Abstract Number: 008-0396

Abstract Title: Dual Technology Management Model of Design and Production utilizing CAE & Experiment

Author: Manabu Yamaji[1)], Hirohisa Sakai[2)], Toshiya Ueno[1)], Kakuro Amasaka[1)]

Organization: 1) Aoyama Gakuin University

2) Toyota Motor Corporation

Address: 1) 5-10-1 Fuchinobe, Sagamihara-shi, Kanagawa-ken, 229-8558 Japan

2) 1, Motomachi, Toyota-shi, Aichi-ken, 471-8573, Japan

E-mail: yamaji@ise.aoyama.ac.jp

Phone/Fax: Tel:+81.42.759.6423, Fax: +81.42.759.6556

Type: POMS 19th Annual Conference

La Jolla, California, U.S.A.

May 9 to May 12, 2008

Dual Technology Management Model of Design and Production utilizing CAE & Experiment

Manabu Yamaji[1)], Hirohisa Sakai[2)], Toshiya Ueno[1)], Kakuro Amasaka[1)]

1)Aoyama Gakuin University

5-10-1 Fuchinobe, Sagamihara-shi, Kanagawa-ken, 229-8558 Japan

Tel: +81.42.759.6423, Fax: +81.42.759.6556, E-mail: yamaji@ise.aoyama.ac.jp

2) Toyota Motor Corporation

1, Motomachi, Toyota-shi, Aichi-ken, 471-8573, Japan

Abstract: At present, one of the specific measures taken is an urgent improvement of intelligent productivity for the purpose of offering highly reliable products to create customer value in a short period of time. Against this background, the author focuses on the New Japan Production Model for establishing a development designing and production engineering system in the automotive industry. This paper presents the Dual Technology Management Model of Design and Production for establishing a development designing and production quality assurance system that is indispensable for CAE(Computer-Aided Engineering) and experiment in the automotive industry and its effectiveness is verified.

1. Introduction

In recent years, the automotive industry is engaging in a global production strategy – for simultaneous achievement of QCD (quality, cost and delivery) aiming to achieve “worldwide uniform quality and production at optimum locations,” in an effort to prevail and survive in the “worldwide quality competition”[1]. One of the specific measures taken is an urgent improvement of intelligent productivity in the automotive production processes of planning and development, designing, prototyping evaluation, mass production preparation, and mass production for the purpose of offering highly reliable products to create customer value in a short period of time. Recently, the development period of a new model has been cut down from 4 years to 2 years, and now it is being shifted even to one year[2].

Among other things, a close look at the development designing and production process stage reveals an excessive repetition of experiment, prototyping, and evaluation that prevents the scale-up effect generated in the bridging stage between prototyping, experiment, evaluation, and mass production. Therefore, innovation of the development and production method, as well as reduction of the development period, is a top priority issue. The authors therefore grasped the effectiveness of as well as problems with CAE (Computer-Aided Engineering) utilization and the importance of CAE education and technology succession through a case study of a leading corporation[3].

Based on the above knowledge, the impact of CAE and obstacles to be overcome are plotted in the relation diagram from the standpoint of CAE management and simultaneous achievement of QCD which realizes the high quality assurance of automobiles. By summarizing the diagram, it becomes clear that one of the problems in applying CAE for the realization of simultaneous achievement of QCD is the “failure to understand the mechanism of the technical problems encountered and apply it to a CAE model”[4].

The second point observed is that, as a substitute for prototypes and experimental evaluation, this CAE analysis proves to be insufficient for reliable prediction and control. The gap (analysis error) between the analysis and the experimental evaluation data must be as much as a few percent, and at present, the “establishment of CAE software and its usage taking error into account” is not at a satisfactory level. Therefore, despite its expansion, CAE cannot be regarded as making a sufficient contribution to the simultaneous achievement of QCD and reduction in development time[5].

Against this background, the author focuses on the New Japan Production Model for establishing a development designing and production engineering system in the automotive industry. This paper presents the Dual Technology Management Model of Design and Production for establishing a development designing and production quality assurance system that is indispensable for CAE and experiment in the automotive industry.

Further, the effectiveness of this model are discussed by the application of the development designing and production engineering. The application of the development designing is bolts tightening problems that difficult to simulate on the computers. The application of the production engineering is strategic manufacturing technology for the *Lean Production* called *TPS-LAS* (*Process Layout Analysis Simulation*) by using *Process Layout CAE System*.

