was equal to 300x120μm.

As presented in Figure 4c the deformation in the two phase materials at the micro scale level is highly inhomogeneous. Regions of martensite phase are locations where stress concentrations appears what may influence final material properties. The presented examples of workflow application highlights possibilities provided by the method. Influence of particular processes and manufacturing stages can be easily taken into account during detailed investigation of the material behaviour at the micro scale level.

5 Conclusions

The paper present the workflow idea applied in the multi scale modelling simulations. The proposed solution supports concurrent design and implementation of sophisticated material models. These models are composed of elementary numerical algorithms dedicated to simulation of material phenomena at micro scale e.g. recrystallization, phase transformation, cracking. The algorithms are implemented on the basis of the CA framework created by Authors in previous work, compiled further as separated services and used during design of workflow.

The approach based on workflow idea facilitates combination of elementary CA algorithms into one complex model and support exchange of models developed by different research centres. The future development of presented solution assumes its application to flexible modelling of production cycles, where each production process would be treated as elementary algorithm, while a cycle would combine basic processes as the complex workflow.

6 Acknowledgement:

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Methodology for Environmental Impact and Performance Assessment of Derivative Electronic Products

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Abstract. This study therefore uses a back-propagation neural network (BPNN) to establish a model for analysis of hazardous chemicals and energy consumption of the product life cycle of derivative electronics, helping enterprises, at the product design stage, estimate hazards of derivative electronic products on the environment across major phases of the product life cycle. In addition, to clarify the performance of a newly developed product's ecological design, this paper applies TOPSIS to develop a performance assessment model for product design for environment (DfE). With the analysis provided above, we may help enterprises better understand DfE performance of its new product as well as similar products of competitors as a reference for modification of product design.

Keywords. Product life cycle, Product design, Back-propagation Neural Network (BPNN), Design for environment (DfE)

1 Introduction

In previous years, most environmental pollution control initiatives focused on end-of-the-pipe pollution control, and then were transformed into process improvement. And now, a concept of initial control is developed [3]. Therefore, the estimated the quantity of pollution load and energy consumption produced at every stage of the product life cycle are reviewed on an overall basis at the product development stage to achieve the goal of reducing environmental impacts and alleviating consumption of natural resources. Meanwhile, environmental regulations such as WEEE (Waste Electronics and Electrical Equipment), RoHS (Restriction of Hazardous Substances Directive), and EuP (Energy using Products, EuP) that give rise to enforcement, design for environment (DfE) is an irresistible trend. If an enterprise fails to timely respond to the requirements of these environmental regulations, it will be subjected to huge losses. After the Energy

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Using Products (EuP) Directive taking effect from August 11, 2007, the EuP Directive first set guidelines for environmental design of some energy-using electronic/electrical products. It is expected to cover all energy-using products in the future. As a result, prior to expansion of the regulation to include all consumer electronics, enterprises have to build their capability of eco-design as early as possible. In the coming years, EuP-regulated items will be fined and shall be banned from being imported to EU countries, if they do not conform to the requirements for eco-design. Undoubtedly, this would be a tremendous impact on relevant firms, most of whose revenues mainly come from consumer electronics. Facing intensive market competition, enterprises should accelerate the launch of new consumer electronic products and therefore should conduct the life cycle inventory frequently. In few of the foregoing facts, this paper develops a methodology for environmental impacts and performance assessment of product life cycle of derivative electronic products. Through the establishment of the methodology, an enterprise may, at its product design stage, objectively estimate the quantity of hazardous chemicals and energy consumption produced at major stages of the product life cycle. To analyze the DfE performance of a new product and similar products from competitors, this study applies TOPSIS to develop a performance assessment model for product design for environment, so that we may have insight into the competitive edge of the new products in the green consumer electronics market.

2 Literature Review

Life cycle assessment (LCA) measures negative environmental impacts and influences of product life cycle ranging from raw material extraction, production and manufacturing, transportation and utilization, to final scrapping, recycling and reuse. The assessment concept changes previous considerations which simply highlighted environmental impacts of process instead of other stages. The International Organization for Standardization [8] has used life cycle assessment as an official international standard and proposed the framework of life cycle assessment. However, the international community hasn't yet reached a general consensus to methods for calculation of assessing life cycle impacts so far. Therefore, this study uses pollutant emissions and energy consumptions as indicators for eco-design performance assessment. Chiang et al. [1] developed an ISO 14048-based integrated service platform, providing life cycle inventory data on standard parts and components and helping Taiwan SMEs perform life cycle assessment for non-standard parts and apply for an environmental declaration. However, existing software applications cannot provide functions such as comparison between similar benchmarking products and environmental regulations for insight into DfE performance. For improvement in design for environment, it is essential to set improvement goals manually. Because of prolonged traditional life cycle assessment procedure that consumes high cost and requires tremendous detail information, relevant studies of simplified life cycle assessment are conducted [5, 6]. Through selecting the biggest impact of a product on environment as assessment criteria or reducing assessment stages required for product life cycle, this method can achieve desirable simplification effects. In addition, Graedal et al. [4] proposed streamlined LCA matrix approaches, which divide the life cycle into five stages, forming matrix-based life cycle assessment approaches, with considerations of five impact aspects. They used a checklist to establish the score of the performance in each matrix element. The score ranges between 0 and 4; the less the score, the larger the environmental impact. The intuitive assessment result may assist product engineers in overview of improvement for their products. In order to reduce the life cycle inventory cost, many literature reports used neural networks as analysis tools and simulated approximate life cycle assessment with data training. Sousa et al. [10], for instance, used high-end product features and environmental impacts obtained from their approximate life cycle assessment as sample data for training of neural networks. From the analysis result, we may find out suitable high-end product features to predict environmental impacts. Park and Seo [9] used neural networks to develop knowledge-based approximate life cycle assessment system and applied the system to environmental impacts of synergetic environmental assessment design scheme. According to the above-mentioned study verification, it is found that neural networks are very suitable for environmental impact assessment. Unfortunately, the environmental impact assessment value is a general performance assessment value, which cannot disclose specific details for further analysis.

3 Methodology for Environmental Impacts and Performance Assessment of Derivative Electronic Products

Figure 1 shows the framework of the methodology for environmental impacts and performance assessment of derivative electronic product life cycle. This paper uses an approximate life cycle inventory analysis model to estimate energy consumptions and environmental impacts (e.g. Dust, CO_2, SO_X, and NO_X) during the major stage of life cycle. First, this study uses the back-propagation neural network to construct a power consumption estimation model. This model applies high-end product attributes for the input value for objective prediction of the quantity of energy consumptions, as well as that of hazardous chemicals generated from the process itself, at the manufacturing and use stages. Besides, this study also establishes a model estimating the quantity of hazardous chemicals at the raw material extraction stage. According to the analysis above, we may obtain the total quantity of hazardous chemicals and energy consumption for life cycle assessment of the newly developed product for various stages early at the product design stage. At last, this study applies TOPSIS to DfE performance assessment and sorting, with which we may have insight into the new product's DfE performance and sorting and provide them to product development manager for reference.

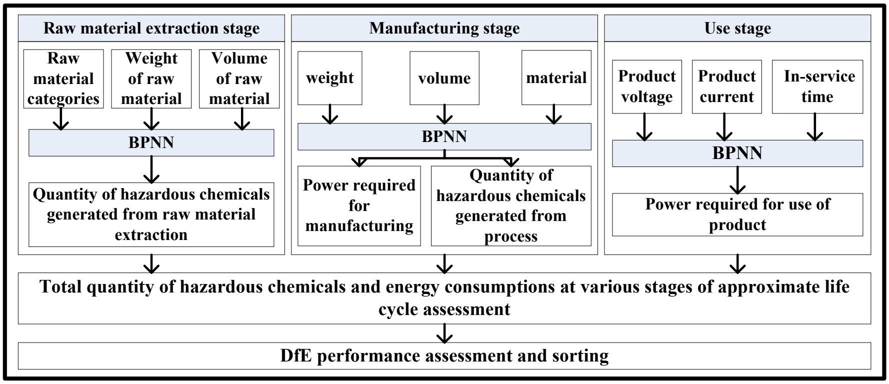

Figure 1. Methodology for environmental impacts and performance assessment of derivative electronic products

3.1 Environmental Impact Assessment Model

This study applies the back-propagation neural network (BPNN) to develop an approximate life cycle inventory analysis model. Because this study focuses on development of derivative electronic products, we therefore may obtain detail design specifications and life cycle inventory data of similar products from the previous product data management system for training of the BPNN so that an approximate life cycle assessment model can be built. The approximate life cycle inventory analysis model at the raw material extraction stage can be used to predict the quantity of hazardous chemicals generated during various raw material extraction procedures required for new products. This study retrieves raw material categories, weight and volume from the database of life cycle inventory software and hazardous chemical data produced from raw material extraction for training of the BPNN to establish a model estimating the quantity of hazardous chemicals at the raw material extraction stage. The input variables of the approximate life cycle inventory analysis model at the manufacturing stage include weight, volume and material of parts and components to estimate power required for manufacturing and hazardous chemicals produced during the production. At the using stage, this study will target at estimation of power consumption for the product. For the utilization analysis of the use stage, we use the BPNN to estimate the total power consumption at this stage, with its input variables including the product's operating voltage, current and total in-service time. Ultimately, after aggregating the quantity of hazardous chemicals and energy consumptions at all stages, product development manager may obtain approximate life cycle assessment for new products.

3.2 Performance Assessment Model for Derivative Electronic Product

This study uses the technique for Order Preference by Similarity to Ideal Solution (TOPSIS) [7] to establish a derivative electronic product performance assessment model. The model's assessment criteria involve the quantity of energy consumptions and various hazardous chemicals (e.g. Dust, CO_2, SO_X and NO_X) of product life cycle. When approximate life cycle assessment of each product is obtained, a decision matrix can be formed, as shown in Formula 1. However, measurement units for energy consumption and hazardous chemicals are different; therefore Formula 2 [2] should be applied to normalize performance assessment value for a new decision matrix.

$$D = \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{15} \\ x_{21} & x_{22} & \cdots & x_{25} \\ \vdots & \vdots & \ddots & \vdots \\ x_{m1} & x_{m2} & \cdots & x_{m5} \end{bmatrix} \quad (1)$$

x_{ij} is the performance value of DfE assessment criteria for Product *i* Item *j*.

$$r_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} x_{ij}^2}} \quad (2)$$

r_{ij} is the normalized performance value of DfE assessment criteria for Product *i* Item *j*.

All the assessment criteria for the derivative electronic product performance assessment built in this study belong to input criteria. The higher the assessment value is, the poorer the ecological performance assessment will be. Therefore, we can use Formulae 3 and 4 to form the sets of positive ideal solutions and negative ideal solutions, and then use Formulae 5 and 6 to calculate the difference between the assessment value and the positive/negative ideal solution for Product i. At last, this study uses Formula 7 to obtain the general performance value of DfE products (Ci*). The closer the indicator approaches 1, the nearer it is to the positive ideal solution. To this end, product development manager can use the general DfE performance assessment value for preference order to evaluate the competitive advantage of the new product in the green consumption market. Besides, we may also search benchmarking products as the key reference basis for product design modification to improve the impacts of a product on environment.

$$A^+ = \left\{ \left(\min \ r_{ij} \middle| j = 1, 2, ..., 4 \right) \middle| \ i = 1,2,\ldots,m \right\} = \left(v_1^+, v_2^+, \ldots, v_4^+ \right) \quad (3)$$

$$A^- = \left\{ \left(\max \ r_{ij} \middle| j = 1, 2, ..., 4 \right) \middle| \ i = 1,2,\ldots,m \right\} = \left(v_1^-, v_2^-, \ldots, v_4^- \right) \quad (4)$$

A^+: Positive Ideal Solution set. A^-: Negative Ideal Solution set.

$$S_i^+ = \sqrt{\sum_{j=1}^{n} \left(v_{ij} - v_j^+ \right)^2} \quad , \quad i = 1,2,\ldots,m \quad (5)$$

$$S_i^- = \sqrt{\sum_{j=1}^{n} \left(v_{ij} - v_j^- \right)^2} \quad , \quad i = 1,2,\ldots,m \quad (6)$$

$$C_i^* = \frac{S_i^-}{S_i^+ + S_i^-} \tag{7}$$

4 Case Study

This study takes an optical mouse development project as an example and makes a comparison with other optical mice from four different brands to understand the new product's competitiveness after its launch to the market. The optical mice for the case study are manufactured and used in Taiwan. In this study, the production process of the optimal mouse product is distinguished into three parts: case, circuit board and USB cable. First, this study use previous product life cycle inventory data for training of the back-propagation neural network to establish an assessment model for estimation of the quantity of hazardous chemicals and energy consumptions at raw material extraction, manufacturing and use stages. Once an approximate life cycle assessment model is built, high-end product attributes of the study case's optical mouse are input in this model as shown in Tables 1 and 2 with which we may estimate the quantity of hazardous chemicals produced during raw material extraction and process, as well as power requirements at the processing and use stages.

