A Decision Support System for "Re-design for X" of Production Processes: Particular Focus on High Tech Industry

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Abstract Main target of product design is to develop excellent products, while considering a multitude of optimization goals which can overlap; be contrary or interdependent. Hereby, a large variety of Design for Excellence (DfX) techniques is available to support product developer. The approaches focus mostly on new products and a specific virtue or life phase. A major part of work is the further development of existing products which are not yet in focus of current DfX-approaches. Therefore, within the contribution a decision support system for "Re-Design for X" of production processes instead of products is developed with the aim of a holistic integration of criteria from different scientific perspectives by using a case study from semiconductor production.

1 Introduction

It is well known that during the design stage of products about 70–80 % of the product life cycle costs are determined (e.g. Dowlatshahi 1996). For this reason scientists from various disciplines try to utilize this time and propose a high number of criteria—summarized under the term "Design for X" (DfX)—to develop successful products. There is a high number of different "DfX" perspectives (Chiu and Okudan 2010). Thereby optimization goals can overlap; they can be contrary or interdependent. The decision situation becomes more complex when the aspects of cross enterprise engineering due to decreasing value added depths, the need for short development times and low development costs are taken into account. Moreover in this context it is important to know that development of new products forms only a minor part—10–30 %—of the work of product developers (Schulze 2011). A major part of the work is further development of existing products.

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Therefore, the reverse engineering of the legacy products workflow—in this context understood as "Re-Design for X"—represents a very specific leverage for boosting overall company goals (time, cost, quality, agility). Following these thoughts the main research question of the contribution is: How a decision support system (dss) should be designed to support staff to make the right decisions within product development and re-design of production processes? For answering the question the paper is organized in the following manner: after this introduction Sect. 2 includes a short introduction into DfX-approaches and theory of decision making. Section 3 comprises a description of the new approach for "Re-Design for X" of production processes and Sect. 4 contains its application by using a case study of semiconductor production. Lastly, a conclusion and outlook for future tasks are put forth.

2 Design for X and Decision-Making

2.1 DfX-Approaches

In general "Design to X" and "Design for X" approaches can be divided. "X" is a variable that stands in case of "Design to X" mostly for objectives, e.g. costs. In case of Design for X, "X" is an expression for feasibility and virtue, e.g. for manufacturing. Chiu and Okudan (2010) categorize DfX-approaches in methods with (1) product scope [e.g. design for quality (DfQ), reliability (DfRe), assembly (DfA), manufacture (DfM) etc.]; (2) system scope [e.g. design for logistics (DfL), supply chain (DfSC) etc.]; and (3) eco-system scope [design for sustainability (DfS) etc.]. Contributions with respect to design for X (to X) vary in the range of qualitative guidelines, metrics, feasibility checks and detailed software tools (Holt and Barnes 2010). Within this article general guidelines, esp. design criteria of different DfX-approaches are in center. Literature analysis showed that DfX-approaches are focused mainly on products instead of processes; furthermore they emphasize the introduction of new products instead of legacy products although only a minor part of the work of product developers is new product development. Furthermore they focus mainly on one or at most two aspects of the product [e.g. DfQ or design for manufacture and assembly (DfMA)]. A holistic integration of criteria from different scientific perspectives in a general information and knowledge system is missing which is also remarked e.g. by Holt and Barnes already (2010) or Schulte (2011). Therefore a comprehensive usage of different DfX-criteria is cumbersome, esp. for users from business practice as knowledge is spread over a high number of publications from different scientific perspectives. Table 1 gives—without claiming to be exhaustive—by an exemplary listing a short introduction into different DfX-criteria by using representatives for the mentioned three perspectives.

