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Directions of Next Generation Product Development

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Abstract: For the last 20 years, the focus has been on product development processes and developing tools to support them, addressing not only technological but also managerial issues. While these tools have been successfully supporting product development processes in a general sense, consensus on the direction of future developments seems to be lacking. In the paper, it is argued that horizontal seamless integration of product life cycle knowledge is the key toward the next generation product development. Knowledge fusion, rather than just knowledge integration, is considered crucial. In this paper, we will try to outline the directions of the next generation product development, its tools, and necessary research efforts.

Keywords: product development, integration, knowledge fusion

2.1 Introduction

Product development is a key process for manufacturing. This process includes product marketing, product planning, product design, prototyping and testing, production planning, production design, and product systems design. In the last two decades, product development focused on such issues as cost, quality, lead time, product variety, integration of various aspects, organization, and design for X. Companies that emphasized these issues, as well as lean production technologies, concurrent engineering technologies, have been successful. Research efforts in product development have resulted in enabling techniques and tools for efficient product development, such as digital design tools (CAD/CAM/CAE), rapid prototyping tools, and design and information management tools (PDM). Undoubtedly, these tools without a doubt contributed tremendously to achieving such difficult goals as cost reduction together with quality improvement and lead-time reduction while increasing product variety.

In this paper, we will try to outline the directions of the next generation product development and necessary research efforts. In Section 2.2, we will review the history of manufacturing and its influence on product development. We will argue that knowledge is the key, as the products become more multi-disciplinary and their boundaries expand to include a large variety of life cycle issues.

In Section 2.3, we will articulate the missing or insufficiently addressed issues within the current product development research trends. The first issue is "more horizontal integration" to include a wider range of engineering activities, and augment the current practices of overemphasizing shapes. The second issue is "seamless integration of activities" beyond data and knowledge-level integration. The activities within product development can include activities such as design, computation, procurement, prototyping, and testing. These might even be extended to supply chain management (SCM) and value chain management (VCM) based on product life cycle management (PLM), because products are now expanding their boundaries from a physical existence to a product-service system in a holistic product life cycle. The third issue is that product development still pursues "better quality, lower costs, more innovation, higher speed, and yet greener performance." Although concurrent engineering practices address these issues, these goals should be further emphasized.

In all of these three issues, knowledge integration plays a crucial role. Section 2.4 points out that knowledge fusion, rather than just knowledge integration, will be more important, because in order to be truly innovative, integrated knowledge is needed.

2.2 Analysis of the Production Development Paradigms

Historical Production Paradigms

Reviewing historical development always gives an insight into future directions. Manufacturing began with craftsmen and then became gradually organized first in the form of domestic industry and then as factory systems. Later, through the Industrial Revolution period, due to the necessity of capital investment of machinery, this factory system became dominant.

In the craft society, a craftsman designed and produced products all by himself. This single-man process was seamless, and there was no apparent division of labour. The knowledge needed for this process was undividable. Soon, however, product-wise specialization took place; goldsmiths used different processes and knowledge from those used by bookbinders. Nevertheless, the master was responsible for the final integration.

This was a qualitatively different division of labour compared with the factory concepts that appeared later in which the labour of many unskilled workers had to be organized and coordinated to achieve mass production. Improvements in productivity of this type of manufacturing, typically after the Industrial Revolution, was possible by employing more workers, by using mechanization that replaced human labour with mechanical operations, and by introducing more powerful and faster machines. This resulted in more specialized work in an organization.

In the early 20th century, two important concepts were introduced. One was the scientific management of production (Taylor system) and the other was the mass production (Ford system). The combination of these two resulted in powerful industrialization, particularly in North America and Western Europe, in the first half of the 20th century. This process was further accelerated by automation technologies (and later by computer technologies), replacing not only muscle work but also gradually the intellectual aspects of human workers.

