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Original Paper

A New Automobile Product Development Design Model: Using a Dual Corporate Engineering Strategy

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Abstract

This study describes a "New Automobile Product Development Design Model" (NA-PDDM) using a "Dual Corporate Engineering Strategy" for the innovation of automobile product engineering fundamental. Specifically, NA-PDDM contains both of the "Exterior design engineering strategy" and "Driving performance design engineering strategy" by using "Customer Science Principle" (CSP). Concretely, the foundation of NA-PDDM consists of the "Automobile Exterior Design Model with 3 Core Methods" (AEDM-3CM), "Automobile Optimal Product Development Design Model" (AOP-DDM) and "CSP-Customer Information Analysis and Navigation System" (CSP-CIANS). The validity of NA-PPMM is then verified through the actual applications to automobile product development design in Toyota and others.

Keywords

New Automobile Product Development Design Model, a Dual Corporate Engineering Strategy, Toyota

1. Introduction

In recent years, customers have been selecting products that fit their lifestyles and their set of personal values. For this reason, manufacturers' success or failure in global marketing will depend on whether or not they are able to precisely grasp the customers' preferences, and are then able to advance their manufacturing to adequately respond to the demands of the times (Amasaka, Ed., 2012; Amasaka et al., 2012; Amasaka, 2017, 2018). Particularly, looking closely at the quality management issues "Unpopularity of appearance design quality and Recalls of driving performance" facing Japanese advanced automotive manufacturing industry both domestically and overseas, it has become clear that a new corporate management technology by focusing "Product development design strategy" is being strongly sought after (JD Power and Associates, 1998; Umezawa & Amasaka, 1999; Amasaka, 2002, 2007a,b; 2014; Nihon Keizai Shinbun, 2000, 2006, 2012).

The mission of automobile manufacturers (automakers) in this rapidly changing management technology environment is to be fully prepared for worldwide quality competition so as not to be pushed out of the market, and also to establish a new management technology model that enables them to offer highly value products of the latest design that are capable of enhancing customer value.

In this study, to strengthen high quality assurance, super short-term products development design process and simultaneous achievement QCD (quality, cost and delivery) for the "customer value creation", the author establishes a "New Automobile Product Development Design Model" (NA-PDDM) using a "Dual Corporate Engineering Strategy". NA-PDDM develops the "Customer Science Principle" (CSP) by employing both "Affective engineering named Kansei Engineering" and "statistical science named Science SQC" (Amasaka & Nagasawa, 2000; Amasaka, 2002, 2004, 2005).

Specifically, NA-PDDM contains both "Exterior design engineering strategy" and "Driving performance design engineering strategy" for the developing "appearance quality and functional quality" that contributes to strengthening of Japanese automobile global corporate strategy. Because of that realization, to develop the "Same quality worldwide and products development design at optimal locations", the foundation of NA-PDDM consists of the "Automobile Exterior Design Model with 3 Core Methods (AEDM-3CM), "Automobile Optimal Product Development Design Model" (AOP-DDM) and "CSP-Customer Information Analysis and Navigation System" (CSP-CIANS), The validity of NA-PPMM is then verified through the actual applications to automobile product development design in Toyota and others (Amasaka, 2020, 2021, 2022).

2. The Key to Success in Automobile Global Production for Realizing Customer Value Creation

2.1 What are the Critical Management Issues for Japanese Automobile Manufacturing?

In recent years, customers have been selecting products that fit their lifestyles and their set of personal values in marketing on the world. Furthermore, with the rapid move towards global production, it has become increasingly critical for manufacturers to drastically shorten the time it takes to move a product from "product development design to production" while ensuring quality of Customer Satisfaction (CS) (Amasaka et al., 2012). Consequently, a market environment was created in which customers strictly judge the products' reliability (quality and value gained from use) of automakers.

For this reason, to develop the marketing creation, it is not an exaggeration to say that automakers' success or failure in global marketing will depend on whether or not they are able to precisely grasp the customers' preferences and are then able to advance their production to adequately respond to the demands of the times (Amasaka, 2005, 2007a, 2011; Okutomi & Amasaka, 2013).

Particularly, the technological renovation of product development design is indispensable in order to realize strengthen global marketing that will achieve the globally consistent levels of quality and simultaneous production at optimal locations (Refer to Appendix A). To realize this, it is important to developing the "high Quality Assurance (QA), super-short-term product development design process and simultaneous achievement QCD (Amasaka, Ed., 2007a, 2007b; Amasaka et al., 2012; Amasaka, 2017, 2018). To carry out the above various subjects, there are two critical management issues in the Japanese product development design section to raise that position as a top-runner from now on, too.

First, as customers' values become increasingly diverse, automobile exterior design is becoming one of the most critical elements influencing customer purchase behavior for automakers. Unfortunately, as people's values and subjective preferences become more varied and complex, it becomes increasingly difficult to accurately define their wants and needs. Therefore, it is important for mapping up exterior design strategy to study on "what style of vehicles would sell in the future?". However, in many cases, automaker's vehicle designers do not have a clear idea of future vehicle styling (Amasaka et al., 1999).

Success of designing directly affects the sale of enterprises. Therefore, design business is established as a marketing strategy and its significance lies in the quality of the proposal. True market-in should be in proposing a desirable thing before it is desired. From Figure 1, it is important for "Design SQC" to contribute to enhancing individual designer's proposing capability using "Science SQC". Conventionally, designing is generally developed directly to the profile design after analyzing the research itself (event analysis) (Amasaka & Nagaya, 2002).

To respond to such a trend of vehicle exterior design, it is essential to conduct a scientific approach whereby the objective preferences of customers' tastes are accurately grasped and reflected in the vehicle exterior and interior designing process for realizing "vehicle appearance quality". Specifically, by employing both "affective engineering named Kansei Engineering" and statistical science named "Science SQC", the author has developed an automobile exterior and interior design tool "Intelligence Design Concept Method" (CSP-IDCM) by the development of the following "Customer Science Principle" (CSP) (Amasaka & Nagasawa, 2000; Amasaka, 2004, 2005) (Refer to Appendix B).

Second, in the midst of rapid change of management technologies, a key challenge facing the

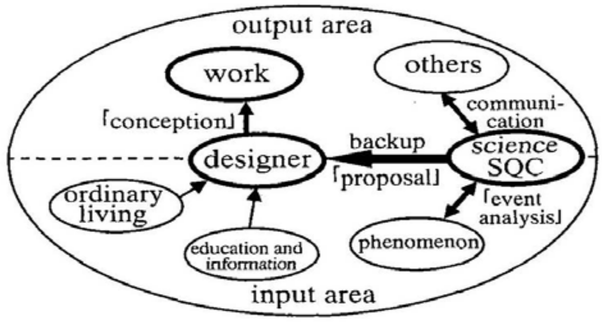


Figure 1. Desirable Relationship between "Designing" and "Design SQC"

automakers is important to develop the new Japanese product development design which provides the latest, highly reliable and customer-oriented products so that they can survive the worldwide quality competition. Focusing on management technology for product development design and production processes, it is clear that there has been excessive repetition "trial-and-error" of prototyping, testing and evaluation for the preventing of "scale-up effect" in the bridging stage between product development design and mass production (Amasaka Ed., 2007a; Amasaka, 2007a, 2017; Amasaka et al., 2012).