In general the approaches aim towards reaching strategic company targets like production cost and cycle time reduction, quality enhancement of products and reducing of environmental consequences of product design (Fabricius 1994). From the exemplary listing (Table 1) it can be seen, that complexity dimensions

Table 1 Examples for DfX-criteria

DfX	Criteria	Source
DfA	Minimize part count (5), (8), (9); minimize variety of parts, materials; use standard parts; design for simple part orientation, handling, automated assembly; consider size, weight and simple shape of parts	Boothroyd and Alting (1992)
DfM; DfMA	Minimize part count and variety of parts, materials; simplify the product structure; consider modular designs; do not overspecify tolerances; efficiency in personnel and investment (2)	Boothroyd (1994), Bogue (2012)
DfQ; DfRe	Robust design (3); redundant design; use of proven components and preferred designs; identification, elimination of critical failure modes, impending failures	Kuo et al. (2001)
DfL; DfSC	Standardization of parts, products and processes (1); part commonality and modularity; minimize number of variants; delay product differentiation (postponement); localization of entities in supply chain; optimization of packaging/transportability; concurrent processing and decoupling of tasks (6), (7); optimization of parts with respect to value, weight, volume, shape	Mather (1992), Lee (1992), Dowlatshi (1996), Schulze (2011), Gubi (2001)
DfS	Modular design; design for material substitution (4); waste source reduction design; disposability, reusability, undesirable substance reduction	Ljungberg (2007)

multiplicity and diversity (Reiß 2011) are addressed by different DfX-approaches, see e.g. criteria of DfA: minimize part count and variety of parts; or criteria of DfL: minimize number of variants etc. Also standardization plays a key role within the approaches, see DfL: standardization of parts, products and processes. It is the most effective way and can be seen as embodiment of DfX-compliance. The challenge is to enable a large variety of products and at the same time minimal internal complexity of all business processes. Well known answers for this are DfL/DfSC-criteria (Gubi 2001), e.g. using part/product commonalities, delayed product differentiation (postponement). Although a similar direction between criteria is visible (e.g. consideration of part characteristics within DfA and DfL) there are goal conflicts, see e.g., construction of products: integral design can be beneficial for short cycle times but unfavorable for recycling. Here, decision theory, which is the topic of the next section, can contribute to make the right choices. Besides combination of DfX-approaches with decision theory the originality/value of the contribution is that criteria for legacy processes instead of new products are derived with the aim of a holistic integration of these criteria from different scientific perspectives by using a case study from semiconductor production in Sect. 4.

2.2 Decision Support Systems

A decision can be regarded as judgment. It is a choice between alternative courses of action (Drucker 1975)—in this case in presence of multiple, maybe conflicting criteria. The decision making process includes the phases problem recognition and definition, alternative generation, model development, alternative analysis, choice and implementation. "Decision support systems are computer technology solutions that can be used to support complex decision making and problem solving" (Shim et al. 2002). The focus is set on the question on how information technology can improve efficiency and effectiveness of decisions. DSS use Multi-Criteria Decision Making approaches (MCDM) for enabling the decision. Those can be divided in Multi-Attribute Decision Making (MADM) and Multi-Objective Decision Making (MODM) approaches. MADM includes the choice of the "best" alternative from a discrete solution space whereas MODM deals with a continuous solution space. We focus on MADM as a limited number of alternatives exists. There are numerous MADM approaches (see e.g. Tzeng and Huang 2011) and the selection of the most appropriate approach is also a decision problem. By using the questionnaire of Sun and Li (2010) we choose the analytic network process (ANP) in the new method (see Sect. 3) which can support esp. alternative analysis and choice phase. The most important reason for using the ANP is that the approach incorporates interrelations between criteria. Within ANP a decision problem is structured as a network, then a system of pairwise comparisons is used to measure the weights of the components of the structure, and finally to rank the alternatives in the decision. A detailed description is not given here as the proceeding is well known and often described in academic literature (e.g. Yang et al. 2010; Chung et al. 2005; Saaty 2004). Two other reasons for using ANP are the ease of use and the available software support as ANP-networks can be modeled by using the software super decisions which can be downloaded for free from website: www.superdecisions.com.