Table 1. Weights of materials

Product		1	2	3	4	5
Case	ABS	0	48	0	0	0
	PS	0	0	0	0	0
	PP	47	0	51	0	0
	PET	0	0	0	52	44
Subtotal (g)		47	48	51	52	44
USB Cable	PVC	18	0	19	22	0
	PE	0	23	0	0	25
	Cu	12	16	13	15	16
Subtotal (g)		30	39	32	37	41
Circuit Board	CCL	0.4	0.4	0.3	0.4	0.43
	Resin and Fiberglass	9.6	10.6	8.5	9.6	10.7
	Chip	0.6	0.7	0.7	0.6	0.7
	Plastic	3.4	3.3	3.5	3.4	3.17
Subtotal (g)		14	15	13	14	15
Total (g)		91	102	96	103	100

Table 2. Specifications/dimension of parts and components

Product		1	2	3	4	5
Case	Volume (cm^3)	223.3	255.3	254.7	244.644	250.56
USB Cable	Volume (cm^3)	10.24947	28.62783	26.24218	29.264	30.21827
Circuit Board	Area (cm^2)	31	31.5	22.5	32	35

To understand DfE performance of a new product, this study uses TOPSIS to develop a DfE performance assessment model. The model takes the quantity of hazardous chemicals and energy consumptions as assessment criteria. First, based on approximate life cycle inventory analysis results of the five products, a decision matrix is established, as shown in Table 3, and then normalized. Formulae 3 and 4 can be used to for the sets of positive ideal solutions and negative ideal solutions for each criterion. As a result, this study uses Formulae 5-7 to calculate DfE performance for each product, as shown in Table 4. A larger C^* value indicates that the product's DfE performance is nearer to the positive ideal solution. Therefore, this study suggests a preference order on the optical mouse's DfE based on the performance value. In accordance with the analysis result, it is found that the company's product No.1 ranks the second in terms of DfE performance in the market, suggesting that there's room for modification; while product No.3 ranks first place. Product development manager may therefore refer to the design as a key reference basis for modification of the design.

Table 3. Decision matrix of product

Product	Dust (g)	CO_2 (g)	SO_X (g)	NO_X (g)	Energy (kwh)
1	95.70364	400.948	109.1859	56.56287	6.453362
2	105.7423	519.1118	120.9136	62.08061	6.481882
3	83.61602	486.6702	97.02952	50.74882	6.455143
4	98.19117	1141.212	115.58	62.51918	6.482001
5	107.5114	674.7127	123.7027	64.39899	5.583727

Table 4. Preference order of product

Product	S_i^+	S_i^-	C^*	Rank
1	0.104969	0.485402	0.822199	2
2	0.189733	0.400126	0.678342	3
3	0.082799	0.458266	0.84697	1
4	0.4976	0.05487	0.099318	5
5	0.25342	0.306295	0.547234	4

5 Conclusion

In recent years, problems of ecological damages and exhaust of natural resources have been exacerbated. To alleviate ecological/environmental impacts and restore natural resources, the design for environment (DfE) concept has become an irresistible trend for enterprises during product development. In particular, environmental protection regulations are becoming increasingly strict in developing and developed countries. Furthermore, because of dramatically reduced electronic product life cycle and the eco-design trend, an enterprise will inevitably encounter problems with life cycle inventory and DfE assessment frequently. With this in mind, an enterprise needs an effective approximate life cycle inventory analysis model and a method for DfE performance assessment. Accordingly, it may estimate the quantity of pollutant emissions and energy consumptions generated during major stages for its new product early at detail design stage of product development and conduct benchmarking analysis, based on other similar products and environmental regulations, to further gain its green competitiveness after its launch to the market. Ultimately, this study uses an optical mouse product as an example to manifest the practical value and significant benefits of the proposed methodology.

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Use Case Based Testing to Improve Smart Grid Development

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Abstract. The United States Power delivery system is being updated with an intelligent, decision-making network. If designed correctly, this smart grid will ensure that the power grid can meet our needs in the coming century. This paper discusses a strategy for defining the goals, use cases and systems tests so this complex, system of systems, meets the needs of the stakeholders today and in the future.

Keywords. Smart grid, use cases, system design, goal modeling, testing, electricity delivery system

1 Introduction

Today we rely on electricity in virtually every aspect of our lives, from computers to medical equipment to environmental control systems. The tools and toys we use every day are powered from electricity delivered through the power grid. As our need for electricity grows we push the limits of this electricity power delivery system closer to its limits. The US grid in particular is being pushed hard as much of the infrastructure is old and the ability to build new generation and transmission/distribution systems is limited by environmental and political concerns.

The fusion of the power grid with a 21st century intelligence network will create a smart grid - a complex power delivery system optimized at many different levels. One important area of optimization is the interaction of traditional power sources with new mini and micro generations (including alternative energy sources). By using load-balancing algorithms to combine these disparate generators with energy storage systems to meet the demand requirements fewer new power generation and transmission systems will be needed even as demand increases. If constructed properly, these power control system can be scaled from microgrids to macrogrids and used with both existing and future systems. Other aspects include; the monitoring of the health of the grid and equipment so potential failures can be detected and avoided, the ability for the customer to work with the utilities so their needs are meet while suing fewer resources, and the enablement of new technologies such as advanced electric vehicles.

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The US Department of Energy (DoE) lists seven high-level goals for smart grid [1]:

- Self-healing from power disturbance events
- Enabling active participation by consumers in demand response
- Operating resiliently against physical and cyber attack
- Providing power quality for 21st century needs
- Accommodating all generation and storage options
- Enabling new products, services, and markets
- Optimizing assets and operating efficiently

These goals represent what is desired in the modern electrical distribution network. By merging the power delivery network with an intelligent decision making network the smart grid has the potential to meet these desires. If, however, the smart grid is not implemented well, grid reliability could go down, costs could go up and this desired functionality may not work as expected.

The concept of the smart grid is quite simple; combine the traditional electricity delivery system with a modern computation system. The smart grid consists of power elements including sources (generation and storage), loads (energy using devices) and the connecting elements (transmission and distribution). The computing side consists of decision-making devices (intelligence) connected by a communications network. The power elements are connected to the computation network through sensors to measure grid parameters and controllers to cause changes to the power network as shown in Figure 1. It is worth noting that the smart grid favors a distributed approach to optimization with each piece contributing to the whole.

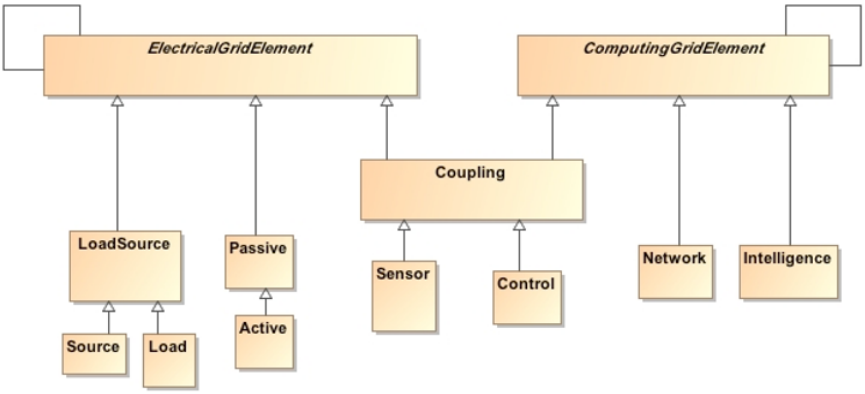

Figure 1. UML Class Diagram showing Smart Grid Building Blocks

While this is a simple concept in theory, in practice it is not. There exist many legacy control systems that have been installed in limited areas over the years that can not be replaced immediately. These systems must be integrated together in a way that the system of systems can act as a whole. There are many different stakeholder including but not limited to; consumers, utilities, regulatory and policy agencies, technology providers and service providers. Each type of stakeholder has a differing (and often conflicting) perspective on the importance of specific smart grid functionalities.

It may be helpful to understand the complexity of the smart grid by dividing it into domains. Seven domains; bulk generation, transmission, distribution, customer, markets, utility operations, service provider have been identified in the NIST Interoperability Framework Document [2] are shown in Figure 2. Each domain has over the years created their own monitoring and control systems independent of the other domains and now these systems are required to interoperate. Even within a domain, different stakeholders often implemented proprietary systems that were not designed to interoperate with other stakeholders' systems. While in an ideal world we could scrap the existing systems and start from scratch the reality is the smart grid must incorporate many legacy systems and more towards the future by building on the past.

It may be helpful to understand the complexity of the smart grid by dividing it into domains. Seven domains; bulk generation, transmission, distribution, customer, markets, utility operations, service provider have been identified in the NIST Interoperability Framework Document [2] are shown in Figure 2. Each domain has over the years created their own monitoring and control systems independent of the other domains and now these systems are required to interoperate. Even within a domain, different stakeholders often implemented proprietary systems that were not designed to interoperate with other stakeholders' systems. While in an ideal world we could scrap the existing systems and start from scratch the reality is the smart grid must incorporate many legacy systems and more towards the future by building on the past.

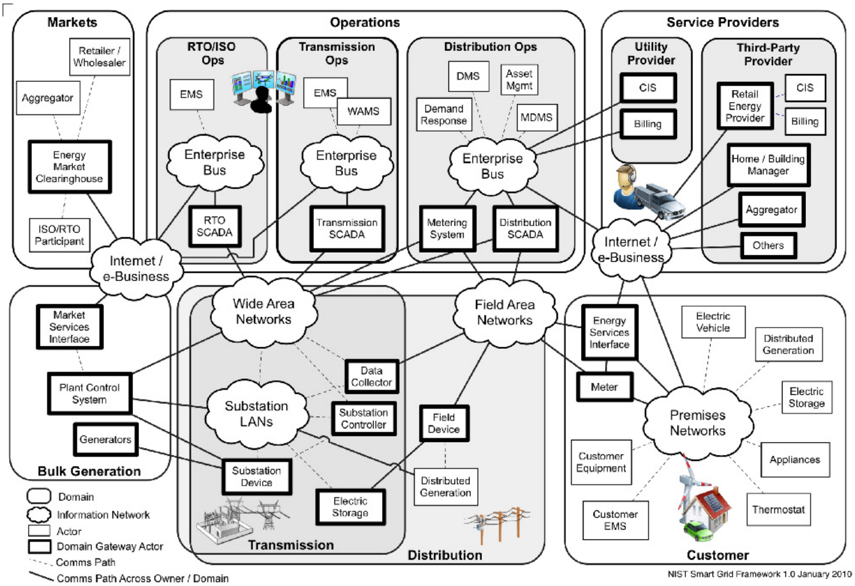

Figure 2. Smart Grid Conceptual Reference Diagram

Achieving optimum complexity of the smart grid is an important goal. Too much complexity will lead to a fragile system that is difficult to create, maintain and use, too little complexity (oversimplification) and results in a system that does not meet the needs of the users.

To manage the complexity of the smart grid systems when designing the systems and standards that will make up the smart grid requires a rigorous systems design approach. By focusing on the goals of the smart grid, developing use cases based on these goals and deriving the system requirements we can be assured that this system of systems has the functionality to meet the needs of the stakeholders. Further, by developing tests directly from the use cases, the specifications laid out in the use cases that are linked directly to system goals. This close link between goals /requirements and final system testing means the systems will meet the goals of the stakeholders.

2 Goals

To ensure that high-level goals are met, bidirectional traceability between high level goals and use case requirements is necessary. This is not trivial: it isn't immediately obvious how a goal like "Enabling active participation by consumers in demand response" should be manifested in the standards that drive vendor implementations. Typically analysts and domain experts work on requirements documents such as use cases with an eye toward the high level goals, but without any formal connection between those high level goals and the requirements documents. More likely than not, however, the requirements are not formalized and end up being small perturbations on legacy systems, that don't optimally realize the new goals.

Understanding goals becomes even more important when different stakeholders have conflicting goals. Normally these differences are either ignored (until they result in much worse problems later), or contested to the point that both parties lose. Exposing these conflicts to scrutiny makes it possible to find win-win solutions that advance the interests of all parties. When goals are not explicit, the more astute or powerful party often benefits at the expense of the other. Usually this is not in the long-term interests of either party.

It would be desirable in an undertaking as complex and expensive as the Smart Grid, to be able to test ahead of time that high level goals really will be met once the system is completed, and conversely, that a given component really does support the system goals. This will result in a system that definitively meets the needs of the stakeholder without added complexity that increase cost and decrease usability.

This traceability between high level goals and system requirements can be accomplished by goal modeling [3]. The idea is to start with the highest level, most abstract goals the complex system is intended to realize. These goals are "decomposed" into more concrete goals that are easier to understand and easier to implement. These concrete goals are selected so that when they are satisfied, it's clear that the higher level, more abstract goals are satisfied as well. Goals are recursively decomposed this way until sufficiently concrete goals are obtained.