Above all, to realize the excellent "vehicle driving functional quality", the advanced automakers must establish the "intellectual evolution of the product development design" in order to realize the "simultaneous achievement of QCD". Specifically, the author has developed a "Total QA High Cyclization Business Process Model" (Amasaka, 2008). This model aims to shifting from the way of insisting on "business process management from experimental evaluation based on tests and prototypes" until now to the combination with "predictive evaluation" through the latest highly reliable numerical simulation (Computer Aided Engineering, or CAE" (Refer to Appendix C).

Concretely, to develop this model, the author has created the "Highly Reliable CAE Analysis Technology Component Model" with four components "problem-modeling-algorithm-theory-computer" as shown in Figure 2 was designed to make the shift from conventional prototype testing methods to effectively applying CAE in predictive evaluation methods. The comprehensive issuance of this model is essential to achieving the desired shift (Amasaka, Ed., 2007b: Amasaka, 2008, 2010).

In Figure 2, the critical aspects of this model include (i) *defining the problem* (physically checking the actual item) in order to clarify the mechanism of the defect, using visualization technology to identify the dynamic behavior of the technical issue; (ii) full use of *formulization techniques* to generate logical *modeling* (statistical calculations, model application); (iii) constructing compatible a*lgorithms* (calculation methods); (iv) developing *theories* (establishing theories required to clarify problems) that ensure the precision of numerical calculations and sufficient computational capability; and (v) comprehensively putting the above processes in action using *computer* (selection of *calculation technology*).

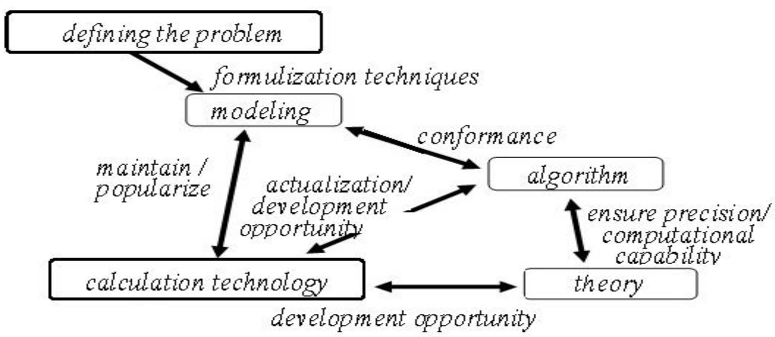


Figure 2. Highly Reliable CAE Analysis Technology Component Model

2.2 Developing Customer Science Principle Aiming Customers' Demand Scientific Analysis

The mission of automakers is to offer products that please customers, and make this serves as a basis for sustainable growth. In this new era, when product development design is required as a basis of global marketing, it is important to establish a "behavior science principle" for strategic product development which can dig deep into the customers' demands (needs, desires and wants) and thus preempt the trend of times (Amasaka, 2003, 2005, 2018). Customers express their demands in words.

Therefore, the product planners or designers engaging in product development design must properly interpret these words and draw up accurate plans accordingly. The "Customer Science Principle" (CSP) aims an automobile exterior design for customer value creation with a clear-cut styling concept based on research of psychographics by the viewpoint of customers' life stage and lifestyle as shown in Figure 3 (Amasaka, 2002, 2005, 2007b, 2018; Takimoto et al., 2010).

It is intended to indicate the desirable state of new business processes for creating wants indispensable to the development of attractive products. In Figure 3, the image of customer's words (implicit knowledge) is translated first into common language (lingual knowledge) and then into engineering language (design drawings as explicit knowledge) by means of appropriate correlation. In other words, objectification of subjective information is important for product development. It is also important to transform objective drawing into subjective information through correlation to check where engineering successfully reflects customer requirements.

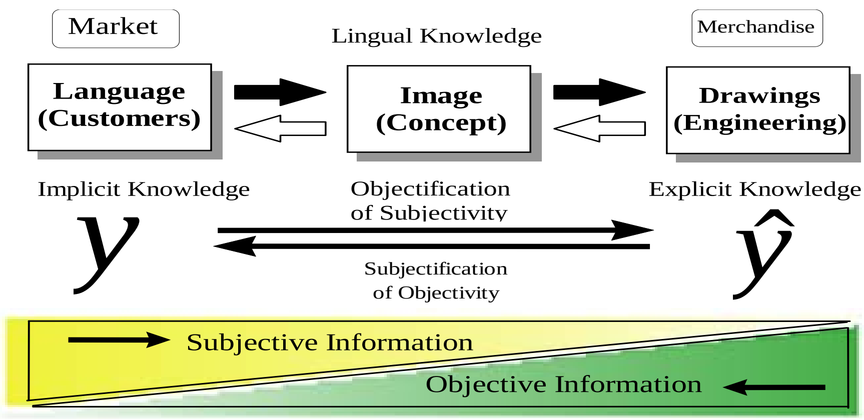


Figure 3. Schematic Drawing of Customer Science Principle (CSP)

This refers to the CSP that converts subjective information (y) and objective information ($\hat{y}$) reasonably to two-way through application of correlation technology. The author surmises that the implementation of CSP improves the precision of "idea—product creation" in the business process of product development and designing and thus further ensures the accumulation of successful cases as well as the failure cases more than ever before. Taking an approach using CSP can convert a variety of issues—why the customers are pleased with this particular product, or why they complain about it, what is the underlying factor in this expression from the customers, and what type of products must be offered next time, or in what situations defective products are manufactured—into a common language, and also into the technical terms relevant to the manufacturing field.

The designing or development staff can convert such verbal expressions into numerical terms using correlation techniques in their laboratory or experiment room for simulation to objectify their parameters in order to confirm where the customers' demands are satisfied. Moreover, in order to double check whether their objectification is properly conducted, it is vital for them to subjectify the results of objectification using correlation techniques to ensure what has been drawn up on a plan that specifically reflects what are the customers' demand. It has been observed that thriving manufacturers today in Japan and in the world, endeavor to convert implicit knowledge into explicit knowledge in an effort to grasp the customers feelings to the largest extent possibly, and to feed-back what has been drawn up to consider whether the original objective has been realized or not, thus, always subjectifying the objectification: Such a humble attitude seems to be the manufacturers' essential growth base.

