IT Support for Product and Process Development in Japan and Future Perspective

Fumihiko Kimura

Hosei University, Tokyo, Japan
fumihiko.kimura@hosei.ac.jp

Abstract. Due to the globalization of market and manufacturing activity, manufacturing industry in industrially advanced countries are facing difficult problems, such as severe competition with the low-cost production in developing countries and radical changes of customer requirements in industrially mature countries, etc. For coping with these problems, it is important to identify hidden or potential customer expectation, and to develop systematized design and manufacturing technology to augment human expertise for innovative product development. It is known that the strength of Japanese manufacturing industry comes from the intimate integration of sophisticated human expertise and highly efficient production capability. For keeping the competitiveness of the Japanese industry, it is strongly required to systematize the product and process development throughout the total product life cycle, and to introduce IT methods and tools for supporting creative and intelligent human activities and for automating well understood engineering processes. In this paper, current issues in manufacturing industry are generally reviewed. Future directions of manufacturing industry are described, and important technological issues and their IT support solutions are discussed. Finally future perspective for advanced IT support is investigated.

Keywords: Product development, Process development, IT support, CAD, CAM.

1 Introduction

Manufacturing is a basic discipline for sustaining economy for advanced industrialized countries, such as Japan, USA and Europe. However due to the recent trends of globalization in manufacturing activities, difficult issues are arising, such as severe competition with very low cost production of developing countries, risk management for global distribution of product development and production activities, environmental problems for achieving sustainable manufacturing, etc. In this paper, the recent advances of product and process development technology, current issues and future perspectives are reviewed from the standpoint of IT support, and particularly Japanese activities are discussed for keeping the competitiveness in the future.

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It is well known that the strength of Japanese manufacturing industry comes from the intimate integration of sophisticated human expertise and highly efficient production technology. For keeping the competitiveness of the Japanese industry, it is essential to maintain the quality and volume of the expert human work force, but it is predicted that the population of Japanese working age people will decease about half in the year of 2050. Therefore it is strongly required to systematize the product and process development technology throughout the total product life cycle, and to introduce IT methods and tools for supporting creative and intelligent human activities and for automating well understood engineering processes. This new IT supported way of product and process development will rationalize the current human-dependent processes, and achieve efficient global collaboration among industrially developed countries and developing countries. The underlying research and development activities are discussed in this paper.

In the next section, current issues in manufacturing industry are generally reviewed. Future directions of manufacturing industry are described in section 3. Then important technological issues and their IT support solutions are discussed in sections 4 to 7. Finally future perspective for advanced IT support is shown in section 8.

2 Current Issues in Manufacturing

Technological, economical, and social situations for manufacturing are changing rapidly in recent years. There are many issues manufacturing industry is facing today, especially in industrially advanced countries. Major issues are reviewed, and specific problems with Japanese industry are discussed.

- Energy and resource constraints

It is needless to say that industrial technology in advanced countries cannot be fully diffused to developing countries due to over waste of energy and resources. For example, today's standard automobiles cannot be directly spread, and small light-weighted energy-efficient vehicles should be developed for mass use in the developing countries. Technology innovation is required for such new developments.

Japan and other advanced countries import large amount of energy sources and other resources. There are always risks of disruption of those supplies due to natural disaster and political problems.

- Competition in global market

Big consumer market is emerging in developing countries, and completely new categories of very cheap products are required for adapting to the global market needs. It is fairly hard for Japanese industry to change their technology from high-end products to commodity products. This change requires not only new product strategy but also new technology.

- Radical changes of world market

In industrially advanced countries, most of the products have been already spread among the consumers, and, generally speaking, consumer's products are not sold well. It is a big problem how to inspire hidden potential demands for new products.

- Service design for product production

Fundamentally it is very important for manufacturing industry to capture potential social expectation for the future, and to propose vision and scenario to approach to it. For example, it is an urgent issue to realize society of higher resource efficiency. Maintenance of social infrastructure, such as roads and bridges, is a good example, and new technology is urgently desired for efficient life cycle management.

- Population problem

In Japan, and similarly in other advanced countries, labour force in manufacturing industry will decrease rapidly in coming 50 years. For sustaining the industrial level, it is very important to amplify human intellectual ability by IT support, and to automate production processes as much as possible.

3 Future Direction for Manufacturing Technology Innovation

For analyzing the issues explained in the previous section, a role of design and manufacturing engineering is investigated, and the issues are classified according to the customer expectation and technology systematization.