As a second instrument we need a group support system (GSS) to enhance the communication-related activities of team members. GSS can be described "along the three continua of time, space, and level of group support. Teams can communicate synchronously or asynchronously; they can be located together or remotely; and the technology can provide task support primarily for the individual team member or for the group's activities" (Shim et al. 2002). Here, MS-SharePoint 2010, which is a web application of Microsoft, is used to support group decisions and virtual collaboration by using a common web interface. It bases on SharePoint Foundation technology. One main function is central document repository and administration (Larisch 2011). Besides that esp. the integrated workflow function is the main reason for using SharePoint. A workflow is characterized by automation of activities. Single activities are combined to a process. It is defined which persons execute which tasks by which means and information. A workflow can be started manually or automated. An initial point can be for example uploading of defined documents, reaching of a specific date or change of a document. Consequently, directives for action follow. A workflow is being executed as long as a previously defined goal or end is reached. Therefore, it is a suitable mean for standardizing progress of the project.

3 Approach for “Re-design for X” of Production Processes

3.1 Requirements and Design Science

Requirements of approaches with focus on redesign of production processes have been discussed for example by Singh et al. (2006) and Wu (1996), whereas Singh emphasizes the importance of enabling and facilitating group work as well as consistent decision-making without subjective influences and Wu technical aspects. Further important requirements proposed by Singh et al. (2006) and Wu (1996) are: efficiency with respect to time and effort required by each team; quantitative and objective data analysis should be enabled; a holistic, systemic perspective of investigation object should be adopted. With respect to design science the new approach is developed on basis of thoughts of Simon (1996) and generally known logic of problem solving process, see e.g. Spalten problem solving methodology in the product development (Albers et al. 2005) with phases situation analysis, problem containment, search for alternative solutions, selection of solutions, analysis of the level of fulfillment, make decision/implement, recapitulate/learn.

3.2 Outline of the Approach

The new approach is a sequence of four steps, which are shortly described below. The focus of this contribution lies on step 4 which will be described more in detail in Sect. 3.3 after the overview in this section.

1. *Preparation, building of flow families and strategic preliminary decisions*
   Within the preparation phase targets, project team and field of investigation have to be defined. In general, the focus is not design but “Re-Design for X”, which means reverse engineering of the legacy products workflow (not the product itself) is the scope of the new approach. “Re-Design for X” of the whole manufacturing sequence for all products and steps in parallel is in case of a multi-variant serial production not possible. Therefore, via a product range analysis (with tools like ABC analysis or portfolio techniques) we identify the most important products (with the highest revenue for example) and build flow families. A flow family (FF) is a united chain of consecutive single process steps which are similar within different product processes of record’s (POR), including the following similarities: sections of complete POR, same or replacing tool types with similar process times for single process steps, and length as well as sequence. A description of the proceeding of building flow families is not the focus of the contribution. The further interested reader is referred to Keil et al. (2009).

In addition strategic decisions need to be made regarding applied Design for X-criteria. That means with regard to which requirements should the process section of the FF be optimized? This is necessary to assure a purposeful analysis, evaluation and re-design phase. In literature it is recommended to use a limited number of DfX-approaches in parallel—namely five to nine—to reduce complexity of requirement system (Huang 1996). Parallel selection of DfX-approaches could be done by using the matrix approach of Watson et al. (1996) which includes six steps: (1) selection and weighting of context suitable DfX techniques by using cost estimates for each life cycle area, (2) categorization of DfX techniques in general design rules or specific design strategies and assignment to the product development phase where it should be used, (3) weighting rules and strategies with respect to relevance in the regarded case, (4) identifying guideline interactions, (5) determining the overall value of design strategies/rules and generating a ranked list with most important strategies for the designer, (6) utilizing the list during design. Another approach is sequential use of DfX-approaches (Gubi 2001). Gubi (2001) proposes for example that DfL can be applied when the product architecture is ready whereas DfM and DfA should not be used in this phase since the detailed design is not complete. For this procedure speaks that DfX-approaches are developed for different design phases, whereas the major portion of the approaches has been developed for late design stages (Chiu and Okudan 2010). But every applied DfX-approach limits the theoretical solution field of the approaches which are applied in the following. Conditions are set and maybe through absence of a holistic view on all design criteria right from the beginning goal conflicts and interrelations cannot be taken into consideration. Therefore, and because criteria of different approaches are overlapping (see Sect. 2.1) as well as for the reason that the field of investigation is product workflow of legacy products a limited number of DfX-approaches is used in parallel here. Requirements which result from applied DfX-approaches should be collected in a criteria catalogue and be described in a standardized form, e.g. as requirement profile. This profile includes according to Klute et al. (2011) information about: reference (regarded property and its characteristics), source (DfX-approach), relations (description of interdependencies), weight (relative importance of requirement) and situation (date of recognition and percentage of completion).

