The Collaborative Digital Process Methodology achieved the half lead-time of new car development

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Abstract. In Brazil, the industry of agricultural machines and implements represents a A Japanese automotive manufacturer finally achieved the less than one year lead-time for product development of its new automotive that was released in 2005.

NOTE, a new automotive released from Nissan Motor Co., Ltd. in January 2005, was thrown into the market after 10 and a half months of product development period, which was the first achievement all over the world. (1) That means "super-shortened process" reduced the lead-time of new automotive development to the half which had needed more than 20 months. The Japanese automotive industry has achieved the less than one year period of "super-shortened process", coming from "five-lot process" in 1980's through "shortened process" in 1990's as a result of its continuous efforts.(Fig.1) I have brought up the methodology called "Digital Collaboration Process Methodology" from the countermeasures which has contributed these 20 year process innovations.

Keywords. Computer Aided Design (CAD), Computer Aided Manufacturing (CAM), Computer Aided Engineering (CAE), Modeling, Concurrent Engineering, Computer Aided Production Engineering (CAPE), Digital Collaboration, Knowledge CAD/ Knowledge Engineering.

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1. Three Process Innovations

Through CAD/CAM unification" in 1980's and "Data Master Process" in last half of 1990's, "Digital Engineering Release Process" has been established recently. It has achieved the innovation "super-shortened process" which conducts only once prototype testing in less than one year. The development lead-time has shortened to 1/3 from 2.5 year development lead-time in 1980's to 10.5 months in 2000's.
Simply saying, the three innovations have achieved in each 10 years. (Fig.1)

1.1 CAD/CAM unification

In 1970's, the automotive manufacturers in the world developed their own "in-house CAD", the first generation CAD program using wire frame and surface, and began utilizing it. Through practical use of "in-house CAD", they reached "CAD/CAM unification" in 1980's. As expressed as the keyword "Clay to Die", a conceptual design model created with clay was directly converted to 3D CAD data, and die processing was unified to NC manufacturing. It greatly contributed to quality improvement in automotive manufacturing.

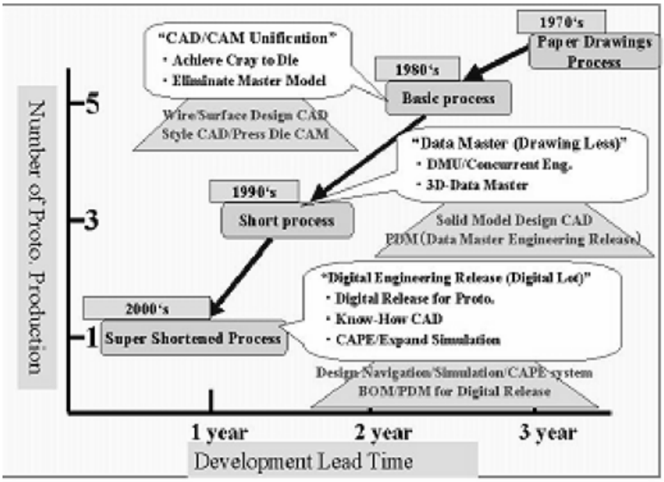

Fig.1. History of Development Process Innovation in Automotive Manufacture

In model based die manufacturing, a wood pattern making expert produces a press die by creating a 3D plaster model (master model) from curves expressed in conceptual design and drafting and by performing profiling the model.

An actual scaled clay model car is measured with 3D geometry measurement equipment. Based on the measured data, the master geometry of faces is converted to CAD data. This data is developed to "vehicle geometry master data" into which

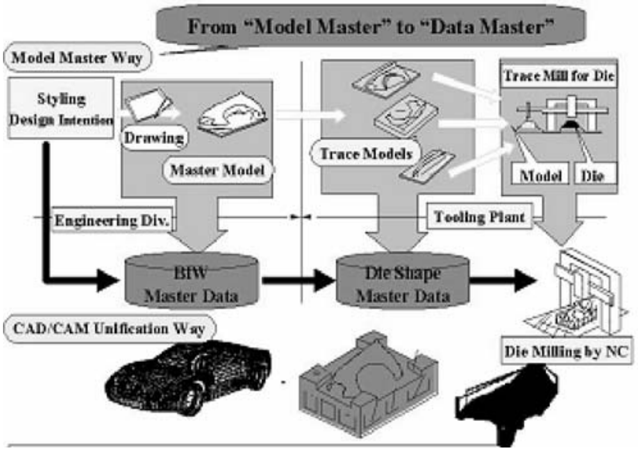

Fig.2. Die Production in CAD/CAM Unification

design information of the internal structure has been incorporated. Adding die-specific addendum and die face geometry to this 3D face geometry, "Die geometry master data" is created; in addition, NC data for die machining is produced with CAM software. In other words, "CAD/CAM unification method" is the procedure that a series of die creation steps is consistently connected by using CAD data united from conceptual design to die creation. (Fig.2)