Figure 1 shows a key role of design and manufacturing engineering. For enhancing the quality of life (QOL), social expectation for technology development and new products is expressed in the form of explicit demands, social scenario or general social vision, through market mechanism and other social /political mechanisms. Based on the level of industrialization of the society, the expectation is very clearly expressed, or is not expressed explicitly. Depending on such expectation or independently, design and manufacturing engineering tries to develop and propose various attractive technology options in the form of new systems and products to the society, based on the contribution from basic science and engineering.

Traditionally what customers want to get was clear, and known to customers themselves and to engineers. In such cases, according to the social expectation, appropriate technology options can be identified, and the developed systems and products are accepted by customers for better QOL. This case corresponds to the Class I and Class II problems in Figure 2, and is further explained below.

Today especially in industrially advanced society, customer demand or social expectation is not explicitly expressed, but only potentially noticed. Then, even though advanced technology and products are available, they may not be accepted by the society, and the customers are frustrated.There seems to be a big discrepancy between customer wish and producer awareness. This case corresponds to the Class III problem in Figure 2, and is further explained below.

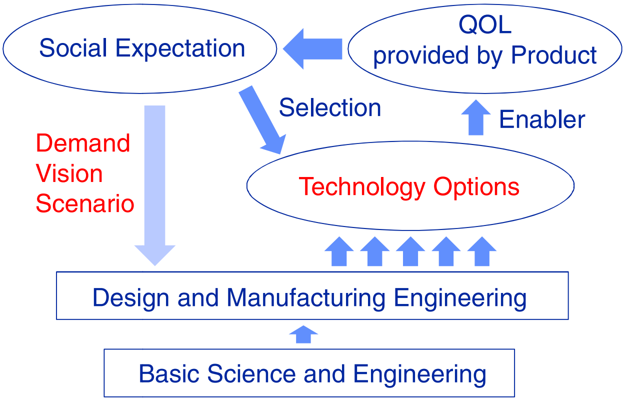

Fig. 1. Importance of design and manufacturing engineering

For clarifying the current issues in manufacturing, it is effective to classify the problems into three classes described in Figure 2 [1]. The classification is based on the level of recognition of the following two factors: social expectation and adaptability to various conditions surrounding the manufacturing.

Class I Problem: Customer expectation is clearly expressed, and surrounding conditions for manufacturing activity is well known to producers. Therefore the problems are well understood, and systematized technology can be effectively applied.

Class II Problem: Customer expectation is clearly expresed, but surrounding conditions are not well captured or not known. In this case, product and production technology must be adapted to the changing and unknown situations. Integration of human expertise is required for problem solving.

Class III Problem: Customer expectation is not explicitly expressed or is not known. In this case, the problems are not clearly described, and tight coupling exists between identification of customer expectation and correponding technology for problem solving. Co-creative approach between customers and producers is mandatory.

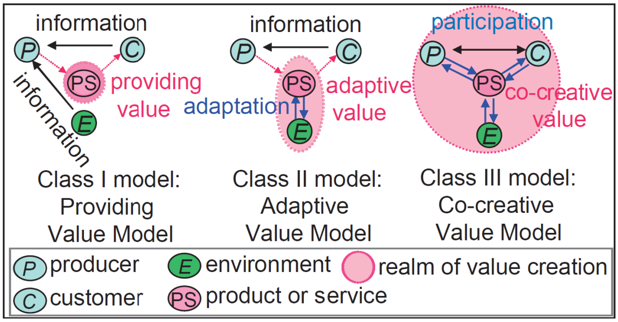

Fig. 2. Classification of design and manufacturing problems [1]

The current situation of Japanese manufacturing industry is explained by use of the above classification. Figure 3 shows the manufacturing problem classification with two coordinates: customer expectation and adaptability to surrounding conditions. Here adaptability to surrounding conditions is considered to depend on technology systematization, and it can be characterized by technology innovativeness and maturity.

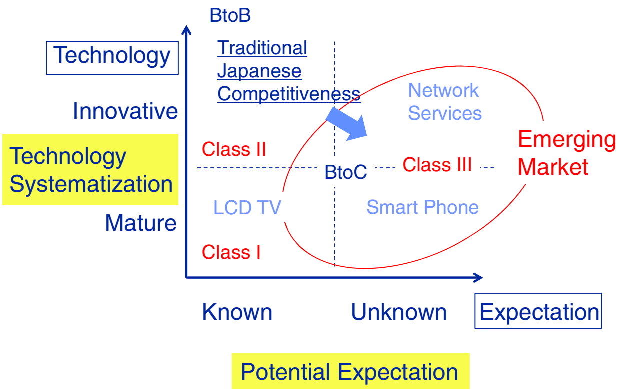

Fig. 3. Current trend of product development

Under the clear target setting situation, traditionally Japanese industry is very strong, even with varying conditions and unknown technology issues, to adapt to the difficult technology problems by applying front-edge technology and very sophisticated human involvement, and to produce very high-quality attractive products. This is a Class II problem, and Japanese approach is called as "Suriawase" in Japanese, which means sophisticated integration of human expertise with problem solving.