3. Establishment of a "New Automobile Product Development Deign Model" using a "Dual Corporate Engineering Strategy"

To strengthen high quality assurance, super short-term products development design process and simultaneous achievement QCD for the "customer value creation", the author has established a "New Automobile Product Development Design Model" (NA-PDDM) using a "Dual Corporate Engineering Strategy" as shown in Figure 4. NA-PDDM develops the CSP by employing Kansei Engineering and Science SQC (Amasaka and Nagasawa, 2000; Amasaka, 2004).

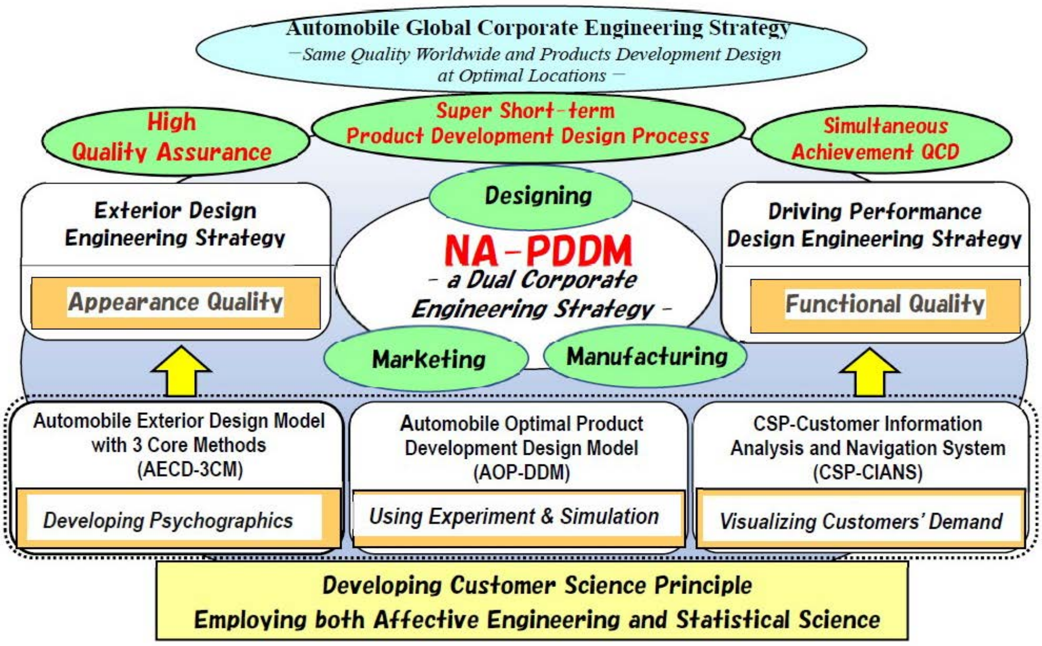


Figure 4. A New Automobile Product Development Deign Model using a Dual Corporate Engineering Strategy

Specifically, NA-PDDM contains the both "Exterior design engineering strategy and Driving performance design engineering strategy" for the developing "appearance quality and functional quality" that contributes to strengthening of Japanese automobile global corporate strategy. Because of that realization, to develop the "Same quality worldwide and products development design at optimal locations", the foundation of NA-PDDM consists of the "Automobile Exterior Design Model with 3 Core Methods" (AEDM-3CM), "Automobile Optimal Product Development Design Model" (AOP-DDM) and above CSP-CIANS as follows;

3.1 Automobile Exterior Design Model Employing 3 Core Methods for Progressing psychographics

To develop above the Design SQC using CS-IDCM for progressing *psychographics*, the author has conducted the "Advanced Exterior Design Project using Science SQC" named "ADS" for raising customers worth in Toyota Motor Corp. in the following (Nunogaki et al., 1996; Amasak et al., 1999).

As for the development of ADS, the author as the chief examiner of TQM Promotion Div. (1992-2000), and Amasaka's New JIT Laboratory of Aoyama Gakuiin Univ. (2000-2017) has organized the (i) Design Div. I of Vehicle Development Center I for the development of new world car "Lexus", Design Div. II of Vehicle Development Center II for other model change of various mid-size cars, and Toyota Design Laboratory Tokyo for Advanced design cars, (ii) Marketing Service Div., Dealer Marketing System Div., Autosalon Amulux Tokyo, U.S. Office, Europe Office and others for the internal and external customers information gathering, and (iii) TQC Promotion Div. for developing Design SQC (Nunogaki, 1996; Nagaya et al., 1998; Amasaka et al., 1999).

In ADS projects, the author has developed the "Automobile Exterior Design Model with 3 Core Methods" (AEDM-3CM). This model combines 3 core methods as follows; (A) Improvement of "Business Process Methods for Automobile Profile Design" (BPM-APD), (B) Creation of "Automobile Profile Design using "Psychographics Approach Methods" (APD-PAM), and (C) "Automobile profile design, form and color matching support methods" (APFC-MSM) as shown in Figure 5 (Amasaka, 2018). As developing CSP, the actual studies for AEDM-3CM have been applied to Toyota and others

In core technology (I), the first aim was to hold the characteristic of the profile design (proportion) such as "BMW518, Benz W123, Jaguar X16, etc." placed on the famous car of the world rationally by

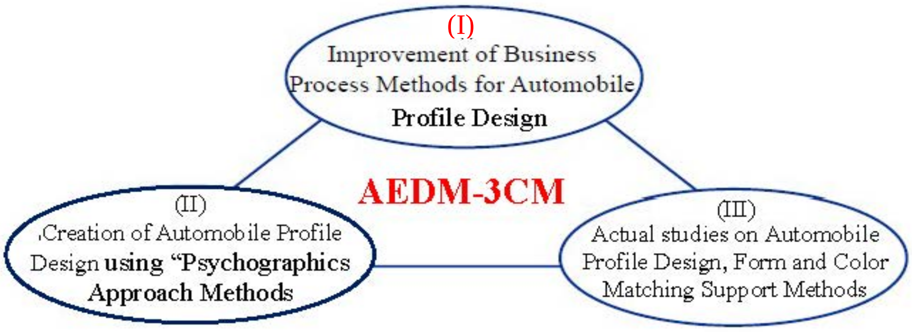


Figure 5. Automobile Exterior Design Model with 3 Core Methods (AEDM-3CM)

the concrete development of AEDM-3CM using Design SQC and CS-IDCM. To realize the above knowledge, in core technology (II), the second aim was the realization of the profile design, which is the main elements of exterior design of Toyota's strategic prestige car "new-model, Lexus" surpassing BMW / Benz by using the "Psychographis" approach method. In core technology (III), the third aim was the realization of the profile design development of various mid-size cars by the application of Lexus exterior design development employing both (I) and (II) (Refer to Amasaka (2018) in detail).