Volume and productivity of production of mono-disciplinary products were achieved, at that time, by simplified mono-disciplinary division of labour, either component-wise or discipline-wise. The integration took place through the physical assembly of final products.

In the last three decades of the 20th century, quality goals replaced quantity goals. Production of many of the same was insufficient in the post-war competition among industrialized nations. First of all, batch size became smaller and smaller, while product variety increased. For instance, the concept of Flexible Manufacturing Systems (FMS), which aims at variety and small-batch-size production, gradually became popular. Secondly, quality became a more dominating factor in production than quantity, while lower costs were still pursued. Technologies such as lean production and concurrent engineering were developed to achieve these contradictory goals.

At the same time, products became increasingly more complex; a good example is mechatronics products that are typical of multi-disciplinary products. Computer based design support tools were critical to develop such complex products with higher quality. This further meant integration of data and information for product development, which was done at the systems level by assembling divided disciplines. Organizationally, efficiency achieved through the work of many-men by specialization and/or by organization was not enough. Competitive quality improvement and cost reduction were possible only through collaborative team work.

The important resources of production have been capital, labour, machines, production, and knowledge. First, in the craft society, all of them were distributed. Then the domestic production system gradually integrated production activities. This was an integration of distributed production. The factory production system started next, which meant that production, as well as machines and labour, was concentrated through capital investment.

As mass production started, capital, labour, machines, and production were all concentrated in one place. However, knowledge was distributed in many parts of the production system, largely in workers. The market system then played a crucial role in distributing those once concentrated production resources, because through the market, we can obtain these. Nowadays, capital is obtainable through the capital market, and even labour has its market. As a consequence of globalization and worldwide competition, except for knowledge, everything else is now obtainable through the market.

Analysis of the Product Development Paradigms

The analysis above outlines the current situation of manufacturing and further implies its influence on product development. The current production paradigm has the following features.

First, due to the ever-developing globalisation and universally developed market principles, we now see different forms of division in manufacturing. One is competence-based division of manufacturing and the other is geographical division. Both forms of specialization require integration through advanced information and communication technologies.

Second, products are becoming more multi-disciplinary. This has two meanings. Opto-mechatronics products, such as DVD players, which integrate more diverse disciplines, illustrate the first meaning. The second is the focus on product life cycle issues that include product life cycle management, end-of-life treatments, and different forms of added value generation such as service and product-service systems [1], due to increasing concerns about the global environment. This means that the shape and boundaries of products are further expanded. Classically, a product is a physical existence with material properties, physical shapes, performance, and functions. However, within the service-centred economy or production paradigm, a physical product is merely a device to deliver services that generate more added value. This means that in addition to PDM (Product Data Management), PLM (Product Life Cycle Management) should be developed to include SCM (Supply Chain Management), VCM (Value Chain Management), and CRM (Customer Relation Management).

These features of the current production paradigm have an impact on product development supported by a variety of tools that have become available over the last 40 years, since the Sketchpad system in 1963 [2]. During this period, as described in the previous section, product development had different goals to achieve, which resulted in a wide variety of technologies, methodologies, and tools. Among others, we can identify three important goals: improving productivity and quality through automation, and reducing costs. For instance, in the early phase of CAD (Computer Aided Design) in the 1960s and 1970s, the goal was to at least "automate of the drafting tasks" for better productivity, although "automation of designing tasks" was one of the aims.

Furthermore, CAD/CAM (Computer Aided Manufacturing) integration was pursued, so that CAM data is automatically generated on CAD. During the 1980s, together with the advances in 3D CAD technologies, product modelling became one of the goals. This further resulted in PDM, combined with the development of CAD data exchange formats such as STEP. In addition, CAE (Computer Aided Engineering) concepts using data defined on CAD systems in the engineering analysis stages have become interesting. There was a strong motivation to create a central database of products that can be used in every stage of product development to first improve productivity, then quality. However, the improvement of products quality has become very complicated during these periods which benefited the trend to reduce costs through automation.