In the following it is assumed that a criteria catalogue is available, e.g. in an excel-based document. Now every team member decides which criteria of this catalogue should be used with respect to the object of investigation. Helpful in this connection can be a prepared excel-sheet, which can be easily implemented in the workflow. The team-leader saves this document on the ms-share-point and every team member has access to it. Therefore, the most frequently mentioned criteria can be easily identified by the team leader. For executing steps like "selection of criteria" there are defined timeframes foreseen within the workflow. When the time span is exceeded, the user is automatically informed via e-mail to complete this step. When every team member has chosen the criteria a team-meeting follows. Here, the team leader presents the most frequently mentioned and maybe newly formulated criteria for discussion. Result of the meeting should be a consensus with a definition of the criteria which are the basis for the following analysis, design and evaluation phase. Relations and weighting of criteria are analyzed within evaluation phase (Sect. 3.3).

2. *Analyze flow families: technology, DfX-criteria and operations*
   Major steps within the analysis phase are: examination of technology and fulfillment of DfX-criteria as well as analysis of operations with focus on process organization. Main focus of technology analysis is similarity observation. As mentioned one result of step 1 are clusters of different flow families and each includes similar sections of POR’s. The sections within a cluster will be compared in detail to detect all variations of available process flows. The variations will be compared with respect to characteristics as used unit processes, process times, kind of applied equipment types and their location in the facility layout. As each variation results in further complexity increasing for all business processes, the focus is set on the question of technological necessity, inflexible customer requirements, capacity constraints of a mature fabrication facility, but also historically grown definitions. The goal is to identify preference technologies to reduce complexity within production system (Gräßler 2004; Keil 2012). As the analysis step is not focus of this contribution the further interested reader is referred to Keil et al. (2013).
3. *Re-Design of alternative future process flows within FF-compliant to DfX-criteria*
   As a result from the analysis phase alternative standard process flows which could be used in the future as new standard reference are generated in re-design phase. As reflected through DfX-criteria from Sect. 2.1 the most effective way and the embodiment of DfX-compliance is homogenization. Besides the efforts toward homogenization for legacy products, the process flows here are re-designed in the manner of business reengineering. This means reviewing the arrangement of process steps of the whole workflow with respect to options regarding elimination, integration, parallelization, swapping, splitting and maybe enlargement due to quality issues. Resulting is a description of re-design options with respect to the requirement list from step 1, that means a description of alternative new process flows for the FF which have to be evaluated in step 4 (Sect. 3.3).

3.3 Step 4: Evaluation of Alternative Flow Families as Focus of the Contribution

3.3.1 Analysis of Interrelations and Identification of Goal Conflicts

On basis of the re-design options which result from step 3, the goal of the evaluation phase is to find the best alternative for the new process flow, which is best in line with company objectives. Aim of this substep is to identify goal conflicts between DfX-requirements (conducted in step 1), which necessitates an analysis of its interrelations. Thereby, it is investigated how a fulfillment of one requirement acts on the other requirements of the system. Four kinds of interrelations can be divided (Rommelfanger and Eickemeier 2002): neutrality (fulfillment of a requirement has no impact on fulfillment of another requirement), symmetrical complementarity (fulfillment of a requirement enhances degree of fulfillment of another requirement), asymmetrical complementarity (fulfillment of first requirement enhances degree of fulfillment of the second requirement, but this does not apply in the reverse direction) and competition (fulfillment of one requirement affects the fulfillment of another requirement, it exists a conflict of goals).