Specifically, then, the design work of (III)"APFC-MSM" which is the core technology of the strategic development of ADS projects at present is illustrated by developing the various psychographics approaches as shown in Figure 6 (Toyoda et al., 2015; Amasaka, 2018). In Figure 6, APFC-MSM starts with the three elements (1) profile design (proportion), (2) form, and (3) color.

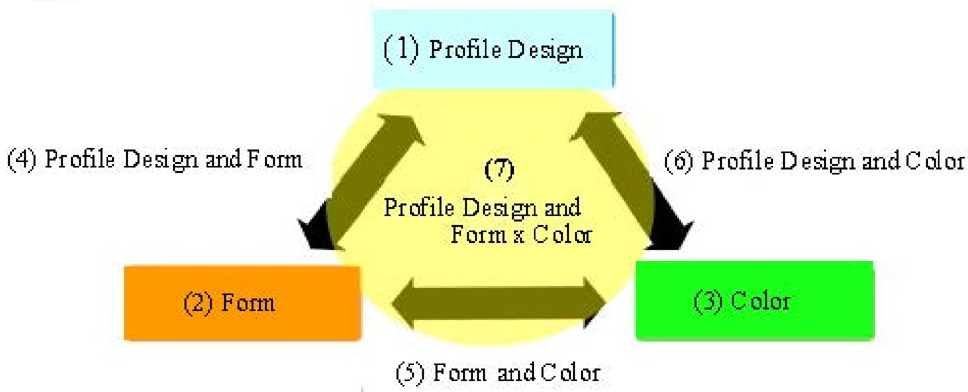


Figure 6. Automobile Profile Design, Form and Color Matching Support Methods (APFC-MSM)

Recent design work strategies make it a point to optimize business processes so that they are in line with the vehicle design concept from the product planning stage. Next, each element must be matched: (4) profile design and form, (5) form and color, and (6) profile design and color. Finally, (7) all three elements "profile design, form, and color" must be integrated harmoniously to address modern market demands. At present, based on the knowledge acquired by above-mentioned subsection (A) and (B), the authors are tackling the development of AEDA-3CM by using APFC-MSM currently.

These studies were carried out in the Amasaka New JIT laboratory by collaboration with Toyota Motor Corp., Toyota Tokyo Design Research Laboratory, Nissan Motor Corp., Honda Motor Co., Ltd., Mazda Motor Corp., Nippon Paint Co., Ltd., Kansai Paint Co. Ltd. and others (Amasaka, 2018). Concretely, to realize the validity of the Design SQC and CS-IDCM, the author has expanded AEDM-3CM employing CSP using CSP-CIANS in the next subsection 3.3, and indicates the applications (A), (B) and (C) in the next Chapter 4 (Refer to Amasaka (2015a, 2021, 2022) in detail).

3.2 Total Intelligence CAE Development Design Model for Realizing High Precision and Control

Generally, at the design and development stage, there is a gap (discrepancy) between prototype evaluation results and CAE analysis results (Magoshi et al., 2003; Amasaka et al., 2012). It has become evident that some manufacturers are not fully confident in CAE results. Then, to win for the world quality competition. the author organized both of "Study Group of the Ideal Situation on the Quality Management of the Manufacturing Industry" in Union of Japanese Scientist and Engineers" (JUSE) and "Working Group No. 4 studies for establishment of a needed design quality assurance for numerical simulation at automotive industry in Japanese Society for Quality Control (JSQC).

Specifically, the author has researched the "New product development design technique employing strategic CAE application" named "New Japan Development Design Model" (NJ-DDM) (Amasaka, 2007a, 2007b, 2015b). As a concrete instance, to develop the above "Highly Reliable CAE Analysis Technology Component Model" using CSP, the author has developed the "Total Intelligence CAE Management Model" in order to achieve highly-accurate CAE analysis equivalent to prototype testing results as shown in Figure 7, which contributes to high quality assurance as well as QCD simultaneous achievement in automobile development design (Amasaka, 2008, 2010; Amasaka et al., 2012).

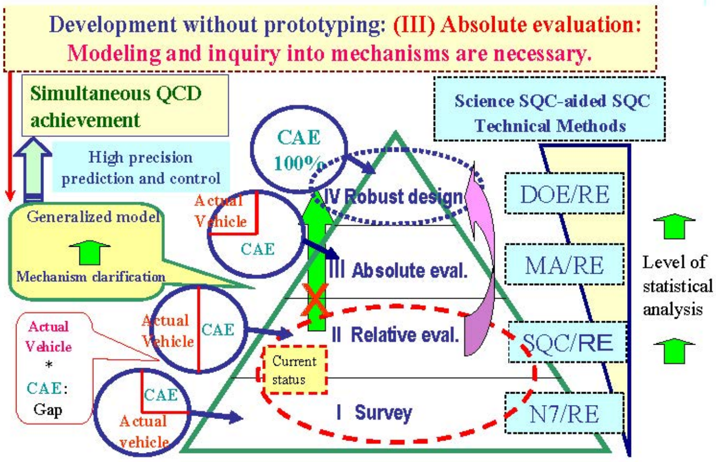


Figure 7. Total Intelligence CAE Management Model

In Figure 7, many manufacturers are aware of the gap between evaluations of actual vehicles and CAE, and not fully confident in CAE results, they prefer to conduct Step (I) survey tests with actual vehicles rather than CAE evaluation. Even among leading corporations, Step (II) CAE utilization is limited to relative evaluation. The author noticed a situation where, as shown in the figure, the application ratio of CAE to actual vehicles is about 25% for surveys and about 50% for relative evaluation revealing the dilemma that the effectiveness of CAE invested for reduction in development time has not been fully utilized. Based on the above, in Step (III), as seen in the figure, the mechanism of the pending technical problem was clarified through visualization technology, and the technical knowledge which enables absolute evaluation through the creation of generalized models was incorporated in the CAE software.

As a result, it was confirmed that the accuracy of CAE analysis had improved and the application ratio of CAE had increased to about 75%. Based on the technical analysis derived from Steps (I) to (III), Step (IV) further incorporated a robust design which take into consideration the influential factors and contributing ratio needed for optimal design, thus enhancing the accuracy of CAE calculation, and demonstrating a remarkable increase in the ratio of CAE application. Then, to successfully develop the above AOP-DDMH, the author has created the “Highly-Reliable CAE Analysis Technology Component Model” required for highly precise CAE analysis software as shown in Figure 8 (Amasaka, 2007c, 2008; Amasaka, Ed., 2007b).