These final goals are supported not by smaller goals, but by processes whose execution will satisfy the goals. These processes consume some resources, and produce others. Each process is then described by requirements documents such as use cases, because goals by themselves are not enough to fully describe the functional and non-functional requirements of a process. Goals and the processes, information, and resources that support the goals can be represented in UML diagrams through the use of a profile that extends UML for this purpose. The profile contains "stereotypes" that further characterize elements in UML models. Stereotypes may confer extra information (called "tags") on a model element, or change the element's appearance. Deriving use cases through goal decomposition ensures that goals will be satisfied: there is no such guarantee if use cases are extracted from the legacy system already in place.

The fragment of a goal diagram shown in Figure 3 [uses a small part of Eriksson & Penker's UML extensions [4] to show the goal decomposition. It starts with two of the DoE high level goals (shown at the top of the figure) and goes down to a couple of the required processes (shown at the bottom of the figure.

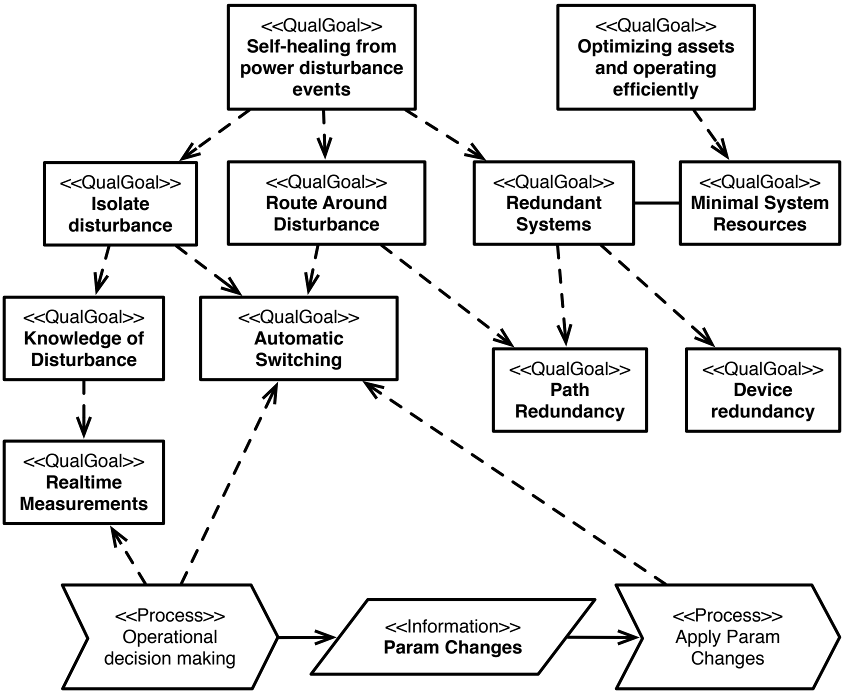

Figure 3. Smart Grid Goal Diagram Fragment

In the diagram rectangles represent goals and dotted lines point from high-level goals to the more concrete goals that support the higher-level goals. For example, in this diagram, the abstract "self healing" goal requires the ability to disconnect (upstream and down) a section of the grid suffering a disturbance, and to re-establish power downstream of the afflicted section, using redundant assets.

Likewise, in order to isolate a disturbance, is the location needs to be known, and to the ability to disconnect it form the rest of the grid is necessary. Skewed parallelograms represent information consumed and produced by processes (which are represented by thick arrows). In this case, automatic switching is proposed which requires a decision making process that takes into account measurements related to stability and power quality, as well as models of how changes will impact stability and power quality (omitted from the diagram). The resulting decisions are then used by another process that reconfigures the grid. These processes need to be further described by use cases. Dotted lines point from resources and processes to the goals that justify the resources and processes.

Solid lines with arrowheads show the flow of information into and out of processes. Solid lines without arrowheads denote conflicts between goals. This example shows a conflict between the "Redundant Systems" goal and the "Minimal System Resources" goals. This may seem like a problem at first, but by using the goal diagram to look at the higher level goals of self healing and optimizing assets, one can infer that a balance between redundant systems and minimal resources is to provide enough resources to support self healing, no more or less.

The bottom level of the goal decomposition shows the processes which are directly supported by specific uses. Goals have been an important part of use cases at least since Alistair Cockburn wrote his landmark paper *Structuring Use Cases With Goals* [5] and the goal diagram shows the link between the high level abstract goals, through the mid level concrete goals, to the processes which are linked to the use cases.

3 Use Cases

A use case is a requirements document that examines how a user (not necessarily human, called the "primary actor") interacts with the system in order to obtain some result of value. Use cases therefore act as contracts (describing functional and non-functional requirements) between the users and developers of a system. Because systems typically must also satisfy stakeholders other than the primary actor (such as regulatory agencies), use cases often additionally take into account stakeholder needs.

Use cases are essential, because they ensure the system will actually deliver value to users. Without considering how something is used, and how users derive value, the development of high value products is haphazard, and products improve incrementally.

There is no single universally accepted model of what goes into a use case, and how it should be organized. Typically each effort settles on a template that defines what should go into a use case. Two generally agreed upon core components are textual descriptions of the functionality, and usage scenarios. Scenarios are composed of a sequence of steps carried out either by the primary actor or the system. Beyond this there is little agreement. Use cases and their templates may be spartan, with little more than the description and a scenario, or very detailed ("fully dressed").

Many templates include a field for the primary actor's goal. The goals of other stakeholders may also be discussed. For example, the Intelligrid template [6] (widely used for smart grid development) does not include any explicit fields for goals, and while the *IntelliGrid Methodology for Developing Requirements for Energy Systems* does suggest embedding the goal in the name, the optional nature of the suggestion means users may put the goal in the description, the narrative, or not even consider it at all. Looking at the names of the use cases listed in the EPRI Intelligrid Use Case repository [7], only a few have names that convey goals. Many have cryptic names like "BCTC – Operations to Planning v2" or "Consumer Portal Scenario P8" making it difficult to associate a use case with a specific goal.

Use case diagrams should be a compliment goal diagrams. Since use cases describe a primary actor working toward a goal, it might seem sensible to wrap all the goals in a goal diagram by use cases, and turn it into a use case diagram. This doesn't quite work out. Firstly, many of the goals in a goal diagram represent the goals of stakeholders other than primary actors. These stakeholder goals would not appear in a use case diagram when use cases are interpreted as proxies for primary actor goals. Secondly, the concrete goals that drive use cases may be very far from the high level goals. You could wrap all the intermediate goals in use cases, and illustrate some of the relationships in use case diagrams, but that creates additional complexity that obfuscates the goal relationships. Use cases that wrap higher-level goals can serve as organizing tools, but they are too abstract to be of practical use as development contracts. In practice, when use case diagrams are your only view of goals, the higher-level goals end up being ignored. For example, the EPRI repository does not have a use case diagram showing the relationships among the use cases in the repository, much less connecting the use cases to higher-level goals.

To better understand what a use case is, it may help to consider what a use case isn't. A use case should not specify a GUI or the internal design of the system. The use case should instead specify the required behavior of the system. Use cases are inputs for the GUI design and system design. The main reason for separating the use case from the design and GUI is that the design and GUI are driven by the required behavior. This separation is harder than it sounds. Since a use case is focused on how the user interacts with the system (whose tangible representation may be a GUI), it's easy to start specifying the GUI, without even realizing it. Likewise it's all too easy to prematurely specify the internal design of the system. Successfully maintaining this separation makes use cases more abstract (they can be realized by any appropriate GUI or design), and most people prefer to think concretely. This separation between requirements and design might sound like a nicety, but it allows the internal design of the system to be developed independently and provides flexibility in how the system is implemented and updated without effecting interoperability with other systems.

This type of use case is referred to as a black box use case. The black box variety describes the user/system interaction and the functional requirements to achieve the goal, but it leaves the details of the inner workings of the system to the implementer. In contrast, white box use cases also describe the internal details of the system, in addition to the interaction and associated requirements, and are therefore prescriptive because they do not allow the implementer to change the internal system design. Using black box use cases is critical to developing a modular and flexible smart grid “system of systems”. It’s worth noting that many Intelligrid use cases have white box aspects, although IEC PAS 62599 [8] states: “Domain experts should describe the interactions with the ‘black box’ system from outside the system. This is a deliberate policy, because it simplifies the description of requirements, and avoids the trap of making assumptions about how this functionality will be accomplished. In other words, use cases capture the ‘What’ of user requirements, but deliberately avoid addressing the ‘How’ of technologies.”

While this is most likely due to the time and difficulty in producing quality use cases and a lack of trained experts to help with the use case development, effort spent up front on the use cases can save much more time and energy in the later stages of the development and implementation process.

3.1 Discovery of Use Cases and System Boundaries

Goal decomposition can eliminate analysis paralysis that often accompanies modifications to complex systems such as the power grid, because use cases are derived from known high-level goals. Without this practice, domain experts sit down and figure out from their knowledge of the legacy system which use cases they decide will be necessary for the improved system. This extrapolation of the legacy system may not end up supporting some of the high level goals, or it may support them sub-optimally.

Black box use cases eliminate the problem of subsystem boundary determination during analysis, because they are concerned with the value a function delivers, and what it must do to deliver that value, rather than where the functionality is located. In contrast, white box use cases usually embed premature guesses about where boundaries are, because they deal with internal details, where it’s natural to consider partitioning.

System partitioning must eventually be addressed, but it’s desirable to do that after functionality has been defined, rather than at the same time (which confounds two issues that ought to be orthogonal). Clustering is one way to perform that partitioning: that topic will be taken up in a subsequent paper.

4 Testing

Testing of a system’s functionality is important to ensure that the system works and with a system as complex and as important as the smart power grid it is critical. The question is, what do we test for? Traditionally, tests are designed to check that implemented functionality works as expected, but what if this functionality is not aligned with the use cases? The system may pass the tests, but not meet the requirements laid out in the use cases (which can be tied back to the top level goals through the goal decomposition). Since the uses cases are linked to the system goals, designing the tests based directly on the use cases testing will check that the system meets the goals of the stakeholders.

Several kinds of tests are necessary to ensure that the high level goals of the system (and the lower level concrete goals of devices) are met. Unit tests ensure that each single chunk of functionality adheres to its specifications: if the tests are constructed correctly, they verify compliance to the standards the use cases specify. Integration tests ensure that the complete system behaves correctly. Interoperability tests ensure different implementations of the same functionality operate the same way, and interoperate correctly together with other devices. Ideally only unit tests would be needed: Integration and interoperability tests really test the standards and unit tests more than they test products.

All of these tests should be traceable to the requirements specified in use cases: without that traceability, many of the benefits of use cases are lost. Tests can be made traceable to use cases manually (with the assistance of spreadsheets and requirements databases), but that's so difficult and laborious that most organizations don't even try. Test traceability to use cases gets even harder when maintenance is taken into account. Automating the creation of the tests directly from the uses cases results in higher quality tests created with less time and effort.

Bidirectional traceability between use cases and tests can be achieved relatively easily with the correct level of automation: one technique is to make the uses cases executable, and provide them with test vectors. Each test vector contains all the data necessary to run a particular scenario. With N test vectors, the scenario can be executed with N different sample data sets. Automation can be achieved by embedding glue code and assertions into the individual steps that make up scenarios. Glue code is in this context a machine interpretable expression of a step. Steps in use cases are primarily for human consumption. Unfortunately natural languages adhere to such complicated rules (and so often break those complicated rules) that it's difficult to make machines understand human readable steps. Sooner or later advances in technology will remove this difficulty, but for now a human needs to explain to the automation exactly how to carry out each step. In a similar fashion, assertions are machine-readable statements of expected conditions. There now exist open source tools that greatly simplify the application of these ideas.

When automated use cases are applied to a device under test that's surrounded by mocks, the use case becomes a unit test. Mocks are fake implementations that are pre-loaded with stimuli and assertions that are specific to given use case scenarios and test vectors. The mocks isolate the device under test from the rest of system: this "divide and conquer" strategy vastly simplifies debugging, by minimizing the scope of the test, and excluding other sources of variability (implementations of the neighboring devices). Furthermore the mock for a given component acts like a simplified reference implementation, illustrating how it should behave (yet without the internal details of a real reference implementation).

After all the components have been individually unit tested, mocks can be replaced by real implementations, and the executable use cases become integration tests. When the integration tests are repeated with different implementations, executable use cases become interoperability tests.

5 Conclusion

As we push the limits of the current power delivery system far beyond what it was originally designed for, we need to use both our electricity generation resources and electricity delivery resources more efficiently. By combining the power network with a modern computational system, control system can be put into place that will allow the optimization of many different parameters. Since this smart grid has many subsystems with different levels of complexity controlled by different stakeholder groups with differing needs all needing to interact, it is necessary to use advanced system design techniques.

Using this approach helps ensure that:

- The highest-level goals are linked to systems requirements and therefore the systems requirements are necessary for meeting the system goals.
- The functionality of the system and how they relate to the system requirements is better understood (and therefore more likely to meet the requirements)
- Automated processes can generate systems tests directly from the use case ensuring that requirement and goals are what is being tested for.