In the first step, interrelations should be analyzed individually by each team member. Then the project leader evaluates the results and invites the group to a meeting where results are discussed with the goal to find a consensus. For illustration of interrelations a correlation matrix can be used (Ponn and Lindemann 2011). Hereby, symmetrical relations should occupy only one half of the matrix to easily identify asymmetrical relations. After identification of interrelations the team-leader explains the ANP-approach and the software super decisions (see Sect. 2.2) to the team and models a network of criteria and interdependencies by using the software. This network is the basis for the following evaluation of alternatives by each team-member.

3.3.2 Evaluation of Alternatives by Using ANP

The project leader uploads the file of the network to the MS-SharePoint folder of the team. Now every team-member uploads the network, e.g. to software super decisions and executes the pairwise comparisons of criteria and alternatives.

3.3.3 Assessment of Results of ANP and Choice of the Most Excellent FF

The project leader assesses the results of the ANP. One main requirement of the general approach (Sect. 3.1) is to avoid subjective influences of single team member. Hereby, esp. variability in evaluations of each single team member is of interest. With respect to this requirement the classical ANP could be enhanced by using standard measures from statistics, e.g. coefficient of variability (CoV) which is a suitable measure to quantify variability (Hopp and Spearman 2000). The normalization allows comparison of variables with big and small averages. The CoV should be computed for the resulting weights (from ANP) for each single re-design criterion. After computing, values can be evaluated by variability classes of production (Hopp and Spearman 2000). In case of moderate and high variability values project leader should open debate in a kind of delphi-process which is “a method for structuring a group communication process” (Linstone and Turoff 1975): first with single team member where deviation occurred and afterwards within the whole group to understand the reasons for deviation. Maybe one team member considered critical aspects that were neglected by the others. As consequence there is the opportunity for individuals to revise views until a consensus is reached.

4 Application by Using a Case Study of Semiconductor Industry

4.1 Characterization of the Case Study

Characterization of the case study is done by using the quality criteria transferability, truth value and traceability for case study-based research from Pedrosa et al. (2012). For short, transferability includes theoretical aim, unit of analysis and justification of the case study as well as number of cases used; truth value contains a description of the data analysis process; traceability comprises a documentation of the research process and data sources.

The theoretical aim of the study is testing the described procedure (Sect. 3). Units of analysis are mature multi-product semiconductor fabrication facilities which produce several hundred products within one facility. This case is used because semiconductor production is regarded as one of the most complex production processes in existence today (Sturm 2007), whereas an easier transfer from complex to simpler cases is assumed. Furthermore, there is a high necessity of logistical improvement. Every product can require more than a thousand single process steps. Studies revealed that the value adding process time in semiconductor production is not more than 2 % (Töpfer 2008), whereas a high proportion of time is transport, handling and storage. Compliant to DfX means here esp. avoidance, reduction and mastering of handling, transport and storage times to reduce high lead times and proportion of non-value adding time by providing simultaneously high quality of products with minimal production costs and energy consumption.

As the length of the complete process flow exceeds in depth analysis at once, flow families are built (see step 1, Sect. 3.2). Regarding truth value: 101 POR’s of two technology nodes have been analyzed via cluster analysis to identify the most promising FF for analysis. Similarity observation shows that a FF with 31 process steps out of the copper metallization module, where transistors of integrated circuits (ICs) are connected, is suitable for two reasons: there are great similarities within process sections of POR’s both within one technology and trans-technology. Due to the cyclical pattern of the semiconductor manufacturing process with re-entrant material flows the FF even is repeated within one POR up to four times. Furthermore, the section is located downstream at the end of the whole manufacturing process where the product has already a high value and therefore should leave the factory as soon as possible. Thus, this study is based on one case of one semiconductor fabrication facility. Nevertheless, the used copper metallization-process section is used by most semiconductor manufacturers for many products in a similar way.