In summary, information technology that has been applied to product development first identified automation as a primary goal, but then gradually turned to conversion of product development activities to an information-centred one as a dominant goal. In other words, data integration over various product development activities was the central issue targeting better productivity as well as quality and cost improvement.

During the 1980s, knowledge engineering approaches have established their role in product development. While the so-called expert systems approach quickly disappeared due to its technological immaturity and insufficient understanding of product development processes, the knowledge-centred view of product development has remained. Today, knowledge management for product development is simply an urgent issue. It aims at integration of knowledge for product development compared with the data integration view. This is considered essential for both quality and cost improvement, while productivity improvement is also addressed.

Concurrent engineering through improved communication among different product development participants has been highlighted from the late 1980s and 1990s, including such technologies as DfX (Design for X) and collaborative teamwork environment. As the products as well as product development processes became more and more complex, it was essential to have better collaboration among different product development participants. These not only shorten the product development lead time (*i.e.*, reduced costs as well as competitiveness) by having greater overlaps between processes that were formerly performed sequentially, but also help to identify design defects before production. Thus, the primary focus was on competitiveness, rather than productivity, through improved costs and quality.

In summary, the next generation product development should focus more on knowledge-centred integration due to the increasing importance of knowledge intensive products and product-service systems that require a wide variety of product life cycle knowledge.

2.3 Future Directions of Product Development

What are the Problems?

We have identified the trends in product development in the previous sections and concluded that products are becoming more multi-disciplinary with their boundaries expanded from just a physical existence to the whole life cycle system. A key to this is the knowledge-centred integration of product development.

In addition, the economy of advanced industrialized countries is increasingly becoming knowledge and service intensive, rather than energy and material intensive. This knowledge intensiveness can have two meanings; one is knowledge-intensive products, which have embedded intelligence for innovative features and functionalities, and the other is knowledge intensive product development. Due to the expanding product boundaries (*i.e.*, a product as a package to a product-service system with life cycle aspects), product development should include these life cycle aspects as well, addressing integration with such activities as SCM and VCM.

Of course, the ever-increasing pressures for product development with better quality, lower costs, and quicker delivery with greener performance still exist for product development. Achieving these goals is only possible by integration of different types of product life cycle knowledge.

Having said these, we recognize that product development processes should still address the knowledge integration about product's life cycle. Also, we should notice that the integration of different types of knowledge is the source of innovation [3]. This integrated knowledge should result in better integration of various activities over product's life cycle. These are summarized in the following sections.

Horizontal Integration

The first issue is "more horizontal integration" to include a wider range of engineering fields, because products are becoming more multi-disciplinary and their boundaries are expanding. Horizontal integration means taking more different fields into consideration during product development.

For example, it is not a surprising practice that during mechatronics products development, electronics and software design are totally separated from mechanical design. However, as concurrent engineering dictates, it is essential to promote collaboration among mechanical designers, electronics designers, software designers and production designers. If such collaboration does not exist, the easiness and cost of modifications at later stages of product development vary depending on the nature of the product. For example, a mechanical design error could be corrected by software modification with less cost. The differences in the degrees of component standardization among these disciplines also contribute to the differences in the development lead time, resulting in a tendency that software development receives extra pressure due to design changes from mechanical and electronics design. This never leads to good product development practices.

Seamless Integration of Activities

The second issue is "seamless integration of activities" based on information and knowledge level integration. The activities within product development can include such tasks as design, computation, procurement, prototyping, and testing. These activities do share a common PDM database, for instance. However, since the shared model is basically a product model, information about the product development process and these activities is not shared. In addition, a proper feedback or feed-forward mechanism that can prevent communication failures is missing from the current systems.

Additionally as product boundaries expand, we need further integration of SCM, VCM, and CRM with PDM to arrive at PLM. This will seamlessly integrate a variety of activities within a product life cycle.