1.2 Data Master Process

In 1990's, with the progress of computer technology, the first generation CAD "in-house CAD" began to be replaced with "second generation CAD", commercial solid modeling CAD system software which had achieved the practical use level. The automotive manufacturers began to employ and utilize this software. "Second generation CAD" reached for the efficiency represented by DMU (Digital Mock Up) and enabled the automotive manufacturers to realize "shortened process", a year and half period of development and three times of prototyping cycle. "Vehicle layout design" typified by engine room layout had been realized in the first generation CAD (wireframe-based). It was enabled to be verified by using solid models, which brought tremendous efficiency gains and improvement in quality of verification to the automotive manufacturers. (Fig.3).

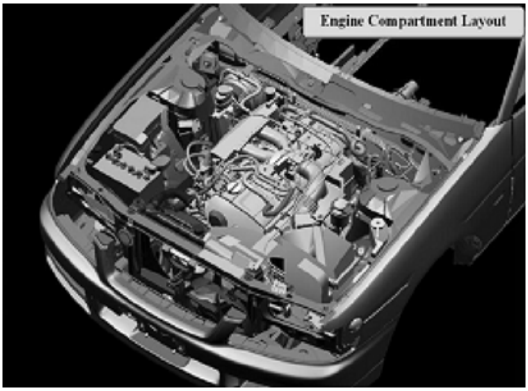

Fig.3. Digital Mock-up by Solid Models

This "DMU realization" has largely contributed not only to design process but also to digitizing and bringing forward the process of productivity verification by enabling "production engineering verification" which had not be realized with the drawing. In body structural analysis field, furthermore, "Digital Performance Evaluation" became possible by supplying CAD DMU data from design department, which had been difficult to evaluate timely because of a long lead-time to prepare the structural analysis model.

Not only design department itself but also both of the production engineering department and performance evaluation department have became able to use DMU data for their tasks on the faith of data. It means that both the departments creating data and using data perform their works using the scheme of "data master =data criteria". From this point, we call these basic design process using DMU as "Data Master Process" (Fig.4)

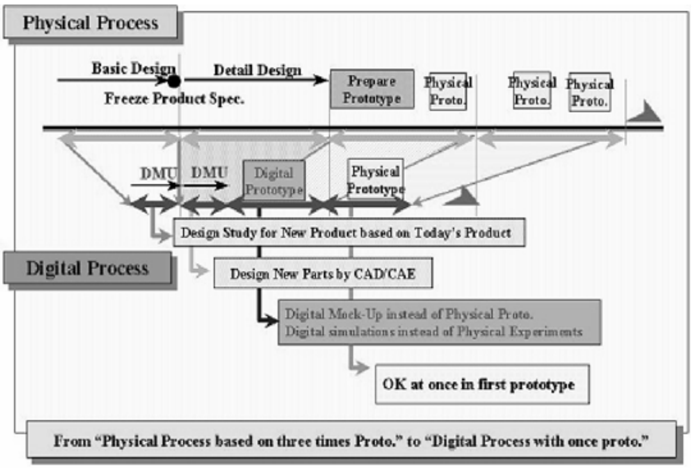

Fig.4. Achieve “Super Shorted Development Lead Time” less than one year

1.3 Digital Engineering Release Process

"Super-shortened Process" realized in the middle of 2000's was achieved by building the new measures on the foundation of "Data Master Process" realized from the late 1990's to the beginning of 2000's. There are four new schemes; "Improvement of DMU as Digital prototype quality", "Design support system incorporated with knowledge (Knowledge CAD)", "Minimization of degree of dependence on physical testing with an actual prototype by expanding analysis simulation" and "Minimization of degree of dependence on an actual prototype by using complete digital process verification" (2).

Thorough "data master process" and accumulation of those schemes led to launch of mass production of a new car with "half of the conventional development period" and "one time prototyping".

2. Seven schemes for digitalization

I explain the major seven schemes, which contributed to achieve three process innovations described above. Table 1 shows the relationship between seven schemes and three innovations, and the contribution to those innovations. I have named these "Seven schemes for digitalization".

2.1. Realization of Styling CAD

A required factor to realize "Clay to die" is "plotting of prototype data" with a Styling CAD system. Styling CAD, which is completing smooth and aesthetic surfaces through the process of "surface creation" called as Fairing based on the coordinate values from measurement of an actual scaled clay model. The most contributing factors to succeed realization of CAD/CAM unification are completion of the Styling CAD system in early 1980's and establishment of its use in the actual operation. (Fig.5).