Specifically, in Figure 8, the process of CAE first starts with (1) “Problem”－Setting of problems to be solved, as well as (2) “Modeling”－Modeling of these problems as some type of mathematical formula. In CAE, when using calculators as a means to analyze the model, such a means of analysis needs to be provided in the form of a calculation procedure, namely, (3) Algorithms－So that the software can perform calculation. (4) "Theory"－The validity, applicable range, and performance or expected precision of such algorithms themselves can be deduced from some kind of theory. (5) "Computer"－Needless to say, the technology related to the computer itself functioning as "hardware" to realize the algorithms, is undoubtedly a factor having a large effect on the success of CAE.

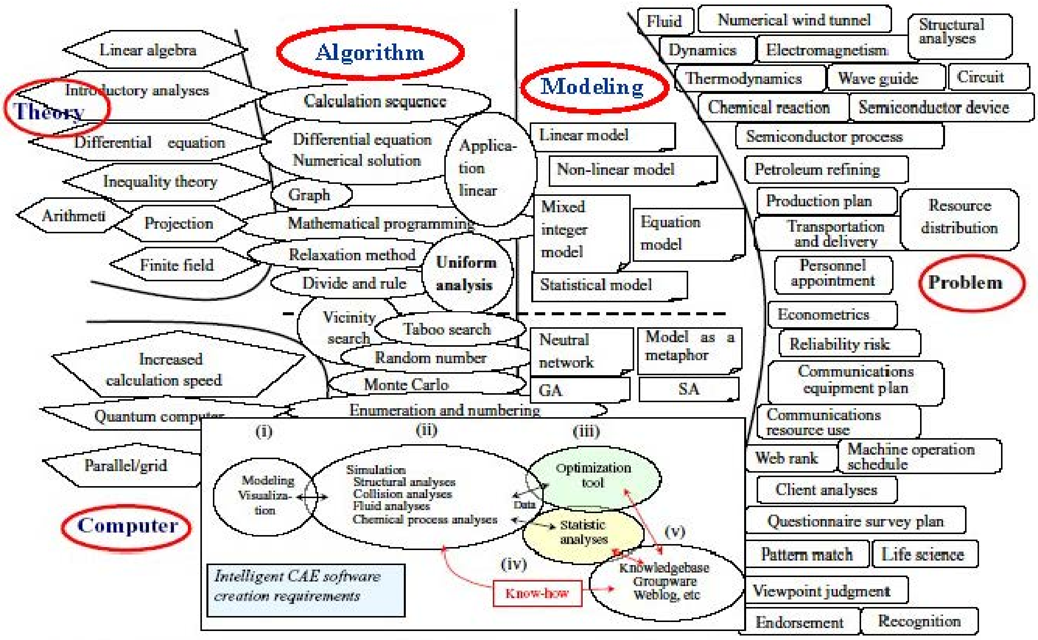


Figure 8. Highly Precise CAE Technology Component Model (HR-CAE-ATCM)

Moreover, from the viewpoint of achieving highly-reliable CAE analysis, the author illustrates the "Intelligence CAE software creation requirements" described in Figure 8 as follows (illustration: Knowhow linkage-cycle with reciprocal action from (i) to (iv)); linkage-cycle (i) Modelling visualization, (ii) Simulation (: Structural analysis, collision analysis, fluid analysis, chemical process analysis, etc.), (iii) Optimization tool, (iv) statistical analyses, (v) knowledge base.

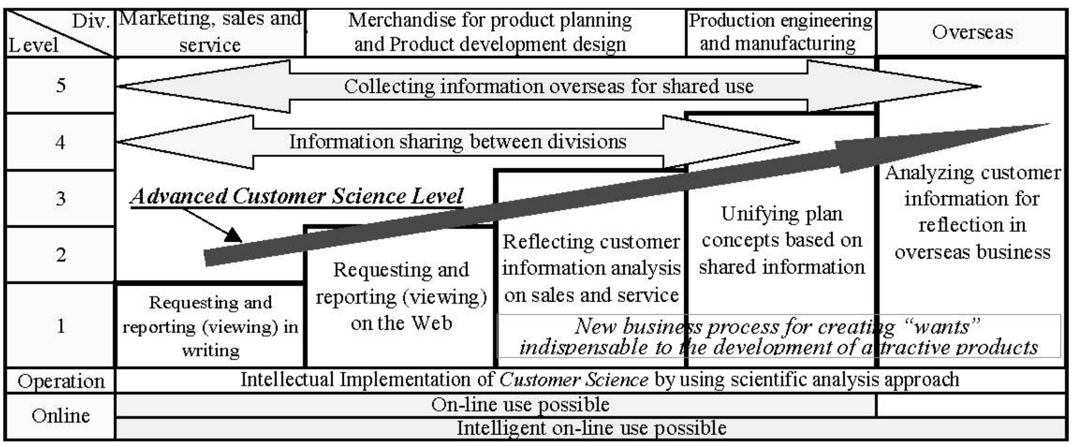
Success in AOP-DDM depends on the "collective strengths" of the elemental technologies. The formulation of such "implicit knowledge" confined to the personal know-how of the engineers is an indispensable step to be taken for sophistication of CAE as a Problem-Solving method. Then, skilled CAE engineers are not experts in all the fields of the elemental technologies, but they understand their characteristics and interactions as the "implicit knowledge" and thus conduct selection combination to obtain favorable interactions and consequently the desired results. Therefore, it is positioned as a major theme in author's work (Whaley et al., 2000; Nonobe and Ibaraki, 2001; Enrique, 2005; Amasaka, 2008, 2010; Amasaka, Ed., 2012).

3.3 CSP-Customer Information Analysis and Navigation System for Visualizing Customer Demand

Today, growing companies both in Japan and abroad try to grasp the unprejudiced desires of their customers from the viewpoint of customer-oriented business management and to reflect these desires in future product development design. However, the actual behavioral patterns (conception methods) of designers (new product planners and development designers) in trying to grasp latent customer desires depend heavily on the designers' empirical skills. Accordingly, designers often worry that their current business approaches are likely to depend on job performing capabilities and on the sensitivity (intuition or knack) of individual persons, which will not improve the probability of success in the future, regardless of whether or not they have "lucky success" or "unlucky failure".

For the realization of strategic products, the collection as well as intellectual analysis of information for creating customers' demands is the core essence for success in CSP. Table 1 shows the levels of systematic utilization of customer information and the modes of intellectual information- sharing among the related divisions inside and outside the company that are necessary to achieve this objective. To advance the level of execution of *Customer Science* activities, it is necessary to evolve customer information-sharing among the "Marketing, Sales and Service, Merchandise for product planning and

Table 1. Systematic Utilization Levels of Customer Information for Customer Science Activities



Product development design, Production engineering and manufacturing and overseas" from off-line to on-line (Amasaka, 2005, 2015a).