2. Necessity of CAE in the Manufacture of Automobiles

CAE is generally interpreted as information technology handling three-dimensional data. On the other hand, at an advanced enterprise of Toyota, they understand said technology as a tool for innovating the process concurrently by visualizing the essential problems latent in conventional system and process, then simplifying and turning them into efficient system and process.

They have applied the CAE to the investigation of vehicles and products and of the production facilities, contributing to the epoch-making reduction of lead-time from the product development to the production preparation process. CAE was applied to the former in realizing a process without using the prototype or solving problems while on the drawing stage supported by computer. In the case of the latter, it contributed to the cost reduction of press molds and the realization of lean production system for the new body line etc..

On embodying the application, the following technical tasks require solution:

(1) making information visually understandable with ease;

(2) sharing information on real time;

(3) turning implicit knowledge into explicit knowledge (properly feeding high level skill in manufacturing back to the production design), etc.

On the other hand, computer simulation is not applied practically. For instance, concerning kanban especially, it consists of two types (ordering quantity model and ordering point of time model), and has several kinds of systems (pull system, push system, SLAMII, CONWIP) and references [6-13]. But they are not applied, because the actual line processes has not the ideal availability and reliability. So it is essential to make a practical model for global production.

3. Expectations for Automotive Development Design and Production utilizing CAE

For manufacturers to be successful in the future global market, they need to develop products that give strong impressions to consumers and supply such items in a timely fashion through effective corporate management. The mission of the automotive manufacturers in this rapidly changing management technology environment, is to be prepared for the "worldwide quality competition", so as not to be pushed out of the market and to establish a new management technology model which enables them to offer highly reliable products of the latest design that are capable of enhancing the value to the customer[1, 2].

In the area of management technology for the development and production processes that is being considered here, excessive repetition of "prototyping, testing, and evaluation" has been carried out for the purpose of preventing the "scale-up effect" in the bridging stage between testing and mass production. This has resulted in an increase in the development period and cost. Therefore, it is now necessary to reform the conventional development and production method[2]. More specifically, it is increasingly vital to realize the “simultaneous achievement of QCD” that satisfies the requirements of developing and producing high quality products, while also reducing the cost and development period through incorporation of the latest simulation technology CAE and statistical science[14,15].

In the vehicle development process employed in the past, after completing the designing process, problem detection and improvement were repeated mainly through the process of prototyping, testing, and evaluation. In some current automotive development, a prototype of a vehicle body is not manufactured in the early stage of development due to the utilization of CAE and experiment activities, and therefore the development period has been substantially shortened[14].

Given this background, therefore, the conventional development process of repeated evaluation using prototypes is no longer capable of handling this task. Collaboration between CAE and experiment activities, which are now faster and more precise, will be indispensable for fully utilizing the accumulated knowledge database. As discussed so far, expectations are high for the realization of super short-term development, which would be done through utilization of CAE. In other words, there will be a conversion from the so-called “development through real object confirmation and improvement” to “prediction evaluation oriented development” [15].

4. Incorporation of Intelligence and High Precision into CAE

Investigation into the management technology issues concerning to managers and administrators of advanced corporations indicate that development designing puts primary emphasis on the technical problems in the process of finding a solution, and resources are concentrated on the pressing issue of developing new models and products on a proposal basis. Recently, the development period of a new model has been cut down from 4 years to 2 years, and now it is being shifted even to one year[4].

For this reason, what is urgently needed, is innovation to promote the advance from the conventional evaluation-based development, that uses the prototyping and experiment process (a method based on the confirmation of real goods for improvement) which had long supported the highly reliable designing to CAE prediction-based designing process, to the establishment of a new development designing technique, the "*New Japan Development Design Model*" [4]. In an effort to realize this, the working group of the author et al. has proposed the "high quality assurance model for super short period development designing, the *Total Intelligence CAE Management Model"* and demonstrated its effectiveness. [3-5]

One of its core technologies is the establishment of a high quality assurance CAE model, "*Automotive Intelligent CAE Methods*". Secondly, it involves innovation of the development designing process by means of the realization of the "*Total Intelligence CAE Management System Approach*"[4] for the purpose of achieving the above. Utilizing this system, the authors organized a Dual Task Management Team that brought together Toyota Motor Corporation, an automobile assembly manufacture, and NOK corporation, a supplier[18, 19]. The authors investigated an oil seal leakage mechanism that contributes to the appropriate design of the transaxle by utilizing visualization devices, leading to the realization of simultaneous achievement of QCD, both systematically and organizationally. Furthermore, based on the technical knowledge acquired, the authors; (i) implemented qualitative modeling of *CG Navigation* using CG (computer graphics), and (ii) achieved qualitative modeling through *Intelligence CAE Software*, realizing highly reliable CAE analysis that corresponds well with results of actual vehicles and experiments.