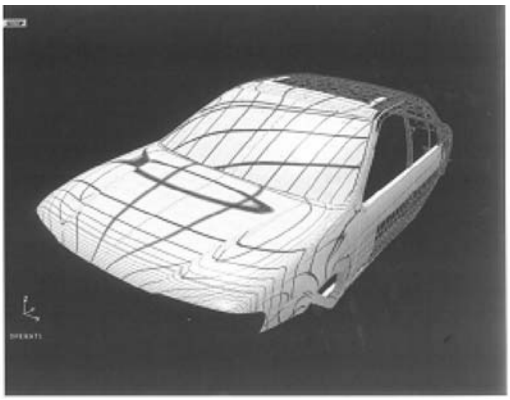

Fig.5. Styling CAD (Exterior High-Light Simulation)

2.2. Body structure master data method, "KOGEN method"

A large issue to succeed "CAD/CAM unification method" is "who will create a 3D model from the results of structural design". In "KOGEN method", a segregated CAD designer is responsible for creating a vehicle structural original image (3D-CAD geometry), modifying and completing it. Dividing the work with other designers enabled to maintain "CAD data quality", create data efficiently and "assure data" toward downstream. Currently, many of the automotive companies have employed this division-of-labor method. The "KOGEN method" is another key factor to support the CAD/CAM unification. (Fig.6)

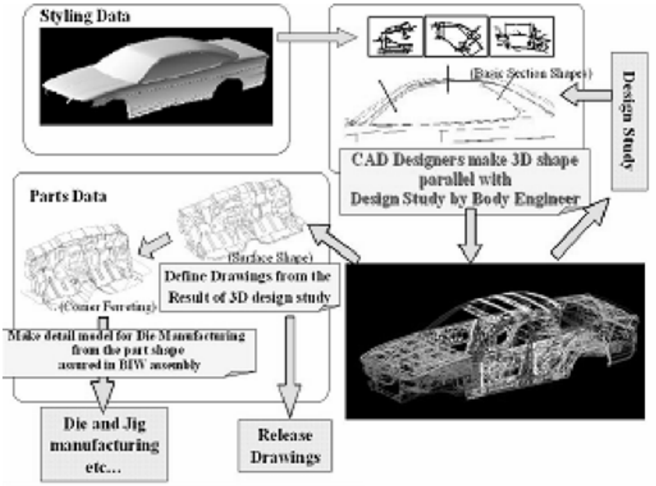

Fig. 6. Kogen Way

2.3. Basic design work with DMU (Digital Mock Up)

By defining all the components composing a vehicle with 3D solids and surfaces, the digital prototype of a new car which was shown like a real experiment car was created. The key factors for this were progress in the second generation CAD software and improvement in performance of workstation platform running such CAD software. This is indeed the innovation of automotive engineering supported with progress in Information Technology.

However, the automotive manufacturers encountered a lot of issues when trying to apply DMU (Digital Mock Up) on the stages of their new product development:

(1) DMU has not been completed until all the components are collected.

(2) To present variation of a product with DMU, product requirements and management of the related assembly components are needed.

(3) How they manage the timing of replacement of assembly component geometry which is intermittently modified with the new one for DMU.

To solve these issues, the following measures were taken:

(a) Establish the system to support creating data for reused components in order to ease designer's burden.
(b) As for components in provision (components on the approved drawing), the component suppliers in charge should be responsible for delivery in 3D data.
(c) Set DMUs under verification planning only necessary times, list required components for individual DMU, and regulate levels of details for creating CAD data of the component.
(d) By using created DMU, clarify items and simulation criteria for "analysis evaluation" and "production engineering verification", and get more precise results of design verification.
Complying with these "DMU operation rules" in an entire company increases the value of using "digital mock up car" and brings successful results. The key here is that the design department creating data assures "segregated analysis group" and "production engineering group" of liability of the product assembly, and engineers can use it on each engineering stage without their concern. Concurrent engineering with DMU cannot be completed unless liability of CAD data is assured.

2.4. Drawing-less process

Compared to the method of assuring creation and maintenance of 2D drawings, the method of creating and maintaining DMU and assuring relative departments or supplies of liability of 3D data forces the designers to take a lot of man-hour. Immediate increase of man-hour turns to a burden even if they well know that the entire product development will be carried out much more efficiently and it will result in less rework and efficiency. As an approach to moderate that burden, "Drawing-less" process had been applied.