If the problem is well understood, and technology to solve the problem is well matured, the whole product development and production process can be systematized, and possibly automated. This is a Class I problem. Products which belong to this Class tend to be mass production products, and their competitiveness mainly depends on cheap price. The current difficulty of Japanese manufacturing industry is the technological and organizational inflexibility to adapt to this problem. By simply applying the sophisticated Class II problem solving method to Class I problems, it results in very expensive products with excessive quality.

If we look at the world market situation, two expanding or emerging market areas are recognized, as shown in Figure 3. One area is a mass production commodity product area, where products belong to the Class I problem, and the price is the most critical competitive factor. Another area is an innovative product area, where products belong to the Class III problem. The most important factor for Class III products is to identify customers' potential or hidden expectation, and to incorporate appropriate advanced knowledge from basic science and engineering toward product innovation.

Based on the above discussion, important future directions for manufacturing technology development are considered.

- Identification of customer expectation

As the product technology is advancing so rapidly, the customers are normally uable to capture the vision of future society, and tend to be frustrated with the proposed products and systems from the producers. It is important to develop a methodology to search for the hidden and potential social expectation, and to identify various requirements of customers for daily life products and social infrastructure. It is effective to utilize IT methods to promote observation, prediction and information sharing for mass population society. This issue is discussed in Section 4.

- Systematization of technology

The manufacturing problems become complex, such as large system problems, complexity problems due to multi-disciplinary engineering, and extremely difficult requiremts toward product safety and energy efficiency, etc. The traditional human dependent approaches only cannot cope with the problems effectively, and it is mandatory to introduce advanced IT support, and to systematize and to integrate various engineering disciplines toward design and engineering methods. These issues are discussed in Sections 5, 6 and 7.

4 Potential Customer Expectation

It is often argued that recent innovative products, such as a smart phone or a hybrid vehicle, could not be commercialized by the conventional market research activity, because impacts of those innovative products are difficult to imagine by normal consumers due to their technological difficulty. Many customers have vague expectation for new products, but they cannot express their wish correctly, therefore their expectation cannot be satisfied. Manufacturers can offer new products based on their revolutional technology, but it is not easy to match their design intention with customers' real wish. It is very important to develop a methodology to capture hidden or potential customer expectation.

In recent years, Japanese industry and research community have heavily disussed this issue, and proposed various practical methods for observing the potential social expectation [2]. It is still pre-mature to develop systematic methods, but several useful existing methods are discussed:

- systematic survey of existing literature,
- multi-disciplinary observation,
- observation of social dilemma and trade-off,
- collection of people's intuitive concern,
- deep analysis of already known social concern,
- re-examiation of past experiences.

Modelling, simulation, and social experiments are useful tools for prediction and information sharing. IT support is very effective for data mining and bibliometrics. Combination of information network and sensor capability has a big potential for extracting unconsciously hidden social wish. Promising approaches are advocated as a Cyber-Physical System [3]. A huge number of sensors are distributed into the society, and various kinds of information are collected and analysed. There are many interesting trials in Japan, such as energy consumption trends of supermarkets, combination of contents and mobility information, zero-emission agriculture, healthcare information, etc. Important aspects are collection of demand-side information and combination of different kinds of industrial activities. It is expected that, by capturing latent social or customer wish, social infrastructure and individual QOL are better servicified by the manufacturing industry.

5 Large System and Complexity Problems

By the diversity and vagueness of customer requirements, industrial products and systems tend to become large in scale and complicated. Large system problems typically occur for designing social infrastructure or complicated products like a space vehicle, etc. Complexity problems are often related with multi-disciplinary engineering, such as designing mechatronics products.

For coping with large system problems, various system engineering methods are already well developed, but these methods are not fully exploited for product design and manufacturing practices. Those methods include the following system synthesis steps [4]:

- common understanding via system modelling,
- subsystem decomposition and structuring,
- quantitative analysis of subsystem behaviour,
- scenario setting and system validation.