The authors investigated the issues related to CAE for the simultaneous achievement of QCD, based on the results of a field survey into CAE utilization at automotive body manufacturers and parts manufacturers. As a result, certain requirements necessary for the high quality assurance CAE model and to realize high quality assurance CAE analysis software have been revealed: that is, (1) the importance of developing CAE software capable of scrutinizing (in theory and reality) and reflecting the "failure mechanisms" (tricks) which grasp the root cause of apparent problems, and (2) the necessity of establishing a methodology for improving the analysis precision of CAE software.

The former refers to "intelligent CAE software" as a support tool for concrete ideas needed for development designers to create excellent design drawings and the latter points to "high precision CAE software" exhibiting no deviation from the "analysis results of actual machine lab tests," and both are indispensable technical factors to be incorporated by all means. [20, 21]

5. Dual Technology Management Model of Design and Production utilizing CAE & Experiment

At present, the Japanese manufacturing industry is rapidly deploying global customer-oriented production throughout the world. This rapid spreading of production sites abroad, however, has brought about many new problems for Japanese production, which has developed a reputation in the past for assuring high quality. As seen in the case of automobiles, the "highly reliable production system" with target productivity equal to that in Japan is spreading worldwide, but the actual productivity (availability) is still often lower [22].

Considering the importance of CAE, the authors here propose, as indicated in Fig.1, New Japan Production Model "Dual Technology Management Model of Design and Production utilizing CAE & Experiment." The following are the functions of the Quality Assurance and TQM Promotion related divisions: as corporate environment factors for succeeding in "global production," customer-first, (1) CS, ES, SS, (2) for high quality assurance and as a strategic factor to realize it, (3) in order to simultaneously achieve QCD, and (4) success in intelligence simulation utilizing CAE and experiment. Shortening of the development period is realized by these. So (5) evolution of CAE analysis is achieved.

More specifically, the (I)Production engineering needs to promote manufacturing of high reliability utilizing digital production engineering. In the (II)development design, digital development design as a support tool for concrete ideas needed for development designers to create excellent design drawings is important.

The uses of statistical science expected to solve technical problems are (i) Variation Factor Analysis, (ii)Control of the Principal Design Factors, (iii) Mechanism Analysis. For this reason, basic statistical science, experiment planning, multivariable analysis, reliability analysis, the optimization method, and time series analysis, etc. are selected according to necessity, and then combined and utilized.