This method removes 2D paper drawings and mainly uses 3D CAD data to arrange the production process. The traditional set of "design requirement", "component structural information" and "paper drawing" was replaced with "electrical design requirement", "component structural information", "3D CAD data" "data note" and "auxiliary drawing". Focused on "3D data incorporated with a minimum of dimension values and annotations", technical contents in 2D drawings can be covered by providing literal information on "data note of worksheet" including Parts No., Drawing No., Author, Material, Thickness and Modification, and by adding "2D auxiliary drawing such as sectional view" which cannot be represented in 3D. (Fig.7)

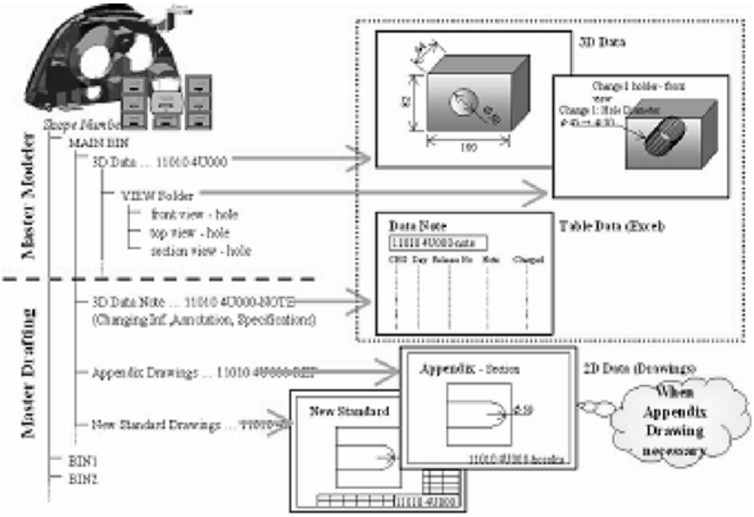

Fig. 7. Drawing Less Release

The largest issue of drawing-less process is insufficient capability of the receiving sites. How do the receiving sites in an automotive company such as manufacturing, quality assurance and purchase divisions perform their traditional tasks without using paper drawings? How does the automotive company deliver necessary information to hundreds of suppliers (parts manufacturers) that treat 70 percent of total vehicle components? Those suppliers would feel difficulties in purchasing and using the 3D CAD system. Nissan Motor overcame this problem by receiving the set of three items (3D CAD data, data note and auxiliary drawing) for drawing-less process and preparing 3D viewer software which can be used for measurement, verification of sections and creation of rough image and providing it to them at inexpensive price.

This approach enabled Nissan Motor to carry out a smooth arrangement for manufacturing process toward the globally extended manufacturing sites; in addition, realize "Real-time arrangement" that was the target of drawing-less process. The "drawing-less process" Nissan Motor introduced ahead of other companies will be a standard process for the Japanese automotive industry in near future.

2.5. Knowledge CAD

Documentation is created after standardizing engineering tasks such as "3D modeling" and "CAD manipulation" which are needed for "design verification" and "production engineering verification". Regarding each detailed task item which consists of the "engineering work flow", engineers "run the 3D CAD system", "do calculation on a worksheet" or "refer technical documents". They use "CAD template" to always output a correct result efficiently when "running the 3D CAD system". This "CAD template" provides the advancement that the functionality to modify dimensions is incorporated into the manipulation history of the CAD system, and 3D manipulation for a same structural work is re-executed for different dimension. Knowledge CAD effectively performs 3D verification on the phase of "Basic design", early in the new automotive development process. (2)

2.6. Use of analysis simulation

"Analysis simulation" called CAE is a dynamics simulation method represented by "Finite element method structural analysis" that divides a product model into a lot of fragments in the digital world and replaces them with matrix calculation to apply theoretical strength of materials to a complex shaped object model in order to calculate deformation and stress. "Analysis simulation" was employed for actual operations in 1970's and has been evolved according to the progress of super computers. There are two purposes for applying "Analysis simulation"; one is, by using computer aid, to help insight of dynamics phenomenon from the engineering view point which is difficult to measure and analyze a real product, the other one is to replace tests which uses a real product with evaluation of functionalities and performance of the product by using a virtual product model. Since then, "3D CAD product model", a base for "Analysis simulation" had been created by designers, and man-hour for creating an analysis model had been decreased, so that the use of "Analysis simulation" had been expanded rapidly (Fig.8).

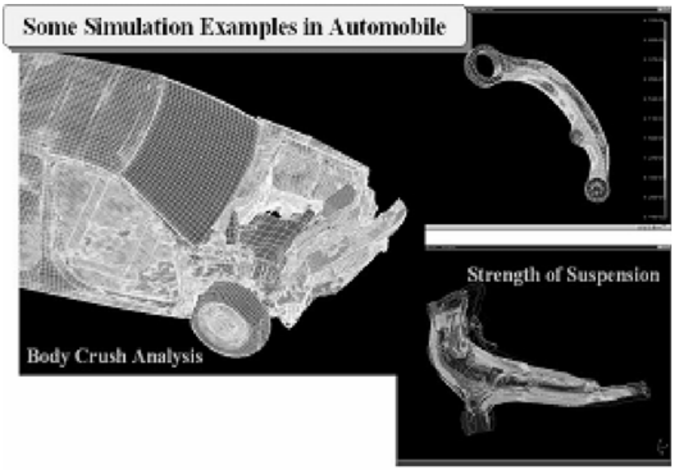

Fig. 8. Apply and Stablish CAE Simulation

For development of a new automotive, there are thousands of "functionality and performance evaluation items" which are required to calculate and verify on the phase of development in order to throw the new automotive to the market. Nissan Motor reported that they had shifted 45 percent of those items from test using a real product to virtual simulation (2). Main contributors to expansion of evaluation with Analysis simulation to such level are "preparation of 3D CAD model as a foundation" and "progress in functionalities of analysis software including pre-post processing such as analysis modeling" as well as "development of analysis simulation technology".