Regarding traceability the informant selection within the case study is based on following thoughts: we choose three process integrators from department of technology development which have a deep understanding about the whole FF. They can estimate the effects of changes of one single process step to the remainder. Furthermore, we had four process engineers (which are responsible for single processes within production) as representatives for the identified process types (see Sect. 4.3). Additionally we selected one employee of production logistics, one from accounting and one from IT which could assess the changes with respect to their core competencies. Moreover we were four representatives from the chair of business administration, esp. logistics. As data collection techniques we used interviews and company internal data based on manufacturing execution system.

4.2 Re-Design Criteria with Respect to Processes

Within the regarded company no design criteria catalogue for re-design of production processes was available as the approach has been applied for the first time. The criteria were derived from literature and adapted both—to special requirements of processes instead of products and to needs of semiconductor production. The criteria were discussed within team meetings with the mentioned representatives (see step 1, Sects. 3.2 and 4.1). Results are criteria for the three categories manufacturing process, sequence and system which are listed in Table 2. Hereby, in column “source” of Table 2, number 1 to 9 show in connection with Table 1, column “criteria” the origin of the new criteria for processes. As most DfX-researchers focus on products instead of processes, criteria for manufacturing systems with respect to process organization within operations and machines could not be identified from literature.

4.3 Re-design Alternatives

As mentioned in Sect. 4.1 a FF with 31 process steps is regarded. Following the thoughts of Sect. 3.2 analysis and carving out of re-design alternatives is task of step 2 and 3. In the initial situation the whole flow has the following structure: 8 main technological process steps (T), 8 cleaning steps (C), 11 measurement steps (M), 4 wafer logistics steps (L). Figure 1 gives an overview of all re-design options (alternatives 1-3) which are described in the following. Hereby, two technologies (TN 1 & TN 2) with their PORs are compared schematically.

Re-Design alternative 1 (A 1): Within A 1 three re-design options are possible, numbered with 1a-c in Fig. 1: in two instances (1a, b) two cleaning steps are in succession with the difference that in the first instance (1a) technology 1 does not

Table 2 Re-Design for X criteria for processes within case study

Cluster	Re-design for X-criteria (node)	Source	Symbol node	Influencing nodes
Manufacturing process	Standardization of unit processes within the flow family of one technology and technology-comprehensive, m.t. # unit process variation/unit process step of flow family	DFL (1)	$d_{2.1}$	$d_{2.4}$
	Technology comprehensive pooling of capacity, m.t. capacity/unit process step of flow family; whereas the total number of tools remains constant before and after re- engineering	DfM (2)	$d_{2.2}$	$d_{2.1}$,$d_{2.4}$,$d_{4.3}$
	Robustness of unit processes, m.t. cp and cpk values	DFQ, DfRe (3)	$d_{2.3}$	$d_{2.1}$,$d_{2.4}$, $d_{3.4}$,$d_{4.1}$, $d_{4.2}$,$d_{4.3}$
	Substitution possibility of unit processes	DFS (4)	$d_{2.4}$	
Manufacturing sequence	Shares of cleaning, measurement and wafer-logistic processes in contrast share of main technological unit processes, e.g. number of measurement steps/total number of steps	DFA (5)	$d_{3.1}$	$d_{2.4}$,$d_{3.4}$,$d_{3.5}$
	Order flexibility, m.t. number of order-flexible steps which can be supported via IT	DfL, DfSC (6)	$d_{3.2}$	$d_{2.2}$,$d_{3.3}$,$d_{3.4}$
	Parallelisation possibility, m.t. number of steps which can be executed in parallel during operation	DfL, DfSC (7)	$d_{3.3}$	$d_{2.2}$,$d_{3.2}$
	Integration possibility, m.t. number of steps which can be integrated	DfA (8)	$d_{3.4}$	$d_{2.4}$
	Care of wafer-logistic steps, m.t. number of steps in between since last wafer-logistic step	DFA (9)	$d_{3.5}$	$d_{3.2}$,$d_{3.4}$,$d_{4.3}$
Manufacturing system	Spatial flow of sequence, m.t. transportation time demand	Not yet in literature	$d_{4.1}$	$d_{2.2}$,$d_{3.1}$, $d_{3.2}$,$d_{3.3}$,$d_{3.4}$
	Flow supporting tools, m.t. number of batch tools		$d_{4.2}$	$d_{2.4}$
	Standardization of production equipment at unit process step, m.t. number of different tool types at one step		$d_{4.3}$	$d_{2.1}$,$d_{2.4}$, $d_{3.1}$,$d_{4.2}$