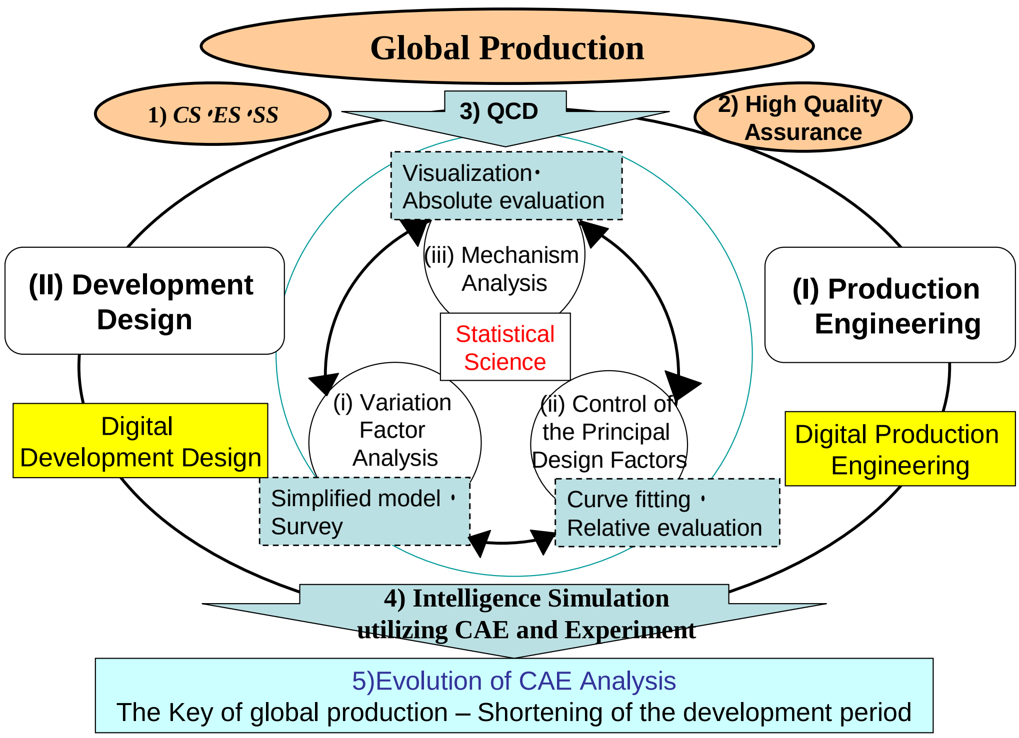


Fig.1. Dual Technology Management Model of Design and Production utilizing CAE & Experiment

6. Application example

The effectiveness of this model are discussed by the application of the development designing and production engineering. The application of the production engineering is strategic manufacturing technology for the *Lean Production* called *TPS-LAS* (*Process Layout Analysis Simulation*) by using *Process Layout CAE System*. The application of the development designing is bolts tightening problems that difficult to simulate on the computers.

6.1. TPS-LAS

The authers have established the *TPS-LAS Model* (Toyota Production System Layout Analysis Simulation) [14], which can effectively realize a higher quality production system in response to digitalized production and for the purpose of innovating high quality assurance and production preparation processes. This model has contributed to shorter-term cultivation of skilled workers as well as the simultaneous achievement of QCD.

The *TPS-LAS Model* is equipped with (i) Logistics Investigation Simulation [23] (-*LIS*), (ii) Digital Factory Simulation [24][25] (-*DFS*), and (iii) Workability Investigation Simulation [26] (-*WIS*) as a component for incorporating digital engineering, computer simulation, and a layout CAE system as shown in Fig.2. Specific layouts are designed by computer, and reductions in workload for on-site skilled workers, as well as the work layout for high productivity focusing on rhythmical work operations, are simulated to enable production preparation fitting actual work operations conducted on-site, contributing to quicker launch of overseas production plants.

The authors present the effectiveness of the application of *TPS-LAS*. The first core element

TPS-LAS-DFS enabled the authors to accomplish an improvement in availability on the assembly line of eight percent on average. Finding out various interferences between the facilities and verifying the arrangement of them and redesigning the production process in the early stage, repeated work was reduced by half. The second *TPS-LAS-WIS* enabled the authors to verify the workload and the workability simultaneously in advance. The facilities were re-designed. The operator's standing position was changed, and they have achieved a demonstration of a 10% improvement in line availability. Furthermore, the number of temporary workers who voluntarily resign could be reduced by showing them a virtual scene of their future work environment and workload in advance before they are hired.

Regarding overtime work issues, the third *TPS-LAS-LIS* enabled the authors to predict the causes of overtime work and declines in the availability of the assembly line in process planning and the line drawing stage related the concurrent engineering. Therefore, the authors were able to discover an optimum number of buffers and transfer equipment and develop an optimum transfer route. As a result, they were able to reduce the amount of instances of one