For example, as for "crash safety performance", one of the most important items of automotive performance evaluation, dependency on "Crash simulation" became extremely higher to maintain a certain level of performance. "Crash safety performance" depends on the basic structure of an automotive. If its performance does not achieve the certain level, engineers have to go back to modification of the basic structure. As a result, loss of time and man-hour caused by the rework would be enormous. The "crash analysis model" had consisted of approximately 10 thousands of elements at the launch of this evaluation in 1980's, while the model is, currently, divided into more than one million elements. This enabled to predict a calculation result with a gap of less than 10% on the amount of deformation after a crash test. Continual efforts on development of the crash analysis technology for 20 years brought success, which is only one time verification with prototype.

2.7. Digital production process verification

CAM, the computer technology for creating die and tools with NC controlled machining equipment, was introduced in 1970's and is currently a typical approach for die creation. Furthermore, there is an approach of more comprehensive verification of production engineering by using computer technology, called CAPE (Computer Aided Production Engineering). This system provides a verification method on production engineering aspects by simulating a series of worker's assembling activities with computer and evaluating the procedure and problems in advance. CAPE also has a long history as software or method; however, its usage has been propagated rapidly for recent several years for which upstream designers have turned to create a 3D product model and supply it to production engineers. To shorten the period of a new automotive development and reduce the rework cycle of prototyping and tests, it is necessary to be able to manufacture the product efficiently at a reasonable cost, in addition to "maintain functionalities and performance".

The key three simulations for the "productivity evaluation" are NC data teaching for welding robot, etc and "equipment movement simulation (robot simulation)" (Fig.9), "worker's assembling activities" and "forming simulation" such as die sequence.

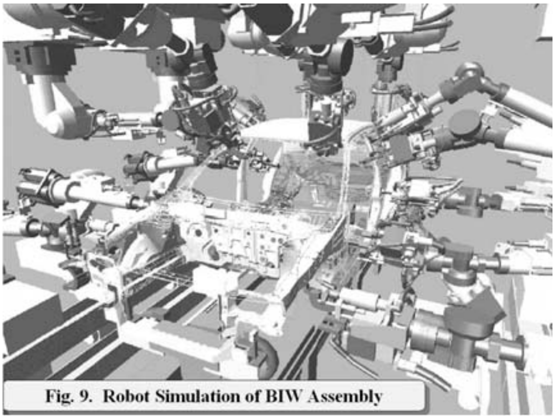

Fig.9. Robot Simulation of BIW Assembly

All of them have more than 10 year history as digitization technology application, and have achieved complete application of CAPE to maintain productivity with only one time mass prototyping. Conventional CAPE used to "check extracted portion" in the process including a potential problem has been improved to standardize necessary items to be checked based on error information from past manufacturing and to extend a limited number of portions to be check to the all. This leaded CAPE to the level that can be called as "Digital prototyping" and realized a successful level of productivity with one-time mass prototyping.
In the CAPE area, although necessary technology was ready to be used, the foundation of "preparation of product data" was incomplete, which had not lead to a large achievement. However, it had been rapidly improved by "reinforcing product data with complete DMU" and by "arranging the environment", and became an innovation.

Table 1: "Seven countermeasures for digitalization" and contributions for "Three Process Innovations"

Process Innovations / Countermeasues	CAD/CAM unification	Data Master Process	Digital Engineering Release Proces
(1) Realization of Styling CAD	◎	○	
(2) Body structue master data method, "KOGEN method"	◎	◎	
(3) Basic design work by DMU (Digital Mock Up)		◎	◎
(4) Drawing-less process		◎	◎
(5) Knowledge CAD			◎
(6) Use of analysis simulation		○	◎
(7) Digital production process verification		○	◎