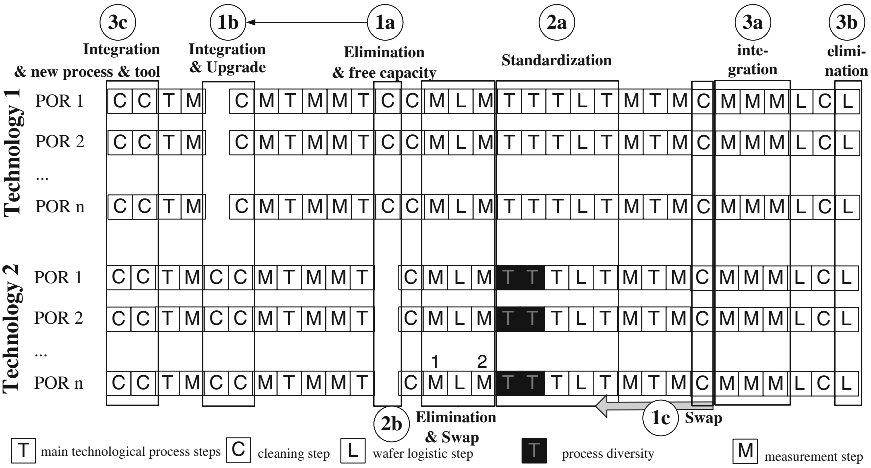

Fig. 1 Re-Design options

require the first cleaning step and in instance 1b the second technology. Analysis showed that with a new process concept the first cleaning step of technology 1 can be eliminated resulting in free available machine capacity. This allows a new process concept for the two cleaning steps of technology 2. They can be integrated as the former process can be done by the free machine type. The third instance (1c) analyzed with technology guys shows that the backside cleaning process causes splashes on wafer-frontside. With swapping this step in front of a technological main process (CMP) this can be polished while quality is improved. Result would be 29 steps (8 T, 6 C, 11 M, 4 L) with a cycle time reduction potential of 8 % compared to the initial situation.

Re-Design alternative 2 (A 2): In addition to measures 1a–c within A 2: the homogenization of two consecutive main technological process steps (2a) across TN 1&2 was investigated. Unit process (UP) diversity value would change from five different processes to three different processes at these two consecutive steps. Also a pooling of capacity (CA) would be possible. Before TN 1 had five tools and TN 2 three. Afterwards both TN's could use eight tools which reduces waiting time within operations. In instance 2b a re-design of the flow with swap of measurement steps would enable a significant reduced transport time as well as a better quality assurance because results of measurement step 2 are needed earlier in production flow. Moreover, the wafer-logistical step between the measurement steps could be eliminated, because informational tracking of material is sufficient. The result would be 28 steps (8 T, 6 C, 11 M, 3 L) with a cycle time reduction potential of 10 % compared to initial situation.