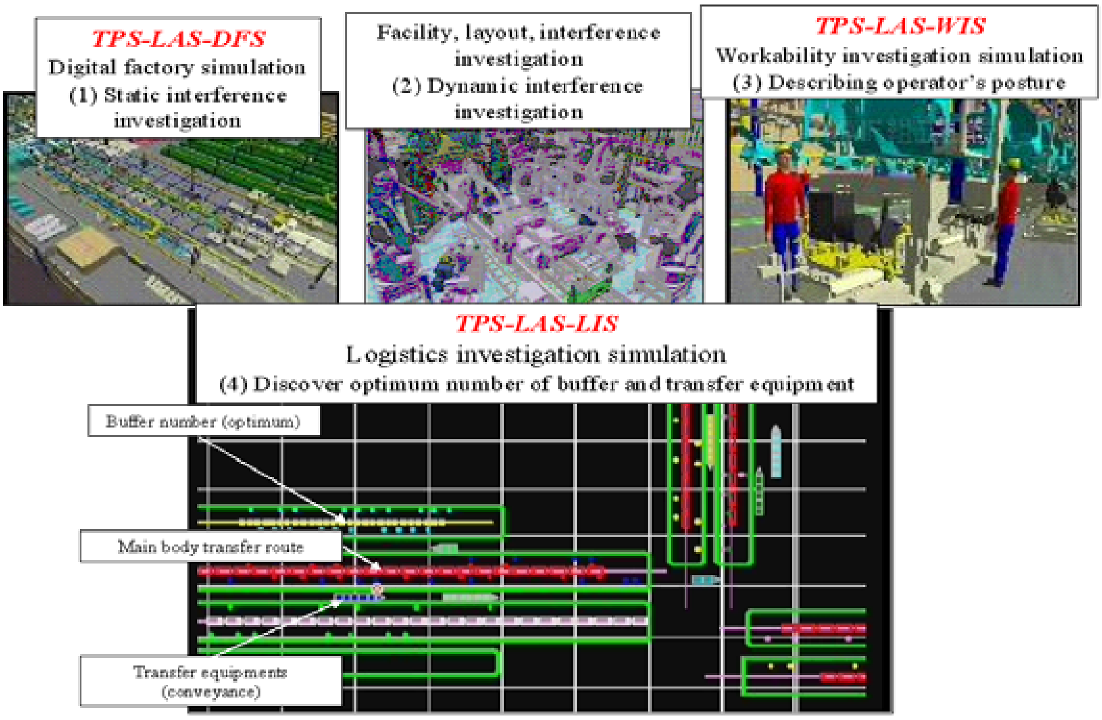


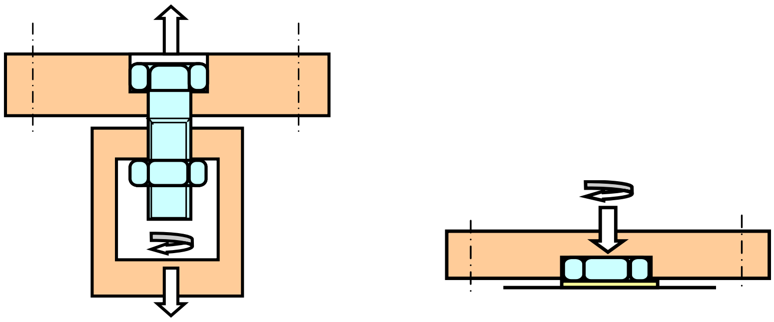
Fig.2. Result of Simulation for TPS-LAS

hour of overtime work. With *Advanced TPS*, the authors were able to achieve the same high productivity and quality at both domestic and overseas plants, and to reduce lead-time and overseas labor force support in global production processes throughout the world. The results of this study have been deployed in Toyota's global production strategy, with its effectiveness verified by the excellent reputation of recent Toyota vehicles for their reliability and common workability in Europe and the United States [27].

6.2. Development of the bolt tightening simulation system

The number of bolts used for an automobile are more than 3,000. The bolts are one of the mostly used part in automobile parts. And, the bolt tightening is necessary for keeping parts together. But, it is important that axial force and torque are in prescribed sizes for display tightening force in bolts. If axial force and torque size are small, the looseness occurrence by various forces such as inertia force by acceleration and slowdown and vibration force from a road surface and engine. And the crack occurrence to bolts and substrate by irregular forces. The important quality problems happen if there is these looseness or crack occurs during a run [28-31]. Therefore, the authors are experimenting and simurating bolts tightening for avoid these matters[32].

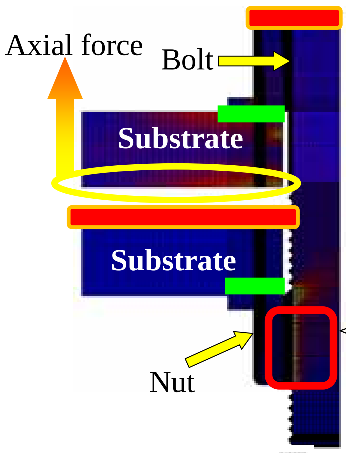
The bolt tightening experiments were conducted using "hexagon flange bolts and nuts" which are actually used in the automotive industry for commercial use. The authors have executed two experiments with this bolts and nuts.The first experiment measures the relationship between axial force and torque of the spiral threaded portion. The second experiment measures the relationship between axial force and torque of the bearing surface.