Table 2: "Seven countermeasures for digitalization" and its Details

Countermeasures and effect	Detail countermeasures
(1) Realization of Styling CAD	(a) Establish Styling CAD system
Assure initial 3D data of styling parts	(b) Train Styling CAD modeler
	(c) 3D shape measurment machine for full size cray model and deployment
(2) Body structue master data method, "KOGEN	(a) Establish the work division of Engineer and CAD designer
Assure "Growth of 3D Data" of auto body combined by Styling and Structure	(b) Train CAD designer
	(c) Create the detail parts shape and assure for Tooling Division
	(d) Release simplified drawing from Body master data
(3) Basic design work by DMU	(a) Establish DMDR
Concurrent engineering with collabolation of desgner, analysit and production engineer	(b) Keep DMU experts team and data creation organization
	(c) Make the rule of DMU-BOM and apply placticaly
	(d) DB system which create and maintain DMU BOM structure and parts 3D data
(4) Drawing-less process	(a) Make rules for three items, 3D-data, asistant drawings, data notes
Speedup of technical information flow from design division to dawnstream devision	(b) Establish the system to connect several division and several companies
	(c) Establish the deliverly rules of Proposal drawing data with suplyers
	(d) Develop and promotion of simple CAD system which is able to receive Drawing-less data
(5) Knowledge CAD	(a) Standerization of design procedure and its digital description
Speedup of design study and keep design quality	(b) Establish "Design guidance system" and penatration
	(c) Develop 3D-CAD Template and penetration for actual work
(6) Use of analysis simulation	(a) Develope technology to evaluate the performance in experiments experience.
DMU performance evaluation instead of physical experiments	(b) Improve the accuracy of Body structural analysis which require longest lead-time.
	(c) Shorten the lead-time to priare the final DMU
	(d) Establish the dedicated body structuring Man-power,
(7) Digital engineering process verification	(a) Introduction CAPE systems and promote
DMU productivity evaluation instead of physical models	(b) Training of Dedicated CAD designers process in German
	(c) Standerization items should be defined, and sutisfy for 1 day stay/

3. The Collaborative Digital Process Methodology

A new product development is defined as that a manufacture "decides consisting components (by designing/choosing them)", "makes a layout for building up the product", "check if the functionalities and performance meet the requirements of the product" and "verifies if the product can be manufactured at a reasonable cost". Currently, most of the engineering needed for product development can be verified in the digital environment such as "layout by DMU", "functionalities and performance by CAE" and "productivity by CAPE".

"Seven schemes for digitalization", described before, have the relation of mutual dependence and mutual contribution. I have named the scenario, which have achieved the "Three Process Innovations" by collaboration of seven schemes, "The Collaborative Digital Process Methodology". It will support the process innovation not only in automotive industries but also in other manufacturers.

"The Collaborative Digital Process Methodology" is constructed by "Growth and Utilization of Data" and "Concurrent Engineering with Event-DR". We can recognize that "Growth and Utilization of Data" is technical methodology and "Concurrent Engineering with DR-events" is organizational methodology.

3.1. Growth and Utilization of Data

"Growth and Utilization of Data" is the approach of defining 3D shapes roughly and using them for layout or analysis roughly on the basic planning phase, and in connection with design progress, developing the 3D shapes to be detailed in order to be supplied for required engineering verification step by step. The old process creating a 3D geometry model from the results of designs created in 2D and conducting verification of analysis and production engineering using the 3D model does not help intentional design, just like making the engineers count the age of dead children. Developing design, engineers create a 3D shape based on undecided design information, verify it with CAE and CAPE, and then decide the design. That is "growth and utilization of a 3D model" (Fig.10).

This Methodology enables to eliminate the loss of big man-power to re-create the model data in early stage of process because of design change. Users can get the biggest advantage in 3D design work by this methodology and establish the most efficient process.

"Growth and Utilization of Data" are supported by "Seven schemes for digitalization" in the following points.

(1) Realization of Styling CAD

This is a necessary tool to create initial 3D data of styling parts. It is impossible to establish automotive 3D process without this tool.

(2) Body structure master data method, "KOGEN method"

This is the main and only one scheme to assure "Growth of 3D Data" of automotive body.

(3) Basic design work with DMU

This work is achieved by the assurance of 3D data of component parts by "Growth of 3D Data"

(4) Drawing-less process

Downstream divisions can use "Drawing-less data" instead of drawings at ease when the design division assures "3D data" and maintains "3D data".

(5) Knowledge CAD

"Knowledge CAD" tools always assure up-to-date "3D data of component parts" and "DMU data" needed for design verification of individual portion.

(6) Use of analysis simulation

The issued 3D DMU data is necessary to build structural analysis model. "Digital experiment model" is built from "Digital Prototype model".

(7) Digital engineering process verification

Digital engineering process verification enabled digital verification of production engineering such as in-advance verification of manufacturability.