Re-Design alternative 3 (A 3): In addition to measures of A 1 and 2 within A 3: in case 3a three measurement steps are in succession. They could be integrated within POR to one step and be flexible within operating. Furthermore, belonging different tool-types of measurement steps should be concentrated in measurement isles. The advantages can be illustrated by following the example: a production lot must be processed at step 1 for measuring defect density. The belonging tool is not available. When steps are integrated and flexible within operating the non-value adding storage time for the lot can be reduced. When the tool for the next measurement step would be available and the lot switches the order of these two steps, utilization of tool capacity could be enhanced, feedback loops would be shorter and transport time portion would be reduced due to the fact that all measurement tools are in one area. In case 3b elimination of a wafer-logistic step is possible with a new IT-concept. In case 3c integration of two consecutive cleaning steps could be done, when a new machine generation which enables a new technological process would be purchased. Result would be 27 steps (8 T, 6 C, 11 M, 2 L) with a cycle time reduction potential of 13 % compared to initial situation.

4.4 Evaluation of Alternatives and Choice of the Most Excellent FF

Step 4 of the described approach (see Sect. 3.3) includes evaluation of alternatives. Before evaluation by using the ANP, the project group examined interrelations between re-design criteria with the result which is depicted in Table 2 (influencing nodes). Due to the shortness of this article this cannot be described in detail. Table 3

Table 3 Results of ANP with respect to re-design criteria

Node	Normalized by cluster	Limiting
A 1	0.12385	00.083036
A 2	0.41238	0.276481
A 3	0.46377	0.310932
$d_{2.1}$ standardization	0.11207	0.021731
$d_{2.2}$ technology comprehensive pooling of capacity	0.09894	0.019185
$d_{2.3}$ robustness	0.00000	0.000000
$d_{2.4}$ substitution possibility	0.78899	0.152990
$d_{3.1}$ number of cleaning, measurement and wafer-logistic steps	0.30116	0.024056
$d_{3.2}$ order flexibility	0.15770	0.012597
$d_{3.3}$ parallelisation possibility	0.07976	0.006371
$d_{3.4}$ integration possibility of steps	0.30908	0.024689
$d_{3.5}$ care of wafer-logistic steps	0.15231	0.012166
$d_{4.1}$ spatial flow of sequence	0.00000	0.000000
$d_{4.2}$ flow supporting tools	0.43137	0.024056
$d_{4.3}$ standardization of production equipment at single process step	0.56863	0.031711

shows the results of the ANP of the whole project group after the Delphi-process. In the previous phase where team leader evaluated results of each member (which executed ANP as described in Sect. 3.3.2 first by their own) variability (see Sect. 3.3.3) occurred esp. regarding re-design criteria of flexibility within operations (see case 3a, Sect. 4.3) with a value of 1.5 of an IT employee. On enquiry of the project leader, the employee responded that establishing order flexibility within MES-system would provoke extremely high IT-efforts. As a result the whole team carried out a further profitability and risk analysis as well as the ANP with the result that A 3 is with a weight of 0.46 the choice of the group with respect to DfX-redesign criteria. Furthermore, it can be seen that $d_{2.4}$, $d_{4.3}$ and $d_{4.2}$ are the re-design criteria with highest priorities.

5 Conclusion and Outlook

The result is an approach for “Re-Design for X” of production processes. Re-Design criteria from different scientific perspectives can be included and prioritized by combining classical DfX-approaches with methods of decision support systems like ANP. Hereby, esp. alternative analysis and choice phase of the decision making process are supported. The approach is verified by a case study of semiconductor industry. A research implication is that a major challenge is to find the right “master” criteria which reflect needs of various scientific disciplines for individual case studies as these criteria represent the fundamental input data for the new decision support system. Furthermore, overlap, contrariness or interdependence between existing criteria must be examined before the criteria are applied. Future work lies in the development of industry-specific or product and process type-specific catalogues of criteria which consider needs of various scientific disciplines.

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