Taken together these benefits mean the final system has a much greater chance of meeting the actual goals of the stakeholders. As systems continue to become more complex the risks of traditional ad-hoc development practices become critical and benefits of this approach will grow.

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Context Model for Testing Analysis Phase of Information Systems

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Abstract: This paper searches to model and use the knolwledge of the system definition phase for defining testing models of agents' requirements and system functionalities. Context objective concept and a Model of Solution Use Context were used. The former as a model of system defintion phase and the latter aiding to find agents' requirements and system functionalities. Social context objetives are adjusted to organizational context objectives and these ones adjusted to system context objectives. All context objectives are expressed in a linguitic template using a verb and its semantic functions. The proposed testing model verfies the correspondence between system context objectives and system operationalizable goals obtained from agents' requirements. For illustrating the proposed model, a system for selecting preregistered co-created contributions (ideas) is used.

Keywords: System Definition Phase, System Analysis Phase, Context Model, Testing

1 Introduction

Context and domain concepts are naturally considered in all approaches for information systems development, but these informally expressed concepts are not always modelled in an explicit way.

Contributions for defining and modelling the context are found in [12], [9], [10], where it is recognized the need of deepening the research in this field. Based on linguistics, we consider the *context* as the space where the knowledge acquires meaning and worth. Derived from the last concept, *context of agent interventions* is defined as the space where the knowledge associated to actions and interactions of agents, aiming to specific objectives, acquires meaning and worth.

C*ontext of agent interventions* includes a set of agents, their interventions, the circumstances, means and method involved in these interventions, context objectives, and agent decisions.

Despite the progress in requirements engineering research and in the developing of approaches accepted in the industrial practices, the need of research for improving the requirements elicitation process, the elaboration of conceptual

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models which contain system functionalities entirely satisfying the correct requirements set, and the development of testing models for verifying the correspondence between context knowledge and the conceptual model is recognized. Aiming to contribute to fulfilling these lacks, in this article a *context* model, known as *Solution Use Context Model* (SUCM) is used for supporting the obtention of system objectives and functionalities, from social and organizational context objectives established in the definition phase of the system. This model constitutes the support for constructing testing models for verifying the correspondence between context knowledge expressed as context objectives and the system goals derived from agent requirements. This is the aim of this article.

After the introduction this article contains the following sections: Models representing the knowledge gathered in the definition phase appear in section 2. Section 3 describes the context model constructed with knowledge resulted from the system definition phase. Testing model of the analysis phase belongs to section 4. Conclusion and future work are considered in section 5. Section 6 contains references.

2 System Definition Phase Model

The purpose of the system to be is the selection of registered agents' contributions (ideas) for defining an innovative product. Next paragraphs explain the use of models of definition and analysis phases for capturing the essential knowledge and controlling its transference to the system functionalities passing by the requirements elicitation.

The essential knowledge for defining the information systems functionalities logics is found in social and organizational contexts. The definition phase contributes with contextual demands, involved agents, their intentions and contextual interventions; theories, technologies, practice and new trends affecting contextual interventions; useful knowledge sources about domains of interest, as well as, knowledge sources for supporting the agent interventions on these domains.

Social and organizational knowledge is synthesized in the proposed approach, in terms of *context objectives*. In Figure 1, social knowledge is expressed in textual way and is summarized in social context objectives. Several objectives may be established, but in this paper only one is developed. Objectives are represented in a goal linguistic formalism enclosing the content of a sentence, composed by a verb and seven semantic functions or parameters: *principal agent*, *interacting agent*, *object*, *situation 1* and *2*, *means* and *method*. The *principal agent* is the responsible of actions expressed by the verb, the *interacting agent* intervenes in the achievement of these actions, *object* is the target of the verb actions, *situation 1* and *2* refer the situations of the *object*, before and after the execution of the verb actions, respectively; *means* indicates the tools for accomplishing the *principal agent* intervention and *method* defines how the verb actions will be carried out using the mentioned *means*.

System for selecting co-created ideas: context Objectives

Extract of context knowledge: ... "The globalization of economies, the development of information and communications technologies, increased interaction of cultures, the rapid changes in consumer´s habits in conditions of competition in markets call for the creation and development of new models and tools that support the generation of innovative products in each of the phases of the innovation chain (life cycle) in collaborative, proactive and creative environments using the most advanced technologies. It is important to apply the concepts of sociology, psychology, pedagogy and in general, the use of human qualities that can help organizations and communities to achieve their goals in a changing and interconnected world. "

Social Context Objective :

[The promoters of social and economic development] $_{\text{Principal Agent}}$ **recommend** [the development of solutions for managing agents' contributions (ideas)]$_{\text{Object}}$ [from the identification of an innovation field] $_{\text{Situation 1}}$ [to assess the social and economic impact of an innovative product delivered to consumers] $_{\text{Situation 2}}$ [using information and communication technologies] $_{\text{Means}}$ [applying methods focusing on co-creation and the commitment of individuals and groups] $_{\text{Method}}$ [involving people and social, scientific, technological, and innovative organizations, as well as organizations from different economical sectors oriented to development and disclosing of knowledge and technological innovation, all these persons and organizations concerned with the treatment of contributions (ideas)] $_{\text{Interacting Agent}}$

↓ Adjusted to

Organizational Context Objective :

[The companies oriented to the development of systems for supporting the innovation processes]$_{\text{Principal Agent}}$ undertake [the development of a system for treating (classification, selection, use) contributions (ideas) to the development of innovative products]$_{\text{Object}}$ [from the classification and selection of contributions (ideas)]$_{\text{Situation 1}}$ [to the application of contributions (ideas)]$_{\text{Situation 2}}$ [using hardware, software, and data base advanced resources]$_{\text{Means}}$ [applying methods of selection and decision to make it easy obtaining and application of contributions (ideas)]$_{\text{Method}}$ [involving people and social, scientific, technological, and innovative organizations, as well as organizations from different economical sectors oriented to development and disclosing of knowledge and technological innovation; all these persons and organizations concerned with the treatment of contributions (ideas)]$_{\text{Interacting Agent}}$

↓ Adjusted to

System Context Objective :

[The system for selecting co-created ideas]$_{\text{Principal Agent}}$ makes [the classification, selection, use, of agents' contributions (ideas) for developing innovative products]$_{\text{Object}}$ [from agents' contributions (ideas) recovering]$_{\text{Situation 1}}$ [to deliver selected and classified agents' contributions (ideas)]$_{\text{Situation 2}}$ [using a hardware-software platform for information processing]$_{\text{Means}}$ [applying methods and resource for software programming and for information and communications management]$_{\text{Method}}$ [for innovative persons and organizations and for scientists and knowledge managers] $_{\text{Interacting Agent}}$

Figure 1. Contextual Objectives

The *principal agent* of a context objective is a context deciding agent belonging to the next high context. Thus, the *principal agent* of a system context objective is a system; for an organizational context objective, the *principal agent* is an organization, and for a social context objective, the principal agent is a macro organization or an association of organizations. For sake of clarity, in this paper, the non-functional features are omitted in the representation of objectives and goals.

An adjustment pattern is used for converting social context objectives in organizational context objectives and these ones in system context objectives. The *principal agent* of the adjusted context objective is a deciding agent of this context, that is, an agent belonging to the precedent high context. The parameter *object* of the adjusted context objective is an aspect, sub-aspect, or attribute of the parameter object of the precedent context objective, taking in account the agent's intentions, in a perspective defined by the purpose of the envisioned system. The *interacting agent* corresponds to agents of two involved contexts, considering the interactions of the SUCM, deemed appropriate by deciders and the application engineer, as well. Parameters *means* and *method* are defined in correspondence to the same parameters in the precedent high context objective. The parameters *situation 1 and 2* are determined in according with situations of the parameter *object* belonging to the new context objective.

3 Solution Use Context Model

The agents and their actions and interactions among them, identified in the context objectives, are represented in a graph. Following with the envisioned system for selecting agents' co-created contributions (ideas) taken as the application case, all possible agents and interactions aiming to fulfil the contexts objectives are initially considered. Some agents and interaction may be postponed for future modules or new systems, delimiting in this way the scope and the frontier of systems. Figure 2 represents agents and their interactions, included in the envisioned system.

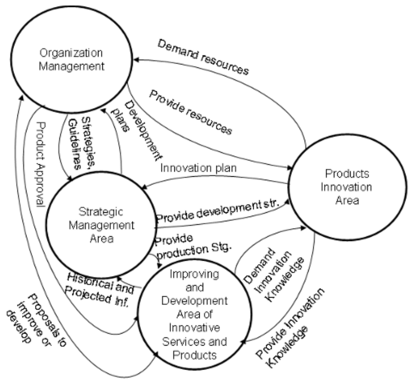

Figure 2. Solution Use Context Model

System requirements correspond to the support wanted by agents for carrying out their agent interactions. The obtention of agents' requirements follows the categories of system requirements proposed in ABC.Besoins [9].

The goals expressing agent requirements are individually converted in operationalizable goals. For each requirement a new goal is formulated, in which the envisioned system, acting as *principal agent*, carries out the actions leading to satisfy the requirement.

4 Consistency Testing

In the correction testing field described in [1], [2], [3], [8], the consistency testing supported on models [4], [5], [6], [11], is a broad space for assuring the information system quality through the system life cycle. The life cycle concept is treated, among others by [7]. In this article, two tests are proposed in order to avoid the lost of knowledge passing from the definition phase to the analysis phase.

This paper describes a context-centred approach, which tests the correspondence between system goals obtained from agents' requirements and the system context objectives. These are adjusted from organizational context and condense the contexts knowledge gathered in the system definition phase. In fact, this test establishes the correspondence between the knowledge acquired in the system definition phase and the knowledge considered in the analysis phase. The test is divided in two stages described in next sections.

4.1 Operationalizable Goals General Testing

At first, the global correspondence between the *system context objectives* adjusted from *social and organizational contexts objectives* and the *system operationalizable goals* elaborated from agents' requirements is established. Many *system context objectives* are defined by considering all agents' interactions of the SUCM, system purposes, and agents' intentions. Using the pattern of nine interactions of agents introduced in [9], each *system context objective* is deployed in nine explicit objectives arranged in three categories: *preparation*, *transformation*, and *results*. For example in Figure 3, only one system context objective of the *transformation* category is enounced in the first cell. This objective is tested against the eleven high level transformation categories of system operationalizable goals obtained from agents' requirements for the envisioned system, Selection of Co-created Contributions (Ideas). The inclusion of goals 1, 6, 7, 9, 10, 11 in the before mentioned system context objective is confirmed. Non included goals belong to other non depicted system context objectives and to goals coming from non-functional features not considered in this paper.

This global test allows confirming the pertinence and diversity of goals and verifying fulfilment of the system context objective.

4.2 Operationalizable Goals Specific Testing

In this subsection, the specific correspondence between *system operationalizable goals* and the nine deployed explicit objectives is established. These objectives, depicted in Figure 4, are obtained using the pattern of nine agents' interactions taken of [9] and instantiating these objectives with the highest level categories of the Domain Services and Objects Structure, not considered in this paper. The nine instantiated objectives are expressed in the goal linguistic formalism composed by a verb and seven semantic functions.

Transformation Goals of the System for Selection of Contributions (ideas) -Derived from System Context Objective-
[Hardware-Software Platform]Principal Agent *processes* [information, elements or confirmations for carrying out each one of contributions selection services: *Selection of contributions (ideas), Definition of objectives, functions and elements in the context of use of the product or service; Selection of methods, and management of selected contributions (ideas)*]Object [for innovative persons and organizations and for scientists and knowledge managers]Interacting Agent [using the application menu]Means.

↓ Correspond to

Transformation goals of the System for Selection of Contributions (ideas) -Derived from Agent's Requirements-
1- *Carry out* ideas selection services : Selection of contributions (ideas), Definition of objectives, functions and elements in the context of use of the product or service; Selection of methods, and management of selected contributions (ideas)
2- *Manage* the integration of services, processes, and systems of the Products Innovation Area with Organization Management, Strategic Management Area, and Improving and Development Area of Innovative Services and Products.
3- *Effect* procedures for assuring the scope, the pertinence, and the quality of contributions (ideas) selection services of the Products Innovation Area, Organization Management, Strategic Management Area, and Improving and Development Area of Innovative Services and Products.
4- *Effect* procedures for the demonstration and simulation of Contributions (ideas) selection services aiding the employers training and the development of the service culture in the areas related to Products innovation.
5- *Effect* procedures for researching and making operative and interactive Contributions (ideas) selection services: Selection of contributions (ideas), Definition of objectives, functions and elements in the context of use of the product or service; Selection of methods, and management of selected contributions (ideas).
6- *Manage* modifications, renovations, and cancellation of innovative contributions (ideas).
7- *Manage* interrogation and handling of registered operation in D.B.
8- *Effect* procedures for applying combinations of innovative contributions (ideas) under particular technical and commercial conditions.
9- *Manage* services achievement involving third parts such as: developers of systems for supporting innovation processes, Control Public Organizations, Scientific Organizations, etc..
10- *Effect* procedures for using information related to organizational, technical, promotional, legal, and quality aspects.
11- *Effect* procedures for using information coming from products innovation area

Figure 3. Correspondence between a System Context Objective and System Goals

The nine deployed objectives cover the three categories: *preparation*, *transformation*, and *results*, mentioned in the last paragraph, and may be compared with the forty nine high level operationalizable goals condensed from the agents' requirements, in the same categories. These goals are confirmed appropriate and tested to satisfy the whole set of system context objectives. For sake of space, these objectives and the operationalizable goals are not included, but the confirmation and testing were already explained in the last paragraph for a set of eleven transformation goals depicted in Figure 3. The structure of the deployed system context objectives is the same as in Figure 4.