Specifically, to realize the "Collecting information overseas for sheared use" described in Table 1, the author develops the "Analyzing customer information for reflection in over business employing CSP strategy. To realize this, then, for strategic product development design employing above AEDM-3CM and AOP-DDM, it is important to explore consumer values, which are the basis for creating "demands" by employing above CSP, through the collection/analysis of customer information, and to reflect as well as exteriorize such values in product development design.

Against this background, the "CSP-Customer Information Analysis and Navigation System"

(CSP-CIANS) was constructed as shown in Figure 9 (Amasaka, 2005). As indicated therein, this system enables the networking the (1) Merchandise Div. to strengthen strategic product planning which explores customer value creation and (2) each division of the Product Development and Design to regularly receive customer data from (3) domestic and overseas dealers which are exposed to the front line of the customer desires through their marketing/sales/service activities. Similarly, the collection of customer data is also possible through (4) Consulting Spaces, namely, the showrooms promoting the company's own products or public facilities for discussions and consultations from the customers. Moreover, (5) Marketing Research Companies via (6) an exclusive company WEB.

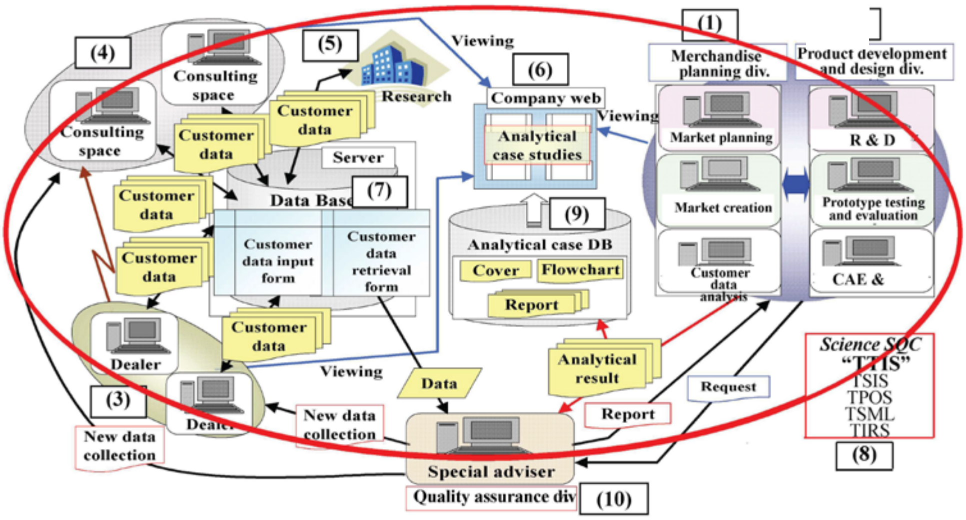


Figure 9. CSP-CIANS, networking of Customer Science application system

All these sections are connected through on-line networking for building (7) a Data Base (DB) via a server of the company's own information system division. Into this system utilizing statistical science approach - Science SQC (8), actually, the core system of SQC integration network system - "Total SQC Technical Intelligence System" (TTIS) including four core elements: the "Total SQC Intelligence System" (TSIS), "Total TQM Promotional Original SQC Soft" (TPOS), "Total SQC Manual Library" (TSML) and "Total Technical Information System" (TIRS). These are accessible for utilization from (9) Analytical case data base (DB). Particularly, cooperation requests for analysis can be submitted to (10) a special SQC adviser in Quality Assurance division (Refer to Amasaka (2004) in detail).

CSP-CIANS is designed in such a way that the collection of analytical results created by total linkage of the merchandise planning, product design, sales marketing and service for the successive development of analytical technology (Amasaka, Ed., 20112; Amasaka, 2015b, 2021, 2022)

4. Applications

In today rapidly changing corporate management technology, the aim of auto-makers by developing NA-PDMM with AEDM-3CM, AOP-DDM and CSP-CIANS is to be properly prepared for the "worldwide quality competition" so as not to be pushed out of market, and to establish strategic new management technologies that are capable of enhancing customer value creation in the world.

4.1 Actual Studies on Automobile Exterior Design Optimization

4.1.1 Developing exterior design engineering strategy using APFC-MSM

In developing APFC-MSM based on AEDM-3CM, examples of actual case studies for the business process innovation that addresses optimizing the exterior design using "psychographics and Design SQC", corresponding to (1)-(7) in Figure 5 and 6, are as follows (Amasaka, 2015a, 2020, 2021, 2022);

(1) The development of prestige car "Lexus GS400/LS430" which realized the compatibility of profile design and package design (interior space) using "Automobile Package Design Concept Support Methods". This research realizes a more creative product design process as an "Intelligence Profile Design Concept Method".

(2) Construction of the "Automotive Design Form Support Method" in order to fully understand the visualizing the relationship between form modifications as a whole (which consists of front, side and rear elements) and subjective customer's impressions using eye-tracking camera, 3D Design CAD software (CATIA V5) and Design SQC.

(3) The author has created an "Automobile Exterior Color Development Approach Model" in order to visualize the success design colors in customer demands (Muto et al., 2011). Specifically, this model determined the 4 factors (classy, luxurious, dignified and sporty) and 6 elements (hue, luminosity, intensity, shine, opacity and graininess) most desired by young buyers,

(4) The author has created the "Strategic Design Support Method for the profile design and form matching" using CSP-IDCM. Specifically, the author has visualized the preferences of younger generation through the combination of Design SQC and 3D Design CAD.

(5) The author has constructed the "Automobile Exterior Design Approach Model" for the form and color matching, which uses biometric devices along with visualization technology, 3D Design CAD and Design SQC to establish the relationship between form and body color which customers observe the overall vehicle design.

(6) The author has created the "Amasaka-Lab's Vehicle Exterior Design Approach Model" for the form and color matching using "market and preference survey, form and color analysis, creation of CAD models and verification". This focuses on the "young women preference car - luxurious, stylish, high-end & chic" using collage boards (: girlish, elegant, casual, trendy & boyish).

(7) The author has created the "Vehicle Proportion, Form, and Color Matching Model" to analyze and catch the customers' attention using "eye camera and electroencephalograph". Specifically, to identify ideal relationships among proportion, form, and color, the author has created the 3D-CAD model cars

using “experimental design and analytic hierarchy process methods”.

4.1.2 Expanding APFC-MSM for raising attractiveness to customer

Furthermore, the author has been advancing the new deployments of AEDA-3CM and APFC-MCM for mid-size and small-size cars for raising attractiveness to customer as follows (Refer to Amasaka (2015, 2021, 2022); the 1st research area is the development of “automobile exterior color and interior color matching” and auto-instrumentation design”. The 2nd is the “Scientific approach to deriving an attractive exterior vehicle design concept for indifferent customers”, and the author has proposed the “Creation of New profile design “(A) Advanced type, (B) Powerful type, (C) Progress type, and (D) Elegant type” in near future.