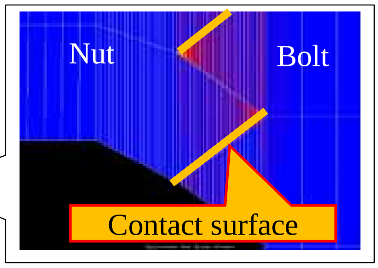
Measuring the friction coefficient of the screw

Measuring the friction coefficient of the seating surface

Fig.3. Experiment of measuring the friction coefficient to tighten bolts



	Friction coefficient	
Axial force	Threaded portion	Bearing surface
20KN	0.059553	0.193976
40KN	0.043705	0.293392
60KN	0.041944	0.293391



Enlarged figure
(Contact of threaded portion)

Fig.4. The axis symmetry two-dimensional model

This analysis is used the axis symmetry two-dimensional model. The authors have set the analysis boundary condition for the same as experiment boundary condition. And, applied axial force to the part of substrate above, and furthermore, bound all directions on the part of bolt head and substrate below. And then the authors have inputted friction coefficient that was calculated by experiments into the part of contact bearing surfaces and contact of threaded portions.

The authors have set a boundary condition like these for the axis symmetry two-dimensional model and compared relationship between toque and axial force of the experiment results and simulation analysis results. The simulation analysis results could match well with experiment results.

7. Conclusion

The author focused on the New Japan Production Model for establishing a development designing and production engineering system in the automotive industry. This paper presented the Dual Technology Management Model of Design and Production for establishing a development designing and production quality assurance system that is indispensable for CAE and experiment in the automotive industry.

Further, the effectiveness of this model were discussed by the application of the development designing and production engineering. The application of the development designing was bolts tightening problems that difficult to simulate on the computers. The application of the production engineering was strategic manufacturing technology for the *Lean Production* called *TPS-LAS* (*Process Layout Analysis Simulation*) by using *Process Layout CAE System*.

Refarences

[1] K.Amasaka, (2003), Development of Science TQM, A New Principle of Quality Management, *International Journal of Production Research*, **42** (17), 3691-3706.

[2] K.Amasaka, (2005), *New Japan Production Model*, An Advanced Production Management Principle: Key to Strategic of *New JIT*, *International Business & Economics Research Journal*, **6** (7), 67-79.

[3] K. Amasaka, (2007), "Highly Reliable CAE Model, The Key to Strategic Development of New JIT", *Journal of Advanced Manufacturing Systems*, pp.159-176.

[4] K.Amasaka & M. Yamaji (2006), *Advanced TDS*, Total Development Design Management

Model, *Proc. of the 2006 International Applied Business Research Conference*, Cancun, *Mexico*, pp.1-15 (CD-ROM).

[5] M. Yamaji, T. Tanabe, H. Tsubaki, & K.Amasaka (2007), Proposal and Implementation of the High Reliability CAE Model, *Proc. of the 7th International Conference on Reliability and Safety, Beijing, China*, pp.114-118.

[6] O.Kimura, and H.Terada (1981), Design and analysis of pull system, a method of multi-stage production control, *International Journal of Production Research*, **19**(3), pp.241-253.

[7] K.Takahashi, S.Hiraki, and M.Soshiroda (1994), Pull-push integration in production ordering systems, *International Journal of Production Economics*, **33**(1) pp.155-161.

[8] S.Hiraki, K.Ishii, K.Takahashi and R.Muramatsu (1992), Designing a pull-type parts procurement system for international co-operative knockdown production systems, *International Journal of Production Research*, **30**(2) pp.337-351.

[9] M.L.Spearman (1992) Customer service in pull production systems, *Operation Research*, 40(2) pp.948-958.

[10]M. L.Spearman, D.L.Woodruff, W. J.and Hopp (1990), CONWIP: a pull alternative of kanban, *International Journal of Production Research*, **28**(5) pp.879-894.

[11]S. R.Tayur (1993), Structural properties and heuristics for kanban-controlled serial lines, *Management Science*, **39**(11) pp.1347-1368.

[12]J.S.Peter, and K.W.David (2003), Data Visualization in Manufacturing Decision Making, *Journal of Advanced Manufacturing Systems*, **2**(2) pp.163-185.