System Context Objective
[System for selecting co-created Contributions] Principal Agent *supplies* [Contributions selection services for developing innovative products]Object [for innovative persons and organizations and for scientists and knowledge managers] Interacting Agent [using a hardware-software platform for information processing] Means. **Instantiation of System Context Objective using agent interactions pattern and the highest level service categories of the Structure of Domain Services and Objects:**
1-[Hardware-Software Platform]Principal Agent *associates* [contributions selection services for developing innovative products: *Selection of contributions (ideas); Definition of objectives, functions and elements in the context of use of the product or service; Selection of methods, and management of selected contributions (ideas)*]Object [for innovative persons and organizations and for scientists and knowledge managers]Interacting Agent [using the application menu]Means.
2-[Hardware-Software Platform]Principal Agent *displays* [contributions selection services: *Selection of contributions (ideas), Definition of objectives, functions and elements in the context of use of the product or service, Selection of methods, and management of selected contributions (ideas*]Object [for innovative persons and organizations and for scientists and knowledge managers]Interacting Agent [using the application menu]Means.
3-[innovative persons and organizations and for scientists and knowledge managers]Principal Agent *start up* [each one, in turn, of contributions selection services: *Selection of contributions (ideas), Definition of objectives, functions and elements in the context of use of the product or service, Selection of methods, and management of selected contributions (ideas)*]Object [Hardware-Software Platform]Interacting Agent [using the application menu]Means.
4-[Hardware-Software Platform]Principal Agent *demands* [information, elements or confirmations for carrying out each one of contributions selection services: *Selection of contributions (ideas), Definition of objectives, functions and elements in the context of use of the product or service; Selection of methods, and management of selected contributions (ideas)*]Object [for innovative persons and organizations and for scientists and knowledge managers]Interacting Agent [using the application menu]Means.
5-[Innovative persons and organizations and for scientists and knowledge managers]Principal Agent *Introduce* [information, elements or confirmations for carrying out each one of contributions selection services: *Selection of contributions (ideas), Definition of objectives, functions and elements in the context of use of the product or service; Selection of methods, and management of selected contributions (ideas)*]Object [to the Hardware-Software Platform] Interacting Agent [using the application menu]Means.
6-[Hardware-Software Platform]Principal Agent *evaluates* [information, elements or confirmations for carrying out each one of contributions selection services: Selection of contributions (ideas), Definition of objectives, functions and elements in the context of use of the product or service; Selection of methods, and management of selected contributions (ideas)]Object [for innovative persons and organizations and for scientists and knowledge managers]Interacting Agent [using the application menu]Means.
7-[Hardware-Software Platform]Principal Agent processes [information, elements or confirmations for carrying out each one of contributions selection services: *Selection of contributions (ideas), Definition of objectives, functions and elements in the context of use of the product or service; Selection of methods, and management of selected contributions (ideas)*]Object [for innovative persons and organizations and for scientists and knowledge managers]Interacting Agent [using the application menu]Means.
8-[Hardware-Software Platform]Principal Agent *sends* [information, elements or confirmations for carrying out each one of contributions selection services: *Selection of contributions (ideas), Definition of objectives, functions and elements in the context of use of the product or service; Selection of methods, and management of selected contributions (ideas)*]Object [for innovative persons and organizations and for scientists and knowledge managers]Interacting Agent [using the application menu]Means.
9-[Hardware-Software Platform]Principal Agent *terminates* [information, elements or confirmations for carrying out each one of contributions selection services: *Selection of contributions (ideas), Definition of objectives, functions and elements in the context of use of the product or service; Selection of methods, and management of selected contributions (ideas)*]Object [for innovative persons and organizations and for scientists and knowledge managers]Interacting Agent [using the application menu]Means.

Figure 4. Instantiated System Context Objectives

5. Conclusion and Future Work

The Solution Use Context Model represents and points at essential social and Organizational context knowledge needed for developing information and knowledge systems. The logics of the system is extracted from this contextual model and the knowledge on which systems work is referred in the domain structures. The quality of systems is founded on the quality of these models. Pertinence and completeness of them constitute the basis for checking the pertinence and completeness of agents' requirements and system functionalities.

Contexts objectives are meaningful models for representing the richness of contexts knowledge and lead to the construction of the SUCM and establish the basis for testing the knowledge conservation along the phases of the system lifecycle.

The application case in the field of selecting co-created agents' contributions (ideas) evidenced the strength of the proposed approach for guiding step by step the development of generic systems in specialized knowledge areas as the collaboration, concurrence, multidisciplinary, and creativity.

This research is a contribution for continuing the enhancement of testing trends in order to develop test models oriented to support the construction and evolution of system, establishing at the same time the way to test the pass of knowledge without losing from one phase to the other.

Ongoing research develops software tools for supporting the contextual and domain knowledge elaboration in order to assure the quality and to contribute to the automatic testing in software engineering processes.

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Product and Service Development with Customers

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Abstract. This paper points out that our traditional product and service development has been too much producer-based and product-focused. If we note that our customers are very active and creative, we can establish another new product and service development approach, where not only products but also processes will yield value.

Keywords. Creative customers, process value, customer involvement, market creation,

1 Introduction

This paper points out that our traditional product and service development has been too much producer-based and product-focused. If we note that our customers are very active and creative, we can establish another new product and service development approach, where not only products but also processes will yield value.

If we get our customers involved in product development, such process values could be generated and product development continues through the whole product life cycle. This is no more product development but product and service development. The importance of product and service development is described.

2 Traditional Product Development: Product Value Focused

Our traditional product development has been one way from the producer to the customer. Value has been evaluated as the functions of a final product. And customers have been thought to be just consumers or users.

As Weber-Fechner law points out, the better product quality becomes, the more difficult it is for the customer to realize its improvement. When a man with a small voice raises his voice a little louder, then everybody notices the difference. But when a man with a loud voice raises his voice a little louder, nobody notices the difference. Thus, industries changed their policy from improving product quality

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more, because it is very difficult for them to convince their customers how much quality is improved. Instead they move toward adding service value to their products. Although they call it service, their views are those of the producer. They believe it is them who produce a product and customers are there to consume or use their products.

Initial concurrent engineering (CE) was developed in this framework. How we can develop and produce a product faster and more flexibly was the goal. But this flexibility is for the producer alone. With increasing diversification, the importance of listening to customer's voice was emphasized. But again this is also the voice of users of their products. As Christensen [1] points out, industries would not listen to the emerging voice calling for new products. They have invested much in the present product development, so they think it would be too risky to invest in another new kind of product.. Thus continued innovation is very much popular, but disruptive innovation rarely takes place.

Toffler [2] proposed prosumer system. This was very unique in that he proposed to get consumers involved in the product development. This is a step forward from the standpoint of concurrent engineering. CE had been producer-centric. No matter whether it was to bring the downstream information upward to achieve parallel processing in time or whether it was to collaborate among experts across different disciplines to respond to the quickly diversifying requirements, CE up to then was producer-centric. Toffler's proposal was very unique because he introduced the idea of collaboration between the producer and the customer.

Recently, **P**rahalad and Ramaswamy [3] proposed value co-creation and emphasized the importance of bringing customers into product development. Their idea of value co-creation is also collaboration between the producer and the customer.

But these proposals are still producer-based and product-focused. Toffler's proposal may be interpreted as an advanced CE to facilitate the product development. The primary purpose of Prahalad and Ramaswamy's proposal is to respond to the diversifying requirements in an age when asymmetry of information is quickly disappearing due to the rapid progress of information technology.

3 New Product and Service Development: Process Value

Although such concepts as PSS (Product and Service Systems) are emerging, they also are focusing their attention to product values, and even though the importance of service is emphasized, it is from the standpoint of adding value to products. Service value is additional and secondary.

But if we take a look at software development, we have many lessons to learn from there. Software used to be developed in the same manner as hardware. Hardware is developed with fixed functions (Figure 1).

But AI (Artificial Intelligence) introduced continual prototyping into software development and now software is developed with growing (evolving) functions (Figure 2).

In software development, very basic functions are provided first. And as customers get used to the functions and gain confidence, a little bit higher functions are provided at the next step in response to the user's requirements. Customers demand such functions based upon their experiences and expectations. Thus, software grows or evolves step by step by adding or improving functions. Customer's ability grows together and his/her confidence increases. Then customers put more trust in the system.

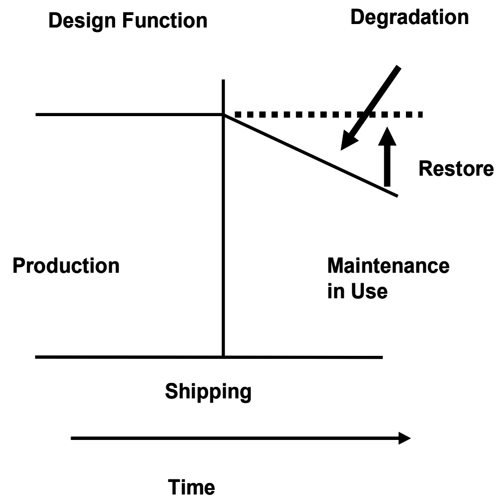

Figure 1. Hardware development

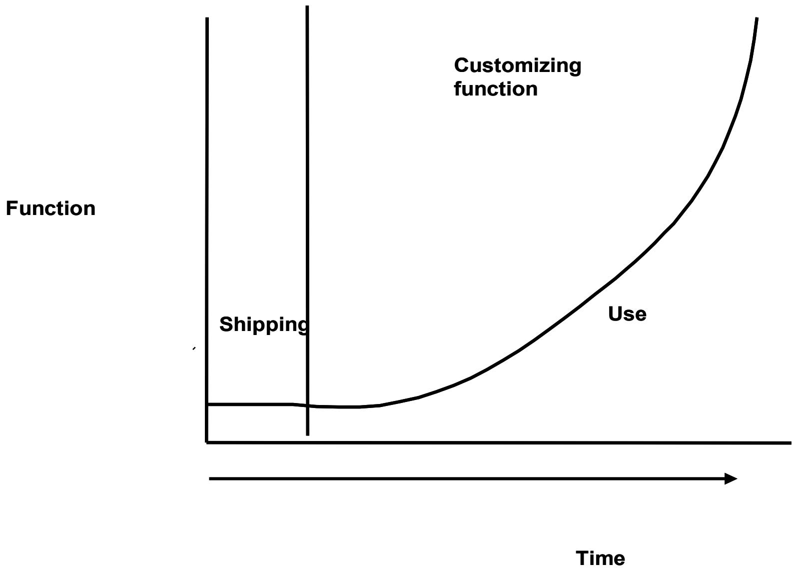

Figure 2. Software development

Interestingly enough, in the German word, confidence and trust are expressed by the same word “Vertrauen”. Norman [4] points out that in the old days machines were simple. They behaved as users expected. So users put trust in machines. But today they are too much complex and they do not behave as users expect. So users are quickly losing trust.

A software development curve is very similar to a learning curve. As we learn more, we gain more confidence and we become more adaptive.

What is important is that the process itself will yield value. As customers accumulate experience and gain confidence, they come to enjoy its experience. Software development demonstrates how the producer and the customer may work together and create value not only from products but from the processes.

Maslow [5] pointed out that the highest human need is self actualization and challenge. In software development, users are satisfying this highest human need. They actualize themselves and make challenges to learn new functions and when it is achieved, they pursue the next higher goal. This process of self actualization or challenge is the highest value for all human beings.

This is service development. What these people care is the processes, not a product. It is very much different from so-called service to add value to a product.

Of course, this approach does not apply to all cases. Such high tech products as airplanes, plants, etc should be developed in the same way as we have done up to now. But even in the case of airplanes, we can build self made airplanes. And when it comes to automobiles, it becomes very easy for us to build (or rather to assemble) vehicles by ourselves if they will change to EVs (Electric Vehicles). Further, personal mobility is getting wide attention these days. So if we can change our product development in such a way as to get our customers involved, they would enjoy producing such a personal mobility or they would enjoy combining parts into an EV.

20th century was an age of product but 21 century is an age of heart. How we can fill our customers’ hearts with satisfaction is an open question today. Our customers do not necessarily want higher and sophisticated functions. Rather they would like to have products and services that meet their expectations or to meet their needs and preferences.