Better, Cheaper, More Innovative, Speedier and yet Greener Product Development

The result of “horizontal” “seamless integration” of activities should help us to achieve product development with “better quality, lower costs, more innovation, higher speed, and yet greener performance.” Concurrent engineering practices address these issues. However, the recent economic development in many areas in the globe demands further drastic improvements in achieving these goals.

It is worthwhile to examine the business practices exercised by the INCS Japanese Company [4]. This company, for example, promises delivery of a rapid prototyped component (using laser lithography technology) within four days after the order and of a moulding die within fourteen days. This kind of speed is possible not only through technology but also through an innovative management style, resulting in innovation in product development processes that improve both quality and cost. This not only signifies the importance of integration through computer-based tools but also addresses an important feature that is missing from the current research in product development; namely, speed.

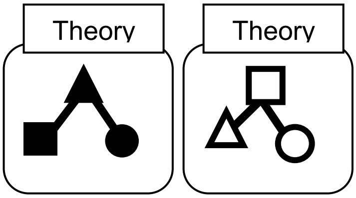
2.4 From Knowledge Integration to Knowledge Fusion

In the previous chapter, we pointed out that “horizontal” “seamless integration of knowledge” about product’s life cycle is the key to arriving at product development for better, more innovative, quicker, and still greener products.

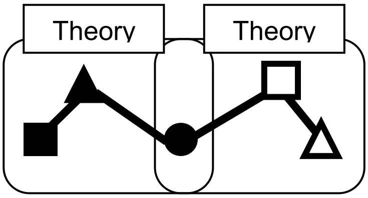
A knowledge system that represents a mono-discipline required for developing a simple, mono-disciplinary product is shown in Figure 2.1 (a). We may then need a set of closely related knowledge systems for multi-disciplinary product development. Integrating these closely related knowledge systems requires defining at least interfaces (Figure 2.1 (b)). Such multi-disciplinary integration is a key for innovative product development [3].

However, to be more innovative, we may need to go one step further; knowledge fusion (Figure 2.1 (c)). Knowledge fusion is to create a new knowledge system that can be operated as a whole to develop truly multi-disciplinary products. Knowledge integration is still a collection of independent knowledge systems with clearly defined interfaces and describes common concepts among those integrated knowledge systems, while knowledge fusion is a situation in which these systems have been totally fused to create a new knowledge system.

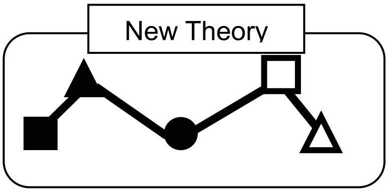
Knowledge fusion is of course not automatically possible. Mechatronics is now considered to form an integrated knowledge system, but still we can see distinctions among mechanical technology, control technology, electronics, sensor technology, and software technology. This suggests that first, only a knowledge system based on knowledge fusion can arrive at better product development, and second, it is not just a matter of developing product development technologies but we need efforts to create a fused knowledge system. While details of knowledge fusion are yet subject to research, we may point out that knowledge-structuring efforts are considered useful [5, 6].



(a) Independent two knowledge systems



(b) Knowledge Integration



(c) Knowledge fusion

Figure 2.1 Knowledge integration and knowledge fusion

2.5 Conclusions

This paper is an attempt to identify the directions of the next generation product development and necessary research efforts. Three key issues were identified. The first issue is “more horizontal integration” to include a wider range of engineering activities. The second is “seamless integration of activities” beyond data and knowledge level integration. The activities within product development can include such tasks as design, computation, procurement, prototyping, and testing, and might even be extended to SCM and VCM based on PLM. The third is product development still pursues “better quality, lower costs, more innovation, higher speed, and yet greener performance.”

For these three issues, knowledge integration plays a crucial role. However, since knowledge integration only arrives at a set of knowledge collection of which interfaces are clearly defined, we may need even another step; knowledge fusion. While knowledge fusion itself is not yet a clear concept, we have identified some research directions in knowledge structuring as being useful.

2.6 References

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