[13]G.Pfeil, R.Holcomb, C.Muir and S.Taj (2000), Visteon's sterling plant uses simulation-based decision support in training, operations, and planning, *Interfaces*, **30**(1), pp.115-133

[14]H.Sakai and K.Amasaka (2005), *TPS-LAS* Model Using Process Layout CAE System at

Toyota, *Advanced TPS*, Key to Global Production Strategy *New JIT*, *Journal of Advanced Manufacturing Systems*, **5** (2), pp.1-14.

[15]M.Yamaji, S.Yamada, H.Tsubaki and K.Amasaka (2007), Effectiveness of Statistical Sciences for reformation of development design process, *Proc. of the 5th Asian Network for Quality Congress, Korea*, pp.270-277.

[18] K. Amasaka (2003), A Dual Total Task Management Team Involving Both Toyota and NOK, *Proc. of the Group Technology/ Cellular Manufacturing World Symposium, Ohio*, pp.265-270.

[19]K.Amasaka and S.Osaki (2002), Reliability of Oil Seal for Transaxle - A Science SQC Approach in Toyota, *Case Studies in Reliability and Maintenance, John Wiley & Sons, Inc.*, pp.571-588.

[20] K.Amasaka, T.Ishii, T.Mitsuhashi, T.Tanabe and H.Tsubaki (2005), A Study of the High Quality Assurance CAE Model of the Car Development Design (2), *The Japanese Society for Quality Control, The 35th Annual Technical Conference, Tokyo*, pp.147-150 (in Japanese).

[21] K.Amasaka (2006), Establishment of Design Quality Assurance System for Numeric Simulation, *The Japanese Society for Quality Control, No.111st Symposium, Tokyo*, pp.41-46 (in Japanese).

[22] A.Gabor (1990), The man who discovered quality: How Deming W. E. brought the quality revolution to America, Random House Inc.

[23] J.V.Leo, H.C.Amos and O.Jan (2004) Simulation-based Decision Support for Manufacturing System Life Cycle Management, *Journal of Advanced Manufacturing Systems*, **3**(2), pp.115-128.

[24] C.Byoungkyu, P.Bumchul and Y.R.Ho (2004), Virtual Factory Simulator Framework for Line Prototyping, *Journal of Advanced Manufacturing Systems*, **3**(1), pp.5-20.

[25] T.Kesavadas, and M.Ernzer (2003), Design of an Interactive Virtual Factory Using Cell Formation Methodologies, *Journal of Advanced Manufacturing Systems*, **2**(2), pp.229-246.

[26] S.Steffen, S.Gunter and H.Siegmar (2003), Distributed Manufacturing Simulation as an Enabling Technology for the Digital Factory, *Journal of Advanced Manufacturing Systems*, **2**(1), pp.111-126.

[27] JD Power and Associates (2007), http://www.jdpower.com/.

[28] S.Izumi, T.Yokoyama, A.Iwasaki and S.Sakai (2004), Three-dimensional finite element analysis of tightening and loosening mechanism of threaded fastener, *Engineering Failure Analysis*, **12**(4) pp.604-615.

[29] T.Fukuoka, N.Yamasaki, H.Kitagawa and M.Hamada (1986), Stress in Bolt and Nut: Effects of Contact Condition at the First Ridge, *Transactions of the Japan Society of Mechanical Engineers. A*, **52**(474): pp552-556.

[30] M.Tanaka, H.Miyazawa, E.Asaba and K.Hongo (1981), Application of the Finite Element Method to Bolt-nut Joints : Fundamental Studies on Analysis of Bolt-nut Joints using the Finite Element Method, *Bulletin of the Japan Society of Mechanical Engineers* **24**(192) pp.1064-1071.

[31] A.Aragóna, J.Alegrea and F.Gutiérrez-Solana (2005), Effect of clamping force on the fatigue behavior of punched plates subjected to axial loading, *Engineering Failure Analysis*, **13**(2) pp.271-281.

[32] T.Ueno, M.Yamaji, T.Mitsuhashi, T.Ono and K.Amasaka (2007), The High Reliability CAE Management system in the Automotive Development Design, *Proc. of the 8th Asia Pacific Industrial Engineering & Management System, Kaohsiung, Taiwan*, pp.1-9 (CD-ROM).