4 Product Value and Process Value

Products are, to use economics terms, goods and they are physical. They can not be divided. Therefore, industries are making their efforts to win in the market. Market competitiveness is most important for them. Hardware development in the current framework bring win-lose relations.

But software is non-physical. Software development is none other than service development. Services can bring win-win relations easily. Kim and Mauborgne [6] pointed out if we look aside, there is a blue ocean lying there. They suggested that instead of fighting blood over blood, we should move away from such a red ocean and find a blue ocean. Product-centric product development is a red ocean but service-focused product development is a blue ocean. To reach a blue ocean, we have to change our design completely so that customers can join and enjoy in product and service development.

Although economists emphasize the importance of experience value, it is at the stage of use. But if we can get our customers involved in product and service development, they can enjoy experience and excitement of real creation. Their desire for creativity will be satisfied.

5 Value Enhancement Throughout the Whole Life Cycle

Value of a hardware product is evaluated when a final product is completed, but its value degrades with use, because hardware deteriorates with time. Therefore, maintenance is very much important to maintain the design functions, i.e., the value of a product.

Again, this approach is very much product-focused. Customers would like to use our products as they like to meet their needs and to their tastes. It takes time for our products to adapt to our customers' environments and situations and it takes time for customers to customize our products. Maintenance is to bring the degrading functions back to the design level. Then our customers have to start customizing our products all over again from the start. Their efforts up to that time are completely wasted.

Repair is something different. The word "repair" comes from "prepare". So repair means to fix our products to meet the expectations of our customers, and not to bring the degrading functions back to design level. Thus, in other words, repair means to prepare our products to adapt to the situation better. Therefore, repair needs fundamentally customer involvement. And if we design our hardware products in such a way that our customers can enjoy repair, then our customers enjoy another experience of self actualization or challenge. It would greatly satisfy their desire of creativity.

6 Less Inspections

What would happen, if we look at product development completely from the opposite side, i.e., from the customer's viewpoint.

To our customers, our products are either good or bad. Their good or bad evaluation comes from how our products meet their expectations. If we can make our customers expectations clear and describe them as a profile, many of the current inspections can be omitted, because not a small number of them are conducted just to verify if they satisfy the design requirements. Design requirements do not necessary agree with customers' expectations. More often than not they come from engineers.

Alps, electronics company in Japan introduced Mahalanobis-Taguchi System [7] to clarify the profile of their customer's expectations and they succeeded in reducing the number of inspections. Therefore, they could reduce cost considerably.

7 Bottom of Pyramid

Such customer-involved product and service development will serve for the Bottom of Pyramid [8] issues, too. The core idea of BoP (Bottom of Pyramid) is that industries in advanced countries grow together with customers in developing countries. Until now, the producer and the customer are separated. The producer has made efforts to sell their product to customers who have buying power. Only existing markets with buying power have been considered. Creating a market from scratch has never been discussed. BoP approach is completely different. We develop and grow a market from scratch. Thus, we have to create a demand. But BoP people are very poor so we have to develop their purchasing power. To meet their purchasing power, we have to start from a very simple product. Then, BoP people not only can buy it, but also can produce, repair and customize as they like. Thus, they can buy such products and grow rich. This cycle is repeated and BoP people can grow richer and richer so that eventually they can afford to buy more expensive products.

BoP product development is very similar to software development. In the traditional hardware product development there is a wall between the producer and the customer. And product development process has been considered to be a cost increasing factor. How we can reduce time and cost was very much important.

Value is often defined as value= performance/cost [9].. This performance has been nothing other than functions of a final product and cost has been product development cost. But if we change from such product-focused perspective to process-focused one, processes are also performances such as experience value, satisfaction of self actualization or challenge, etc. Thus, if we take process values into consideration, development processes are no more a cost increasing factor. And as the wall between the producer and the customers is disappearing as demonstrated by Web 2.0, the definition or meaning of workforce has changed very much. We all are the producer and the customer at the same time. Software is a good example. BoP is another example. Workforce development is no more a cost increasing factor. It will yield another process value.

8 Summary

If we change our design and product development from the current producer-centric and product-focused approach to customer-centric and process-focused one, we can yield value not only from products but also from processes. Such process values are nothing other than service values so that it is easier to establish win-win relation and to create a new market.

Such an approach would satisfy not only our customers' desire for creativity but also their need for self actualization or challenge. And it would also serve for industries to develop BoP strategies.

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Mahalanobis Distance Approach for Insulated Gate Bipolar Transistors (IGBT) Diagnostics

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Abstract. Insulated gate bipolar transistors (IGBT) are used in critical application areas such as inverters in hybrid cars, motion control systems for variable speed motor drives and high power switch mode power supplies. In these critical applications, diagnostic approaches are required to monitor the health and predict the reliability of these devices to prevent system downtime and costly failures. In this study, Mahalanobis distance (MD) was used for anomaly detection for non punch through (NPT) IGBTs. The IGBTs were aged by electrical-thermal stress under a resistive load until their failure. Monitored collector-emitter voltage and collector-emitter currents were used as input parameters to calculate the Mahalanobis distance (MD). The MD values obtained from the healthy data were transformed using a Box-Cox transform and three sigma limits were obtained from the transformed data. The upper three sigma limit of the transformed MD healthy data was used as a threshold to detect degradation in the IGBTs. The MD anomaly detection approach allowed for detection time of anomalies in NPT IGBTs up to 77% before failure.

Keywords. Mahalanobis Distance, IGBT, PHM, Diagnostics

1 Introduction

Improved methods for anomaly detection and diagnostics can help reduce the time for inspection and qualification of products as well as improve their reliability. These methods can lead to faster product development times by concurrently improving the testing, reliability and qualification processes. In this study, an anomaly detection approach using Mahalanobis distance (MD) was evaluated for insulated gate bipolar transistors (IGBT). IGBTs are the devices of choice for medium and high power, low frequency applications such as inverters in hybrid cars, traction motors, high power switch mode power supplies and variable speed drives [8]. IGBT devices are reported to fail under excessive electrical and thermal stresses [4] which motivate the need to develop diagnostic and prognostic approaches to monitor the health and predict the reliability of these devices to prevent system downtime and costly failures.

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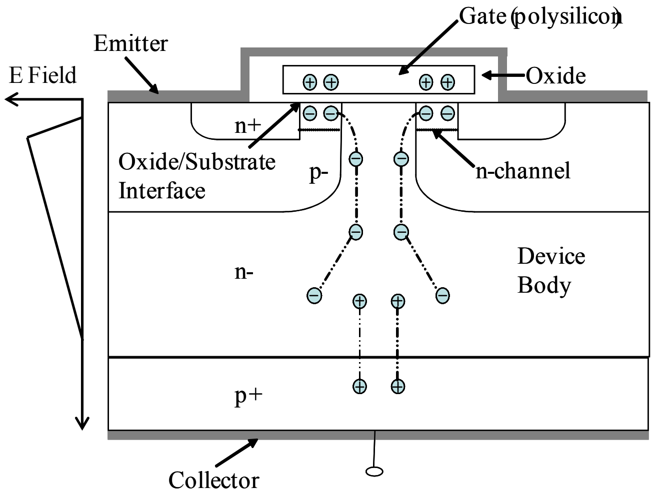

Figure 1. Non punch through IGBT

The IGBT is a combination of the metal oxide semiconductor field effect transistor (MOSFET) and the bipolar junction transistor (BJT). IGBTs are controlled by voltage like a MOSFET and have high current carrying capability of a BJT. The devices evaluated in this study are classified as non punch through IGBTs as the electric field developed does not punch through the device body as shown in Figure 1 [7].

Mahalanobis distance (MD) is a distance measure that determines the similarity between two sets of data. In this work, MD was used to determine the similarity between test data and healthy data.

2 Experimental Procedure

Ten NPT IGBT devices (N1-N10) from International Rectifier were evaluated in this study. The IGBT devices were packaged in a TO-220A package along with a soft recovery diode. The devices were rated for a collector-emitter voltage of 600V and gate-emitter voltage of 20V. The maximum junction temperature rating was 150°C. The schematic for the aging testbed used for power cycling of IGBTs under a resistive load is shown in Figure 2.

For the aging of IGBTs, a 50% duty cycle was used with a gate voltage of 15 V and a collector-emitter voltage of 5 V. The 5 V setting for the collector-emitter voltage ensured that the device was powered on and off in the active region of transistor operation at a gate voltage of 15 V. The device was cycled between the temperatures T_{min} and T_{max}. T_{mean} in this study was set to 300°C and the minimum and maximum temperatures were set to a range of ±15°C from the mean temperature.

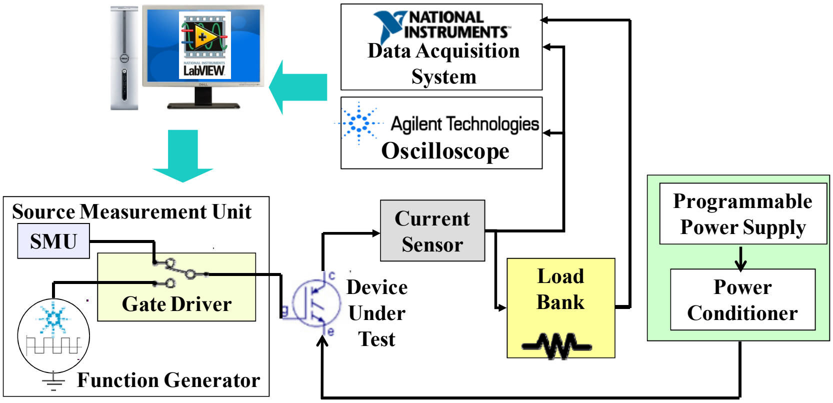

Figure 2. Experimental setup for power cycling of IGBTs

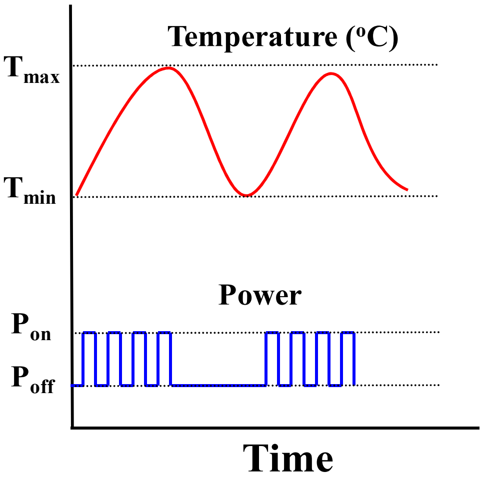

Figure 3. Schematic of temperature and switching aging profile

The devices under test were repeatedly switched on and off until the maximum temperature T_{max} was reached. When the maximum temperature was attained, the device was switched off until the temperature drop to T_{min}. Then the switching was resumed again. The aging process schematic is shown in Figure 3. In this aging condition, failures observed were either due to latch-up due to the activation of the parasitic thyristor. In-situ measurement of the collector-emitter voltage, collector-emitter current and package temperature was performed every 400ms until failure of the IGBT under test and recorded using a National Instruments data acquisition system (NI-DAQ). The latch-up failure mode was observed as a large increase in collector-emitter current as shown in Figure 4.

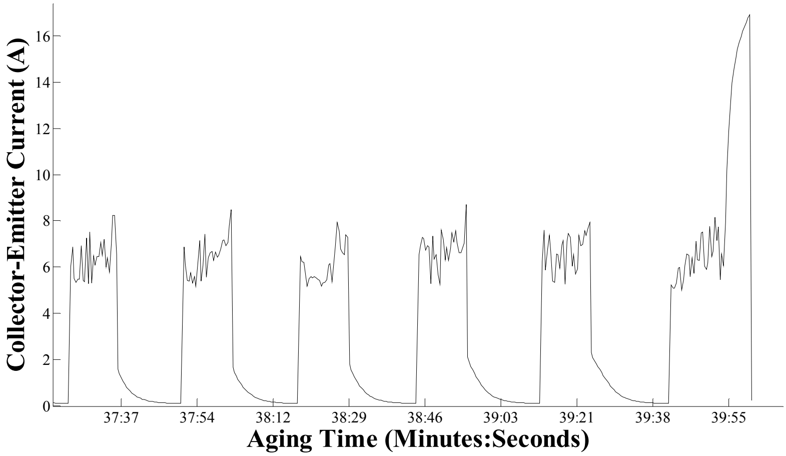

Figure 4. Latch-up of FS IGBT as recorded using the NI-DAQ

The collector-emitter voltage and collector-emitter current waveforms were recorded using an oscilloscope. The input gate pulse for the oscilloscope measurements was of a magnitude 1.5 times greater than the aging pulse which was 15V. The pulse used for oscilloscope measurements was 1ms in duration with 50% duty cycle.