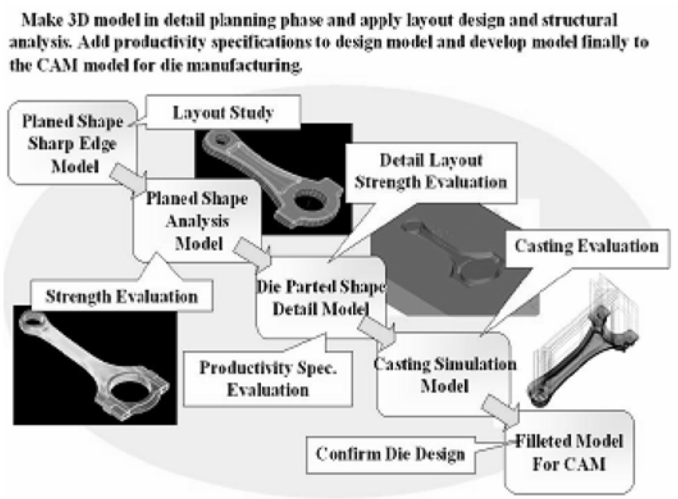

Fig. 10. Growth of 3D Model and its application

3.2. Concurrent Engineering with DR (Design Review)-events

"Concurrent Engineering with DR-events" is the approach of communicating geometry information decided in the design phase to the analysis and production engineering divisions at real time, and performing engineering verification by the specialist timely. The collaboration by several organizations is the key point to reflect production engineering to product design in the basic design phase.

The design work is defined that "a designer decides design specifications temporarily", "a performance reviewer evaluates whether or not the functionality and performance meets the specifications", and "a production engineer verifies the productivity using the specifications". The design work is also defined as the collaborative task that the expert in each field shares same 3D data and modifies the best specifications for a certain level of satisfaction (Fig. 11).

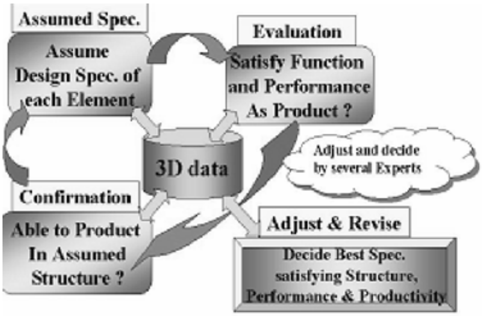

Fig. 11. Design work with collaboration

Practically, as shown in Fig. 12, "Product designer", "Parts designer", "Analysis engineer" and "Production engineer" make collaborative work and progress the product development according to the processes "Concept design"--> "Detail design"--> "Design release for prototype".

"Concurrent Engineering with DR-events" is supported by "Seven schemes for digitalization" in the following points.

(1) Realization of Styling CAD

Styling CAD enabled to release the styling data timely to the design division and die division. It has achieved early feed back to design and early start for die production.

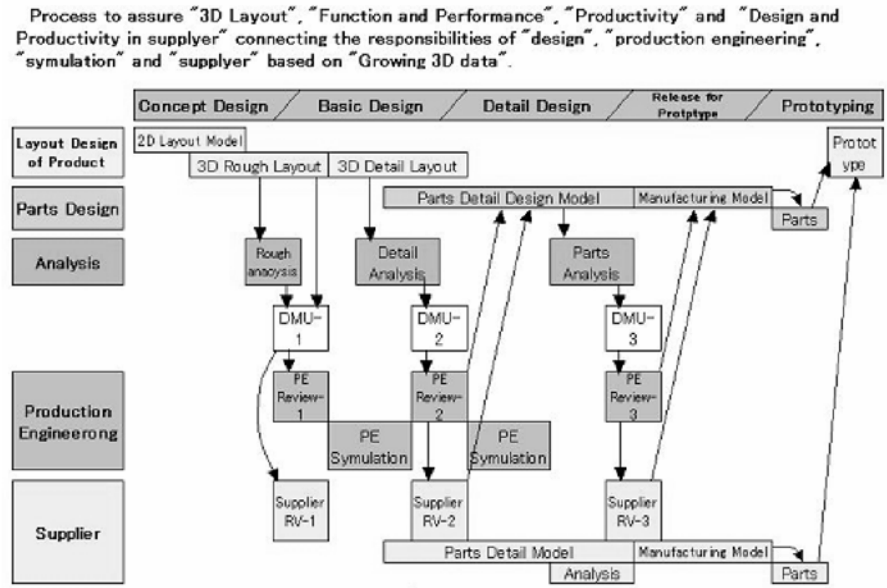

Fig. 12. Digital Collabolation Process

This contributed the biggest role to establish the concurrent engineering.
(2) Body structure master data method, "KOGEN method"
(3) Basic design work with DMU
Basic design work with DMU is the concurrent engineering itself performed with collaboration by designers, analysts and production engineers.
(4) Drawing-less process
This achieved the speedup of technical information flow from the design division to downstream divisions.
(5) Knowledge CAD.