4.2 Actual Studies on Automobile Product Development Design Optimization

4.2.1 Automobile Optimal Product Development Design Model using experiment and simulation

In general, experienced development design staff and CAE engineers understand the mechanism that is causing the bottleneck technical problem as implicit knowledge (Magoshi et al., 2003). While many examples of calculation based on CAE analysis have been reported, the accuracy of estimation has not to be improved for satisfactory vehicle development (Amasaka, Ed., 2005).

Therefore, the author has created the “Automobile Optimal Product Development Design Model” (APFC-MSM) in an effort to help solve the bottleneck technical problem that had become a global technological issue as shown in Figure 10 (Amasaka, 2007c, 2008). To accomplish this, as the first stage, it was important to the (A) “Visualization”- visualize the dynamic behavior of the problem” by employing “Actual vehicles and equipment and carrying out testing” using “Hypothesis”. At this point the expertise of specialists from both inside and outside the company was brought together through the “Partnering” activities.

As the second stage, it was vital to deduce the (B) “Mechanism”- fault mechanism using various “Techniques”. To carry out the precise fault analysis and factor analysis, new seven tools (N7), statistical quality control (SQC), reliability engineering (RE) multivariate analysis (MA) and design of experiment (DOE) were combined and utilized to search out and identify previously unknown or overlooked latent causes. In this way, a logical thinking process was used to carry out a logical investigation into the cause of fault mechanism for the “Modeling”.

Moreover, as the third stage, all of this knowledge and information was then unified through the (C) Creation of “CAE Navigation Software” that employs “Computer graphics” (CG) to reproduce the visualization of the actual vehicle and testing data so that it can be made consistent to a “Qualitative model”. At this stage, it was important to carry out actual vehicle and testing work so that this qualitative model could be made for the “cause and effect relationships” of the unknown mechanism. It would then become extremely important to use this model to reduce the divergence (gap) between the results from the actual vehicle testing and CAE to develop the “absolute value evaluation”.

As the fourth stage, in addition, at the stage of developing the (D) “Numeric value simulation”, exhaustive actual vehicle testing was carried out in order to convert the leak mechanism from implicit

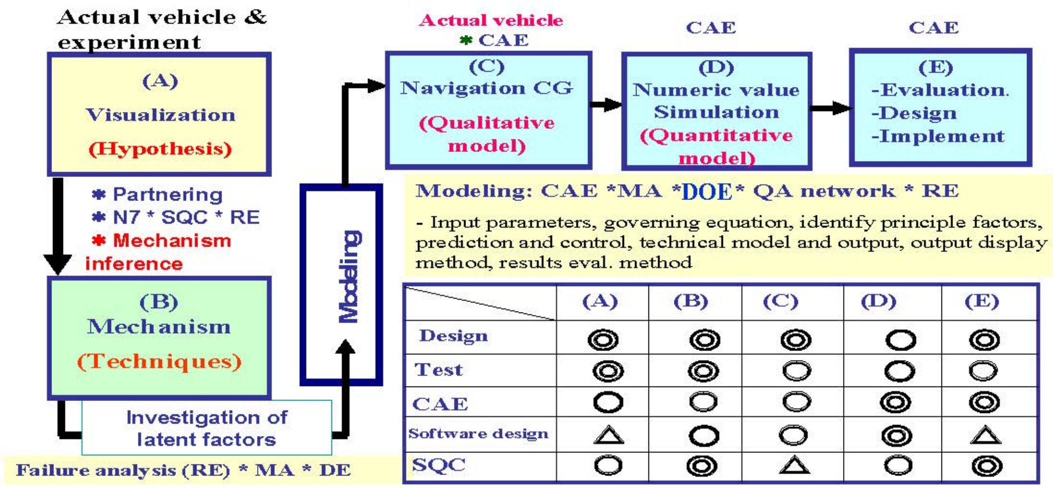


Figure 10. Automobile Optimal Product Development Design Model (AOP-DDM)

knowledge into precise explicit knowledge. The information gained from these work processes would then be unified and a “highly credible numerical simulation (Quantitative model)” would be carried out to make absolute value prediction and control possible.

In the final stage, as the (E) “Evaluation, Design and Improvement”, the CAE analysis results are then verified by comparing them to the actual vehicle testing results. In the case of a decentralized organization and business process (such as shown in Figure 7), it is essential that the specialists in the fields of design, testing, CAE analysis, CAE software design, and SQC carry out cooperative team activities, “partnering” (◎ Main, ○ Sub, △ Support) at each stage of the work process (A to E).

4.2.2 Application to AOP-DDM for raising attractiveness to customers

Then, as the application of AOP-DDM for raising attractiveness to customers, the author was able to apply the AOP-DDM to critical development design technologies for automotive production, including predicting and controlling the special characteristics of the “urethane seat foam molding” (Amasaka, 2007c), “anti-vibration design of door mirrors” (Amasaka, 2010), “transaxle oil seal leakage”, “brake pad quality assurance” (Amasaka, 2017), and “looseness of the bolt-nut tightening” (Amasaka, 2019).

In each of these cases as well, discrepancy was 3–5% versus prototype testing. Based on the achieved results, the model is now being used as an intelligent support tool for optimizing product design processes (Refer to Amasaka (2015a, 2021, 2022) in detail).

5. Conclusions

In this study, the author has created a NA-PDMM using a “Dual Corporate Engineering Strategy” for the innovation of automobile products engineering fundamental. Specifically, NA-PDDM contains the both "Exterior design engineering strategy and Driving performance design engineering strategy" for the developing "appearance quality and functional quality" that contributes to strengthening of Japanese automobile global corporate strategy using CSP.

Concretely, to develop the "Same quality worldwide and products development design at optimal locations", the foundation of NA-PDDM consists of the AEDM-3CM, AOP-DDM and CS-CIANS. The validity of NA-PPMM is then verified through the actual applications to automobile products development design in Toyota and others

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Appendixes

Appendix A: Necessity of business process renovation in automobile product development design

To provide the attractive products with customer's orientation permanently, the establishment of "new development design technologies" to take customer's needs in advance is today's challenge and current issue. Therefore, to realize this, the renovation of the business process of the automobile product development design becomes important as shown in the Figure A (Amasaka, Ed., 2007b).