To determine the effects of aging without the influence of temperature changes, the collector-emitter voltages and currents at the mean aging temperature were extracted for this study as shown in Figure 5. The collector-emitter current reduced with aging and the collector-emitter voltage increased. This behavior is attributed to degradation in the die attach and the gate oxide [6]. Hence with increased degradation, the internal resistance of the devices increased with aging time leading to a drop in collector-emitter current and a corresponding increase in collector-emitter voltage. Finally, failure occurred due to latch-up as a result of the activation of the parasitic thyristor inherent in the device structure.

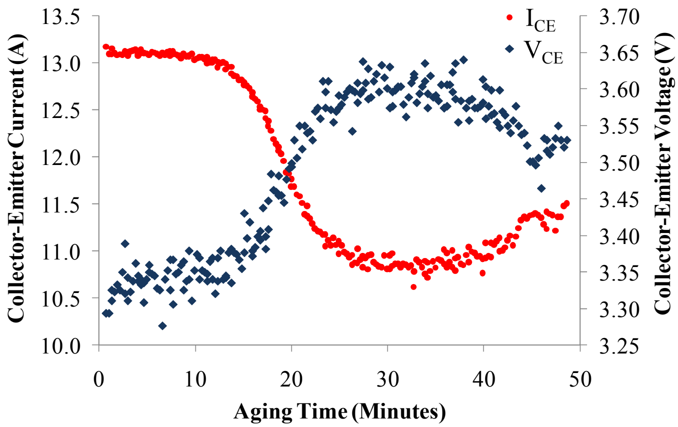

Figure 5. ON state collector-emitter current and voltage vs. aging time

3 Mahalanobis Distance

Mahalanobis distance (MD) is a distance measure that is used in applications such as anomaly detection, pattern recognition and process control [2]. In electronics, MD has been used for detecting anomalies in notebook computers and multilayer ceramic capacitors [3] [5]. The MD approach reduces a multivariate system to a univariate system, thus simplifying analysis. It is sensitive to changes between various parameters monitored as it takes the correlation between the different parameters into account. It is not sensitive to the differing scales of the parameters monitored, as MD values are calculated using normalized parameters [3].

The parameters that are used as the input for MD calculation are denoted as X_i, where i = 1, 2, …, p. Here, p is the total number of parameters used in the MD calculation. The observation of the ith parameter, on the jth instance, is denoted by X_{ij}, where i = 1, 2, …, p, and j = 1, 2, …, m; m is the total number of measurements performed for all the parameters considered. Each individual parameter in the data vector is normalized using the mean and the standard deviation (S_i) of that parameter calculated from the healthy data. Thus, a parameter's normalized values are

$$Z_{ij} = \frac{\left(X_{ij} - \overline{X}_i\right)}{S_i} \tag{1}$$

$$\overline{X}_i = \frac{1}{m}\sum_{j=1}^{m} X_{ij}, \quad S_i = \sqrt{\frac{\sum_{j=1}^{m}\left(X_{ij} - \overline{X}_i\right)^2}{(m-1)}} \tag{2}$$

The MD values are calculated using the normalized values by using Equation 3

$$MD_j = \frac{1}{p} Z_j^T C^{-1} Z_j \tag{3}$$

where C^{-1} is the inverse correlation matrix. Equation 4 is used to calculate the correlation matrix

$$C = \frac{1}{(m-1)} \sum_{j=1}^{m} Z_j Z_j^T \tag{4}$$

The MD is first calculated using the healthy data. The mean and standard deviation obtained from the healthy data set are used in the normalization of the test data. Next the inverse correlation matrix obtained from the healthy data along with the normalized test data are used to compute the test MD values by Equation 3.

4 Threshold Estimation and Anomaly Detection

Thresholds values are typically defined based on expert knowledge of known fault conditions and economic factors such as the need to reduce the number of false alarms. These approaches may not be able to detect anomalies when *a priori* knowledge of faults is not available. It is therefore useful to implement a generalized probabilistic approach to determine thresholds for anomaly detection [3]. The first step in implementing this generalized approach involves calculating healthy MD values using Equation 3. In this study, two parameters, the monitored collector-emitter ON voltage and current were considered for the MD calculation (p = 2). The first 50 observations (m = 50) at the mean aging temperature were selected for a given device under test (DUT) to create the healthy data. The remaining data from the test for a given DUT were labeled as test data. MD values calculated for the healthy data were found to not follow a normal distribution. The Box-Cox power transformation is useful for transforming data that are positive and not normally distributed. This transformation was used to transform the healthy MD values into a normal distribution. The Box-Cox transformation is defined by the following equations [1]

$$x(\lambda)=\frac{(x^{\lambda}-1)}{\lambda} \quad \lambda \neq 0$$
$$x(\lambda)=\ln(x) \quad \lambda = 0 \tag{5}$$

where the vector of data observations is $x = x_1, \ldots x_n$ and $x(\lambda)$ is the transformed data. The power λ is obtained by maximizing the logarithm of the likelihood function.

$$f(x,\lambda)=-\frac{n}{2}\ln\left[\sum_{i=1}^{n}\frac{(x_i(\lambda)-\bar{x}(\lambda))^2}{n}\right]+(\lambda-1)\sum_{i=1}^{n}\ln(x_i) \tag{6}$$

$$\bar{x}(\lambda)=\frac{1}{n}\sum_{i=1}^{n}x_i(\lambda) \tag{7}$$

The λ parameter obtained by maximizing the logarithm of the likelihood function in Equation 6 was used to transform the MD values using the Box-Cox transform from Equation 5. The histograms of healthy MD values before and after transformation are shown in Figure 6 for one IGBT device.

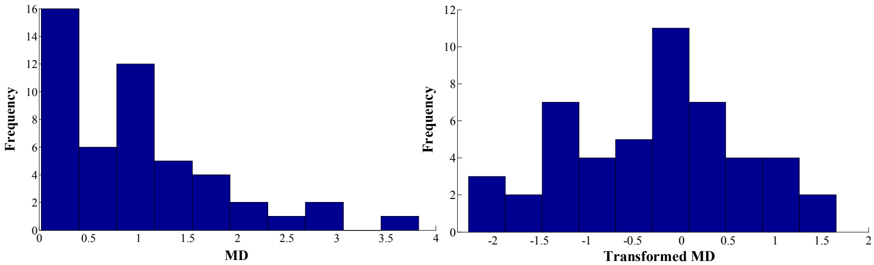

Figure 6. Healthy MD values before and after transformation

The mean (μ) and standard deviation (σ) of the transformed healthy MD values were used to obtain 3σ bounds about the mean. The upper bound ($\mu+3\sigma$) was used as a threshold for anomaly detection as increasing MD values indicate degradation in the IGBT. Using the 3σ upper bound as a threshold obtained by evaluation of the healthy data, the test data for each IGBT was evaluated for anomalies. The transformed MD values for the test data along with the 3σ bounds for an NPT

IGBT are shown in Figure 7. The part failed due to latch-up at ~47 minutes and anomalies in the device was detected at ~13 minutes.

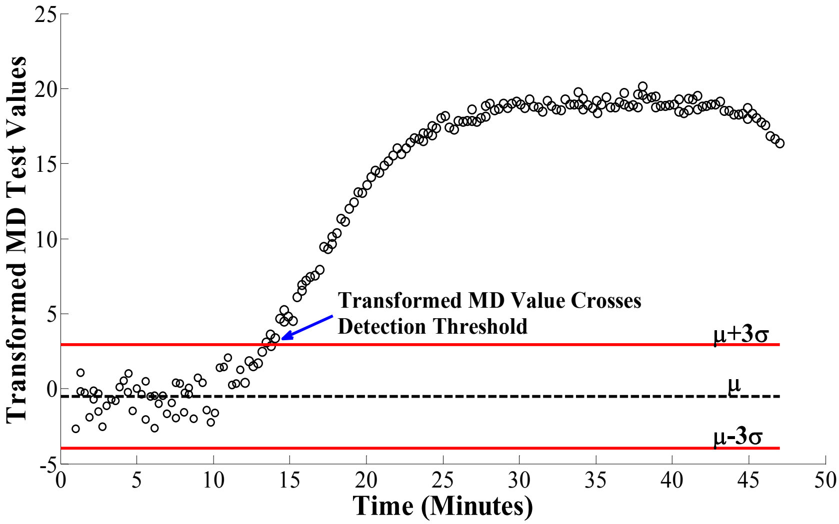

Figure 7. Transformed MD test data

Anomalies were detected for NPT IGBTs up to 77% time before failure. A common trend in test data observed was an initial large variance of the transformed MD values about the mean. With IGBT degradation, the transformed MD values shifted away from the mean and exhibited smaller variance. The results of the detection approach are summarized in Table 1.

Table 1. Anomaly detection time obtained for NPT IGBTs

Device ID	Detection Time (Minutes)	Failure Time (Minutes)	% Time to Failure after Detection
N1	13.5	47.1	71.4
N2	12.8	55.8	77.1
N3	12.3	48.7	74.7
N4	18.7	60.0	68.9
N5	11.4	39.4	71.0
N6	12.6	56.2	77.6
N7	17.1	42.6	59.9
N8	17.5	41.0	57.3
N9	14.9	54.8	72.8
N10	15.0	34.8	57.0

5 Discussion and Summary

The initial measurements of voltage and current for a given IGBT under test were used to define the healthy state. The subsequent measurements were considered as test data and compared with the healthy data to determine anomalous behavior. The voltage and current values were used to calculate the healthy MD values. These healthy MD values were found to not follow a normal distribution and were transformed using the Box-Cox transformation to a normal distribution. The mean and standard deviation from the normal distribution were used to define a threshold for anomaly detection.

One of the alternative approaches to define the threshold is to use a best fitting parametric distribution for the healthy MD values and then using an upper cumulative percentile of the distribution. The parametric fit approach can also give good results but this approach may not be generalized to all IGBTs. The best fitting distribution may be different for different IGBT technologies or even between IGBTs of the same technology. Normalization of the healthy MDs provides a generic framework that can be applied to all IGBT technologies. Another advantage of normalization of the data is that it allows for the use of other techniques such as process control rules to determine the threshold.

The MD based anomaly detection approach was able to detect anomalies for all the NPT IGBTs evaluated in this study. The maximum anomaly detection time was 77% before failure of the IGBT under test. Future work includes extending the use of the generalized framework presented in this study to other IGBT technologies.

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Estimation Design Rework Efforts in the Early Phase of Design and Development

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Abstract. A design rework efforts estimation (DREE) framework is developed in order to identify design rework efforts in the early phase of product design and development. An automotive water pump is used as a case study in this paper. Dependency among components, which are assesed numerically by Analytical Hierarchy Process (AHP), is a key driver on design rework efforts estimation. And then, Work transfer matrix method (WTM) is a mean to estimate design rework efforts. Results based on worst case scenario were validated with experts from an engine manufacturer.

Keywords. Design rework efforts, Estimation, Concurrent Engineering, Functional Analysis

1 Introduction

Concurrent Engineering (CE) approach is a well known best practice to reduce development cost and lead time now a day. However, it is necessary to understand the characteristics of design rework efforts in order to fully enhance the benefits of CE design approach. This issue has a strong link to cost of design and development project, because it is always viewed as inherent within cost incurred in a design phase. Design efforts are realised as efforts of which considered as time to accomplish a design task by one person (person-month, person-hour), while design rework efforts is define as unnecessary iterations which are the results of design error or design failure due to neglect something previously known or lack of knowledge as discussed in [1]. The repetition efforts spent on requirement changes is considered as out of scope of this paper, because it behave like non-linear phenomena. The aim of this paper is developing a methodology to estimate design rework efforts due to components dependency within a considered product. In this paper, an automotive water pump is used as a case study.

All components in a product are assumed to conduct concurrently design until sign off for manufacturing [2]. Design rework efforts are estimated after design validation and verification (V&V) phase finish. Design issues are obviously captured during design V&V, after that analysis will take actions to resolve problems and efforts in this stage is called design rework efforts in this paper. Dependencies among components are the key to achieve design rework efforts estimation, and this framework helps design team to address components which

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have high design rework efforts in the early phase of product design and development.

Development of design rework efforts estimation (DREE) framework is explained in the next section. The work transfer matrix (WTM) is applied to estimate design rework efforts for a particular component as represent in section 3. Framework validation as well as conclusion and future work are in section 4 and 5 consecutively.

2 Design Rework Efforts Estimation (DREE) Framework

Krishnan[3] and Loch[4] are two major researchers in design efforts estimation area both of which consider total design efforts as aggregation of design rework during product design and developments. Krishnan developed the framework to estimate design efforts by considering sentivity of downstream design tasks reacting to changing on an upstream design task. Loch enhanced Krishnan's work by focusing the impact of incomplete information exchange from the upstream design task. These two papers considered design reworks and iteratives effort due to changes and aggregate all of them as design efforts. However, this paper pinpoints design rework efforts in design V&V only because it is vulnerable to high penalty to schedule of a project. Furthermore, more than two design tasks scenario are studied in this paper, which is different from those two mentioned earlier. Other literatures in this area are reviewed in [1].