Table 3: “The Collaborative Digital Process Methodolody” and “Seven countermeasues for digitalization”

Process Innovations / Countermeasues	Growth and Utilization of Data	Conccurent Engineering with DR(Design Review)-events
(1) Realization of Styling CAD	◎	
	Create Initial 3D data of sdtyling parts	"Early design feed back" and "early start to manufacture die"
(2) Body structue master data method, "KOGEN method"	◎	○
	Assure "Grawth of 3D data" of Body	Biggest contribution to realize "concurent Engineering"
(3) Basic design work by DMU (Digital Mock Up)	○	◎
	Assure component 3D data and "Grawth of 3D data" of Body	Realyze concurent engineering by collabolation with several division.
(4) Drawing-less process	○	
	Assure 3D data	Share technical data by several division
(5) Knowledge CAD		◎
	Assure "Parts data", "DMU data" in recent	"Early styling feed back" and "early manufacturing feed back"
(6) Use of analysis simulation	○	◎
	Achieve Digital experiment car	Collabolation of "Design spec." and "Evaluation by Productibity"
(7) Digital production process verification	○	◎
	Achieve Digital puroduction car	Collabolative Process for "Design Specs." and "Productivity confirmation"

With speedup of design study, it contributed the early feed back to styling change and early consideration of engineering requirements.
(6) Use of analysis simulation
By establishing "Early analysis evaluation" through DMU, it enables the speedy feed back cycle between "design specifications" and "functionality and performance evaluation".
(7) Digital engineering process verification
The collaboration cycle between design and production engineering has become speedy because all of the parts were processed in 3D data and the BOM system assured related data including specifications with the design division. It achieved the efficient study by production engineers and tremendously improved accuracy of verification.

3.3. Procedure to make "The Collaborative Digital Process"

To make "Process innovation action plan" for the targeted product development work, characteristic of the product, development organization and today's progress of digitalization should be considered. It is not true that "Seven schemes for digitalization" is always adaptable for any products or any organizations. We will study and analyze today's works at first, decide what work should be focused on, and select what schemes should be applied from "Seven schemes for digitalization" and 25 detail schemes. Through these processes, we are going to make the most suitable action plan and receive an approval from the person in charge to get start the action.

Fig. 13 shows the practical process, beginning with "Study current situation", through "make schemes" to make up "action plan" finally.

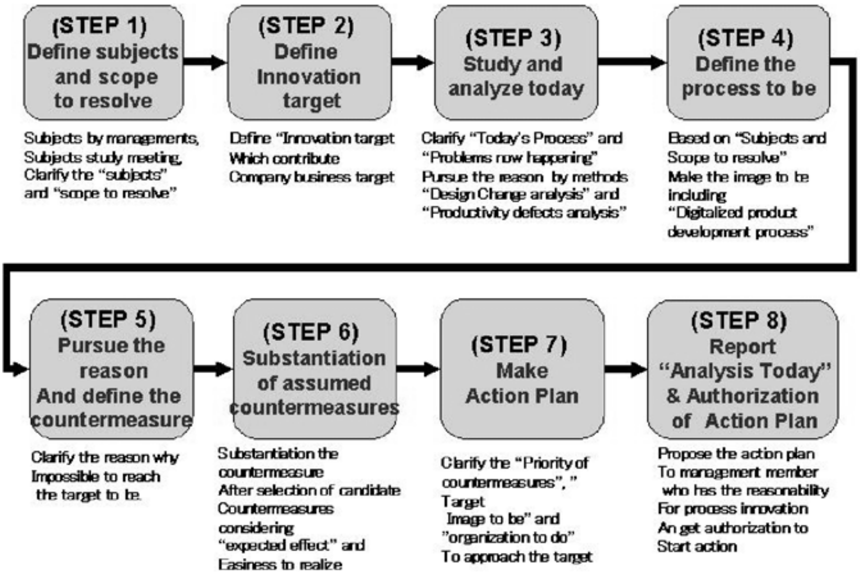

Fig.13 Procedure to make "The Collaborative Digital Process"

4. Conclusion

Today's "super-shortened process" is the result that the automaker has extruded the maximum synergy effect combining the "Seven schemes for digitalization" organically. I have established "The Collaborative Digital Process Methodology" based on my experiences to achieve these process innovations in the automaker.

Japanese automotive manufacturers have had advancement in product design and product manufacturing technologies. Japanese manufacturers have a big challenge that the automotive manufacturers have to use digitization technology efficiently and appropriately and continue having the ability to release their attractive products to the market in a short period of time. It can be said that 30-year effect for improvement in the Japanese way leads to their ability to develop the best products in the world. That is derived from their cleverness on using digital technology with scrap-and-build policy and from their effort "Continuation is power".

I would like to make effort to achieve the digital process innovation by this "The Collaborative Digital Process Methodology" for all of the manufacturing industries, using "Seven schemes for digitalization" and 25 detail schemes.

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