There are important viewpoints for system design, such as harmonization of local optimization and global optimization, multi-scale consideration, structural approach to sensitivity analysis, etc. Standardization and modular concept are essential for effective system decomposition. The V-Model approach in system engineering is valid, but decomposition, verification and validation processes become very complicated with multi-disciplinary engineering activities in product design and manufacturing.

Various kinds of model-based approaches are proposed, and standardization for model description scheme and languages is progressing. For coping with large scale and complexity problems, it is important to take into account of the following aspects:

- modelling and federation at various abstraction levels and granularity,
- modular and platform approach,
- multi-disciplinary modelling.

For system decomposition and modularization, it is effective to utilize a concept of function modelling as a basis, instead of physical building blocks. Product development processes are modelled, starting from requirement modelling, via function modelling and structure modelling, to product modelling. Those modelling should be performed in multi-disciplinary domains, and appropriately federated. Many research works are being performed, but industrial implementation are not yet fully realized.

6 Upstream Design Problems

It is argued that inappropriate product functionality and product defects are often caused at the upstream of product development processes. It is very expensive and time-consuming to remedy such problems at the later stages of product development, because many aspects of products have been already fixed. It is very effective to spend more time and effort at the stages of product requirement analysis, concept design and function design.

In Japan, it is currently a big problem that products tend to have excessive functions, and become the so-called "Galapagos" products, as shown in Figure 4. "Galapagos" products mean products designed to incorporate available leading technology as much as possible for product differentiation, and it results in very expensive products. Now the big market is expanding into developing countries. As the "Galapagos" products cannot be sold well in such market, it is required to eliminate excessive functions, and to make the products cheaper. But, it is difficult to compete with the cheap products designed especially for such market from scratch.

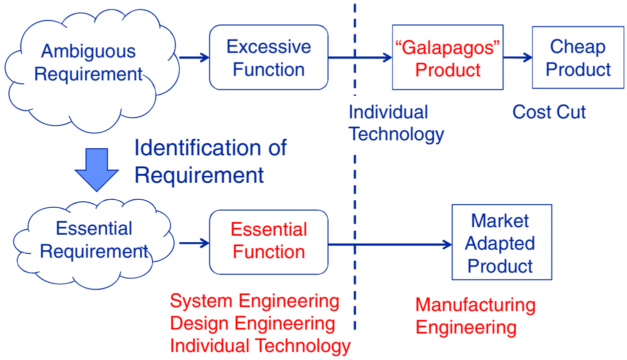

Fig. 4. Identification of essential requirement

This problem happens from the ambiguity of product requirement identification. The following approach is important for coping with this problem:

- identification of essential product requirements,
- realization of essential functions with science-based methods,
- rationalization and simplification of traditional functions and processes,
- minimization of required resources.

The above approach cannot be implemented by conventional technology only, but requires dedicated advanced technology specifically tailored for the target products, such as extremely light-weighted materials, highly energy-efficient processes, etc. This is a way that Japanese industry can take for competitiveness.

A systematic approach to upstream design is a very keen research issue in Japan. An interesting approach is advocated by the name 1DCAE [5]. There are many IT tools available today for doing precise engineering simulation. However it is very cumbersome to use those tools for upstream conceptual design activity. Also those tools are inconvenient for thinking and understanding product functional behaviour in an intuitive way. 1DCAE tries to establish a methodology to systematically utilize any available methods and tools to enhance the true engineering understanding of product characteristics to be designed, and to support the conceptualization of the products. 1DCAE is to exhaustively represent and to analyse product functionality, performance and possible risks at an early stage of design, and to provide a methodology for visualizing the design process and promoting the designer's awareness of possible design problems.

Figure 5 shows a 1DCAE approach for mechatronics product design. For conceptual design, various existing IT tools are used based on mathematical analysis and physics, such as dynamics, electronics and control engineering. Through good understanding of product concept and functional behaviour, detailed product models are developed.