Dependencies among design tasks are one major key drive amount of design rework efforts [5]. Relationships among components are derived by developing functions-components relationships matrix [6], and components-components relationship is developed indirectly later on by matrix operation. This method is dissimilar to direct method shown in [2]. The detail development of DREE is revealed in section 2.1 to 2.4.

2.1 Developing Functional Structures

Before developing components-components relationships matrix, it is necessary to develop functional structure of product being considered. There are several methods to derive functional structure such as Axiomatic Design or developing functional structure by flow of information, energy, and materials [7]. However, the Function Analysis System Technique (FAST) [8] is selected after optimising on academics and industrial aspects, because it is a well establish method in Value Engineering and it is known in industries.

Physical design solution is given before developing FAST, and this is the assumption for this paper. For example, Deliver coolant to engine is the requirement and an impeller type water pump is selected to satisfy it. Then, FAST for automotive water pump is developed. In FAST technique, there are two types of functions, Basic and Support functions. Basic function is the function in which without it no need to perform the other function; therefore, Deliver coolant to the engine is the highest level basic function. By starting from Basic function, the functional structure can be decomposed into lower level. Support functions are the functions helping the other function to perform successively or reliable. Each function is named by two words, verb-noun combination. Guideline for verb and noun is obtained from [6]. The functional decomposition for the automotive water pump is shown in figure 1.

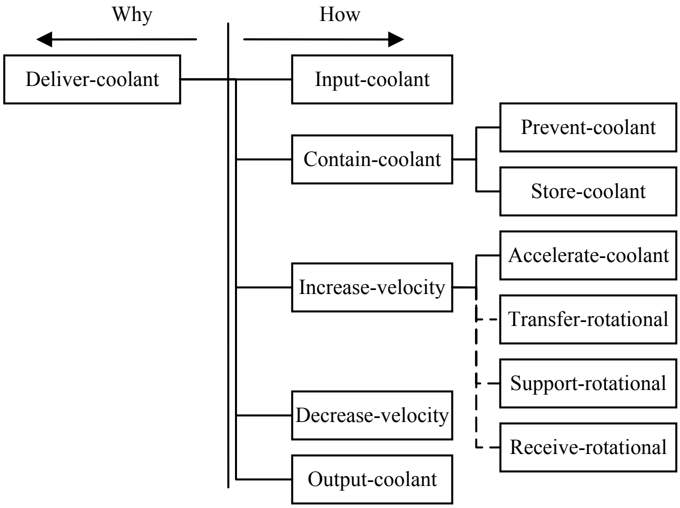

Figure 1 FAST diagram for an automotive water pump

FAST is developed from left and expanded to right hand side. The left most function is basic function mentioned before. A function on the left hand side explains how to achieve the adjacent left hand side function. Therefore, reading from left to right is explaining how to achieve the function on the left hand side, and reading from right to left is giving the reason of existing for functions on the right hand side. For example, Contain-coolant could be satisfied by achieving Prevent-coolant and Store-coolant. Accelerate-coolant exists because it helps Increase-velocity to accomplish. From figure 1, solid line represents the primary link of basic function, while dash line exposes the support functions.

2.2 Allocate the Percentage of Design Efforts to Components

Analytical hierarchy process (AHP) is suitable to allocate design efforts, because the total weighted score derived from pair wise comparison is always equal to 1 unit [9] which is able to interpret as percentage allocation. Therefore, it is used to allocate design efforts for each component. From figure 2, FAST diagram is converted into table format and represented the allocated results. The number in each cell represents the efforts contributed to the function on the left hand side. The aggregation in each roll is equal to 1 unit due to AHP principle; therefore, reading in the same roll shows components contribute to the left hand side function. AHP scoring was completed by a cooling expert from a sponsored company. All AHP results are complied with the Consistency Ratio (CR) equal or smaller than 0.1 as required by AHP principle. More details of AHP can review in [9].

2.3 Developing Components-Components Relationships

The components-components relationship matrix is developed indirectly from figure 2 by using matrix operation as shown in equation 1 [6].

$$\Lambda_c = FC^t \times FC \tag{1}$$

where Λ_c is a components-components matrix. FC is a functions-components matrix.

Function Level1	Function Level2	Gear	Impeller	Water pump body	Ball bearing	Needle bearing	Shaft	Water seal	Oil seal	Outer clip	Inner clip	Gasket	Back plate	Bolt
Input-coolant				1										
Contain-coolant	Prevent-coolant			0.14				0.29	0.14	0.05		0.17	0.17	0.04
	Store-coolant			0.32								0.32	0.29	0.07
Increase-velocity	Accelerate-coolant		0.50	0.50										
	Transfer-rotational						1							
	Support-rotational			0.42	0.30	0.23					0.05			
	Receive-Rotational	1												
Decrease-velocity				1										
Output-coolant				1										

Figure 2 Functions-components Matrix (FC)

In ref. [6], the functions-components matrix is a binary matrix; therefore the strengths of relationships are represented as integer, while real number is appeared in this paper, figure 3. This difference is additional contribution presented in this paper.

The strengths of relationships are the multiplication products of equation 1. The logic to use multiplication products are as follows. First of all, AHP helps to allocate proportion of design efforts to each component under a considered function. For example, 0.5 unit of design efforts for Accelerate-coolant function are assigned equally to impeller and water pump body. If the whole impeller has to be reworked, it means 0.5 unit of Accelerate-coolant function has to do rework. If 0.5 unit of the function is reworked, it will knock on to water pump body to be reworked with its proportional. In this case, the water pump body has to change 0.25 unit (0.5×0.5). This logic is a conclusion from observing correcting actions in design V&V phase. After identify the failure components, not only a particular components will be investigated but also the related components, which are obviously working together to deliver a function. Therefore, the strengths of relationship are perfectly fit with matrix multiplication results. From figure 3, the relationships in Λ_c show interdependent relationship only. It is very difficult in reality to justify relationship as dependent because every design activity is done iteratively. The diagonal values of Λ_c, figure 3, are taken out for estimation design rework efforts in the next section.

2.4 Estimate Design Rework Efforts with Work Transfer Matrix (WTM)

Work Transfer Matrix (WTM) is developed originally for estimating to total design efforts by considering strength of relationships among identities with fully concurrent assumption [2]. However, WTM is used to estimate design rework efforts in design V&V phase by modifying method to obtained relationship matrix as mentioned from last two sections, and modifying input (initial condition, u_0).

Components	Gear	Impeller	Water pump body	Ball bearing	Needle bearing	Shaft	Water seal	Oil seal	Outer clip	Inner clip	Gasket	Back plate	Bolt
Gear													
Impeller			0.25										
Water pump body		0.25		0.126	0.0966		0.0406	0.0196	0.07	0.021	0.1262	0.1166	0.28
Ball bearing			0.126		0.069					0.015			
Needle bearing			0.0966	0.069						0.0115			
Shaft													
Water seal			0.0406					0.0406	0.145		0.0493	0.0493	0.116
Oil seal			0.0196				0.0406		0.07		0.0238	0.0238	0.056
Outer clip			0.07				0.145	0.07			0.085	0.085	0.2
Inner clip			0.021	0.015	0.0115								
Gasket			0.1262				0.0493	0.0238	0.085			0.1217	0.292
Back plate			0.1166				0.0493	0.0238	0.085		0.1217		0.271
Bolt			0.28				0.116	0.056	0.2		0.292	0.271	

Figure 3 Components-components relationship Matrix (Λ_c)

Function Level1	Function Level2	Gear	Impeller	Water pump body	Ball bearing	Needle bearing	Shaft	Water seal	Oil seal	Outer clip	Inner clip	Gasket	Back plate	Bolt	Total
Input-coolant				295											295
Contain-coolant	Prevent-coolant			50				96	48	19		60	59	15	347
	Store-coolant			22								22	20	5	69
Increase-velocity	Accelerate-coolant		311	311											622
	Transfer-rotational						269								269
	Support-rotational			438	309	239					56				1,042
	Receive-Rotational	269													269
Decrease-velocity				364											364
Output-coolant				403											403
Total		269	311	1884	309	239	269	96	48	19	56	83	79	20	3,680

Figure 4 Matrix of Allocated Design Efforts for Each Component

WTM give the results of design rework efforts with regarding relationships (knock on effect). Therefore, design rework efforts for a particular component are composed of efforts from itself and from knock on effect. The design rework efforts are calculated from equation 2. However, this knock on effect still consider as linear, because the whole relationships of components remain unchanged.

$$U = S(1-\Lambda)^{-1}S^{-1}u_0 \qquad (2)$$

where U is a total work vector. S is a corresponding eigenvectors of Λ_c. Λ is a diagonal matrix of eigenvalues of Λ_c. u_0 is initial value of design rework efforts.

Each cell in figure 4 represents allocated design efforts of each component against each function. The last column on the right shows design efforts for each function, while the last row at the bottom reveals design effort for each component. This matrix is further development from functions-components relationships matrix, but it is not focused in this paper. It is used as an input to estimate design rework efforts. Eigenvalue and eigenvector are not shown in this paper, but reader can calculate it from Λ_c, figure 3.

The initial work vector u_0 is a 13x1 matrix represent the initial design rework efforts. Each initial value of design rework effort is taken from figure 4 based on issues. The initial value of design rework efforts will be considered on one component at a time as shown in figure 5, which is the example of design rework on impeller. For this example, u_0 is assumed to do design rework for 100%; therefore, 331 hours is put into u_0. The rational in this example is in the next section.

Components	Initial Efforts
Gear	0
Impeller	311
Water pump body	0
Ball bearing	0
Needle bearing	0
Shaft	0
Water seal	0
Oil seal	0
Outer clip	0
Inner clip	0
Gasket	0
Back plate	0
Bolt	0

a)

$$u_0 = \begin{bmatrix} 0 \\ 311 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \end{bmatrix}$$

b)

Figure 5 Example of u0 for Impeller a) Full u0 definition b) u0 Matrix

3 Obatining Rework Effort Estimation in Early Design and Development Phase

Failure Mode and Effect Analysis (FMEA) is a well establish technique to eleiminate risks of design failures in the early phase of development [6]. Risks of design failures are defined by Risk Priority Number (RPN), which are reviewed from Ocurrence, Severity, and Detection scores. All of these score are focused in the scenario in service phase, while DREE is capable to assess risk of design failure from design rework efforts point of view. Table 1 shows the example of design rework efforts from correcting cavitation issue due to impeller. Design rework efforts from column 6 show the knock on effect of solving impeller to others. Gear and shaft have no effect because both of which have no links as shown in Λ_c. The total design rework efforts are 428.66 hours.

Table 1. Estimated Design Rework Efforts for each Component Under Failure Mode

Failure modes	Failed Components	Components	u_0 (hours)	U (hours)
Cavitations	Impeller	Gear	0	0
		Impeller	311	333.28
		Water pump body	0	89.13
		Ball bearing	0	11.92
		Needle bearing	0	9.46
		Shaft	0	0
		Water seal	0	4.84
		Oil seal	0	2.56
		Outer clip	0	0.93
		Inner clip	0	2.16
		Gasket	0	13.07
		Back plate	0	12.04
		Bolt	0	3.27
		Total		482.66

4 Framework Validation

There is a report called Failure Mode Analysis (FMA) given by an industrial participant. The failure causes are captured from manufacturing, quality and design point of views. However, there are three design issues from water seal, ball bearing and impeller, and the design rework efforts in worst case scenario are 125.95, 428.15, and 482.66 hours consecutively. From interviews, there are two engineers working full time eight hours a day for five days a week; therefore, design rework period is around 3.24 months. The expert in cooling systems memtioned that the worst case design rework period is about four months, and this judgement was also confirmed in the validation session with three experts in cooling systems. Therefore, the estmated results are closed to expert judgement in industrial context.

5 Conclusion and Future Work

DREE framework can be achieved in the early phase of design and development, if the physical design solution is given. The components-components relationship matrix is develop indirectly through functions; however, the method to give the strenght of relationships by AHP are exhausive, if there are more than seven factors to compare. Therefore, method of incomplete comparison would be helpful to solve this problem.

Design rework efforts are not only Computer Aided Drawing (CAD) modeling efforts but also review, analysis, and testing either by simulations or testing as mentioned in [10]. Therefore, the related components have to review all. Relationships among components are derived from a considered function only, while some relationships are not from similar function. For example, the failure in ball bearing comes from non-optimise torsional activity among gear, impeller and ball bearing. These three components are not working together to deliver any functions, but their interactions cause ball bearing to do reworks. This is one aspect to be focused in the future. Moreover, the Λ_c illusrates the full couple matrix, which is undesired in Suh's Axiom as reviewed in [7]. Therefore, this is another issue required more investigation.

With limitation of time and resource, a decision support tool to select a group of high design rework efforts would be helpful for development team to focus. In addition, all design problems in design V&V are not nescessary to be reworked under worst case scenario. Therefore, finding a group of components with variation amount of u_0 is a key challenge. Implementation optimisation method to solve this challenge is a proposed solution at the moment, and the objective is finding 20% of factors which cause design rework efforts up to 80% to total design efforts.

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