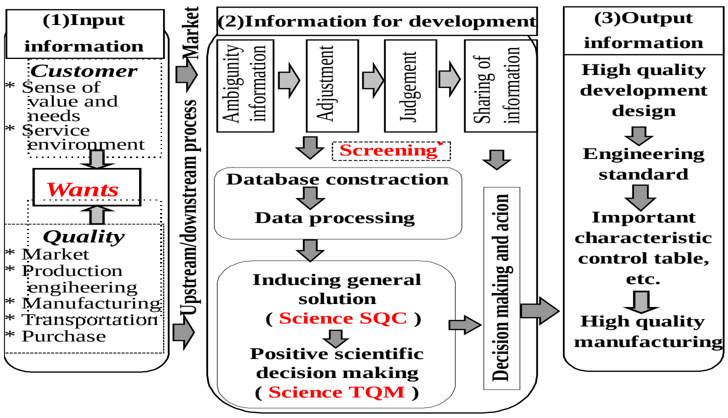

Figure A. The business process of product development design, and manufacturing

In Figure A, then, use this information to create "wants" as part of a market creation activity and also to establish an intellectual structure and system for development and production that is capable of offering new products. In the implementation stage, it is important to apply the Science SQC and Science TQM, via a verifiable scientific business approach, to each step ((1) Input information, (2) Information for development, and (3) Output information) of the business process of product development designing and manufacturing. This is done in order to effectively carry out to bring about the evolution of corporate management technology that can ensure high reliability business process which realizes the customer's "Wants" (Amasaka, 2004, 2005, 2007b 2008a).

Appendix B: Automobile Exterior and Interior Design Method "CSP-IDCM)

This tool is the objective of this study to find the guideline for establishing a method for scientifically supporting the designing so as to establish it expressly as a more creative activity from the state of tacit knowledge. It is considered that the very analysis process for establishing it as an activity would be the key to the successful conception making. It is necessary for us to create a particular live solution that catches the liking of the next generation. In this connection, "Science SQC" with a core method "SQC Technical Methods" is applied to the flow designing to actually enhance the quality of the designer's job named Design SQC as the scientific new methodology "Mountain-Climbing for Problem-Solving" by using "Customer Science Principle" (CSP) in Toyota (Amasaka, 2002, 2004, 2005).

Specifically, in automobile product development design process, the author develops a scientific approach to identifying customers' tastes employing CSP, named "Intelligence Design Concept Method "CSP-IDCM" as the developing automobile exterior and interior design tool .as shown in Figure B (Amasaka et al., 1999). In Figure B, the author thinks that the analysis process that turns implicit knowledge into explicit knowledge constitutes the secret to the conception as the event analysis to the exterior design in three steps of researches from Step 1 to 3 in Figure B.

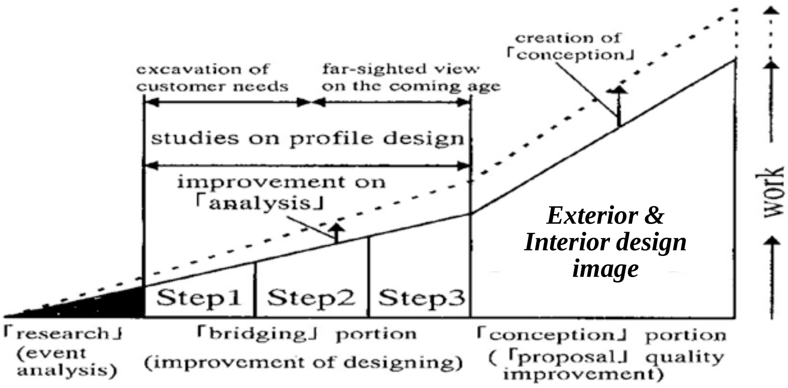

Figure B. Automobile Exterior Design Concept Method "CSP-IDCM"

Step 1 analyzes relationship between images of vehicles desirable and those actually selected to research, and it actualizes apparent relevancy whereby a vehicle type can be specified by the desirable image. Step 2 grasps what part of a vehicle customers observe to evaluate it. By coming down from the overall assessment, partial assessment and detailed assessment, this clarifies which design factor should better be given priority to satisfy customers. In Step 3, the designers research the excellent exterior design by grasping the relevance of vehicle images and profile design (called proportion) data. CSP-IDCM will help improve the designing process (work) for creation of exterior and interior design image involving the matching profile design, form, and color optimization.

Appendix C: Total QA High Cyclization Business Process Model

To minimize discrepancies in the results obtained from testing of actual products and CAE, it is necessary to properly formalize the expertise on the many technical analysis required for CAE analysis. This model is created from the standpoint of verification and validation (divergence of CAE from theory and divergence of CAE from testing) in order to make possible highly reliable CAE analysis that is consistent with the market testing theory profile. The author therefore recommends the introduction and utilization of a Total QA High Cyclization Business Process Model, which systematically and strategically realizes high quality assurance by incorporating analyses made via the core technologies of *Science SQC* as shown in Figure C (Amasaka, 2004, 2008).

For example, to solve the pending issue of a technology problem in the market, it is necessary to create a universal solution (general solution) by clarifying the existing six gaps (① to ⑥ in Figure C) in the process consisting of theory (technological design model), experiment (prototype to production), calculation (simulation), and actual result (market) as shown on the lower left of Figure C.

To accomplish this, the clarification of the six gaps (① to ⑥) in the business processes across the divisions, shown in the lower right of Figure C below, is of primary importance. By taking these steps, the intelligent technical information owned by the related divisions inside and outside the corporation will be fully linked, thus reforming the business processes involved in development design.

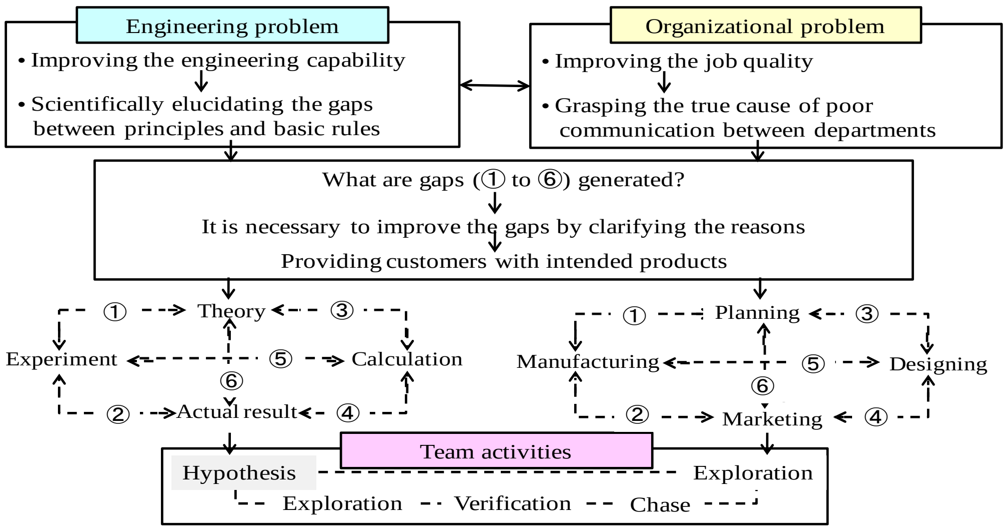

Figure C. Total QA High Cyclization Business Process Model