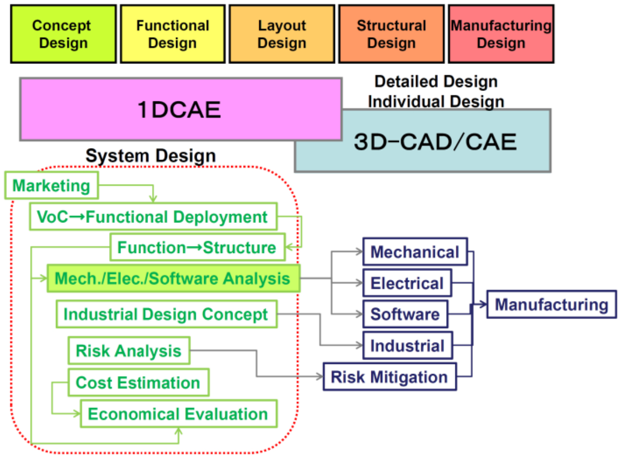

Fig. 5. 1DCAE approach for mechatronics product design [5]

Figure 6 represents a 1DCAE approach for large scale system design, such as a spacecraft. In this case, system optimization and risk mitigation are the very important design target. Design process is optimized by using DSM (Design Structure Matrix) method, and every necessary technological aspect of the products is modelled at appropriate granularity for simulation.

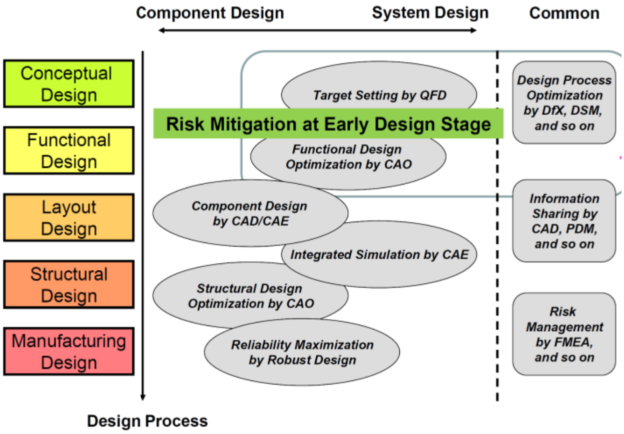

Fig. 6. 1DCAE approach for large system design [5]

7 Importance of Basic Technology

In addition to the various system technologies, the basic individual technology is also important. In recent years, remarkable progress of product and process development technology has been achieved by use of high speed computing capability. As indicated in Figure 1, there are many interesting and useful research results in basic science and engineering which could be effectively applied for practical design and manufacturing. However, many of those are not yet utilized. Science-based approach enables generally applicable reliable technology. Quite often the so-called expert engineering know-how or "Suriawase" technology can be rationalized by the science-based developments. By these developments, traditional manufacturing practices relying on veteran expert engineers and workers can be replaced by comprehensive automated systems, as discussed in the next section.

By sophisticated engineering simulation with supercomputers, extreme technologies have been developed, such as light-weighted high-strength materials, low-friction surfaces, nano-machining, low-energy consumption processes, etc. Advanced modelling technology is developed, which can represent volumetric information including graded material properties and various kinds of defects in the materials. Powerful measurement methods, such as neutron imaging, are being available to visualize internal structure of components and assemblies. By such precise modelling, accuracy of computer simulation is very much enhanced, and delicate engineering phenomena can be captured, which is difficult for physical experiments.

Ergonomic modelling and robotics technology have evolved, and behaviour of human-robot interaction can be simulated precisely by computer. This is a basis for designing comprehensively automated production systems, as discussed in the next section.

8 Future Perspective for Advanced It Support

Various kinds of CAD/CAM systems are effectively utilized in industry today, and they have already become indispensable tools for daily product and process development works. However their functionality is not satisfactory from the future rquirements for IT support discussed in the previous sections. Two important aspects for advanced IT support for product and process developments are identified. One is comprehensive support of intelligent human engineers for creative product design, and the other is systematic rationalization and automation for well developed engineering processes.

The possible configuration of advanced IT support for product and process development is shown in Figure 7. "Virtual Product Creation" deals with intelligent human support for product design, and "Error-Free Manufacturing Preparation" performs comprehensive support and automation of well developed engineering processes. A core part of the system is "Integrated Life Cycle Modelling", which represents all the necessary product and process information for intelligent support and automation. Technologies discussed in Sections 5 to 7 are somehow integrated in these system modules.

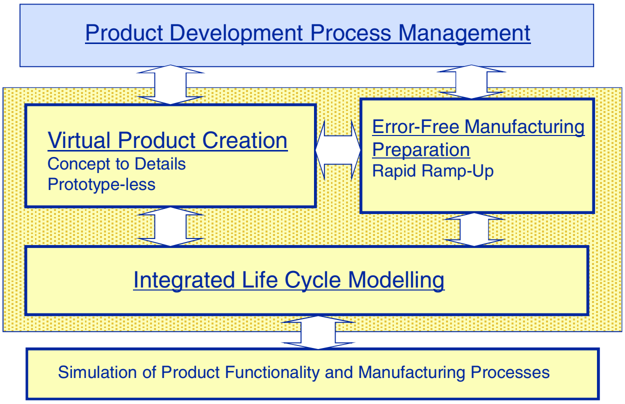

Fig. 7. IT support for product and process development

In Japanese industry, some part of those system functionalities are implemented individually as in-house applications, and some are realized as commercially available IT support systems. Figure 8 shows an example of digital pre-validation of production lines for electronics components. Recently Japanese companies operate such factories in foreign countries. By using the digital pre-validation, most of the required engineering works can be done in Japan before actual implementation of the factory equipments in foreign contries. Line design work load of human expertise can be radically reduced by this support system. This system incorporates many sophiscticated modelling and evaluation engineering know-hows, and exhibits differentiated characteristics from the conventional factory simulation systems.

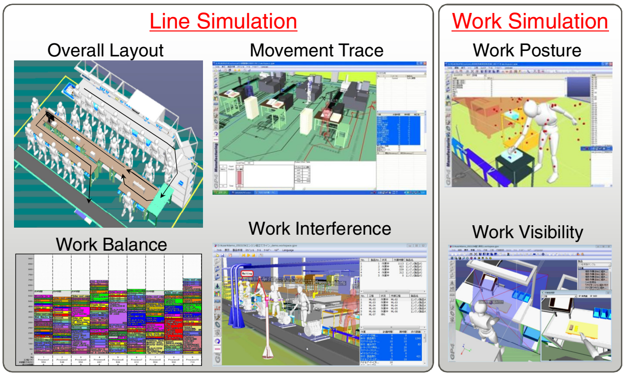

Fig. 8. Digital Pre-Validation of Production Lines [6]

There are several critical issues for realizing future-oriented IT support systems as shown in Figure 7. One of the important problems is to integrate well developed practical design methods into IT support systems. There are many such methods as Quality Function Deployment (QFD), Functional Modelling, First Order Analysis (FOA), Design for X (DfX), Design for Six Sigma (DFSS), Design Structure Matrix (DSM), Optimization Design, Design Review, Failure Mode and Effect Analysis (FMEA), Fault Tree Analysis (FTA), Life Cycle Assessment (LCA), etc. For implementing those methods in digital support systems, it is necessary to represent pertinent engineering information, such as qualitative/quantitative product behaviour, functional structure, tolerances, errors and disturbances, etc. It is still pre-mature to install such engineering concept into practical IT support systems. Figure 9 shows an example of product model representation which can accommodate various kinds of disturbances arising during production and product usage, and can support the computerization of practical reliability design methods. Further theoretical work and prototyping implementation are desired for practical use.

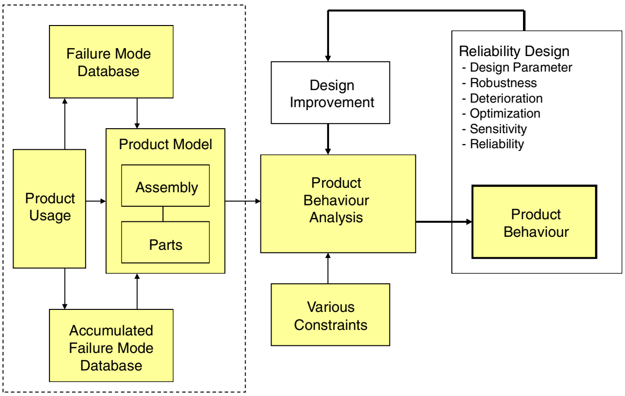

Fig. 9. Model based engineering with disturbances [7]

9 Summary

With the globalization of market and manufacturing activity, manufacturing industry in industrially advanced countries are facing difficult problems, such as severe competition with the low-cost production in developing countries and radical changes of customer requirements in industrially mature countries, etc. For coping with these problems, it is important to identify hidden or potential customer expectation, and to develop systematized design and manufacturing technology to augment human expertise for innovative product development. As Japan expects the radical decrease of population in coming 50 years, it is very important to systematize the product and process development technology throughout the total product life cycle, and to introduce IT methods and tools for supporting creative and intelligent human activities, and for automating well understood engineering processes. In this paper, current issues in manufacturing industry are generally reviewed. Future directions of manufacturing industry are described, and important technological issues and their IT support solutions are discussed from the viewpoints of potential customer expectation identification, large system and complexity problems, upstream design problems and important basic technology. Finally future perspective for advanced IT support is investigated.

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