Integrated Manufacturing Information System (IMIS) for Sustainable Innovations: Case Study of Japanese Firms

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Abstract--**This article aims to present Integrated Manufacturing Information System (IMIS) that fulfills multiple objectives simultaneously in the form of timely responses to the customer specific requests, design capabilities for products with high customer value, and excellent translation competence of embedded tacit knowledge into explicit applicable system knowledge. For this goal, this new IMIS should be able to evaluate entire business strategy based on internal product development information data base. We further provide an architecture analysis framework as a specific IMIS implementation tool and two relevant case studies are included for illustration purpose.**

I. INTRODUCTION

Until 1980s Japanese firms have enjoyed competitive advantage in the global market through their manufacturing capabilities [1], [2]. Japanese competitive advantage had been through integral product architecture with high quality management practices. The unique strength of Japanese *monozukuri* (i.e., integrative manufacturing system) is the extended functional domain (e.g., R & D, engineering design, production, supply chain field, sales, and service field) as a synergistic system. Thus, it is crucial to construct integrative system that brings this vast array of tacit knowledge chain into organic work processes.

There is a strong literature support that recognizes the outstanding capability and performance impact of Japanese *monozukuri.* Even in the areas of software industry which is regarded somewhat less competitive than the US counterpart, its overall quality of products and services are still comparable. As Japanese *monozukuri* with enormous level of tacit knowledge is extended to serve global markets, the existing IT system is deemed inadequate. Thus, it is crucial to design reliable information linkage system to ensure smooth tacit knowledge flow for timely and effective business decision making.

This article aims to present Integrated Manufacturing Information System (IMIS) that fulfills multiple objectives simultaneously in the form of timely responses to the customer specific requests, design capabilities for products with high customer value, and excellent translation competence of embedded tacit knowledge into explicit applicable system knowledge. For this goal, this new IMIS should be able to evaluate entire business strategy based on internal product development information data base. This article presents the IMIS that supports Japanese integrative *monozukuri* from the viewpoint of Japan. This article discusses the key dimensions of IMIS in terms of data gathering processes, cross-functional requirements for successful products in the market and systematic evaluation criteria for mid-to long-term business plans.

II. LITERATURE REVIEW

A. Three types of core competence and sustainable innovations

Core competence differentiates any firm from its competitors [3], [4], [5]. The theoretical base of core competences derived from classical theory of firm and innovation [6], [7]. Afterward it was [8] who proposed a theory of firm growth and other scholars in 1990s applied this theoretical perspective in competiveness in firm level [9], [3]. They evaluate three points to see if they are true core competences; (1) relevance, (2) difficulty of imitation, (3) breadth of application. Core competences must influence customer's purchase decisions. In that meaning, to brainstorm customer needs is critical. Core competence also should be difficult to imitate and something that opens up a good number of potential markets.

As core competences are internally developed over a long period of time, too often these firm specific competences may not adapt to rapidly changing market requirements in timely fashion and thus not become a competitive weapon. As firms focus on routine aspects of innovation, they may not be ready to respond to changing market requirements or compete against the growing threats of competitors. In view of such competitive reality, it is important to renew core competences to adapt to changing global market needs [5].

First of all, we discuss the importance of the building process of linkage competence for sustainable innovations from the standpoint of global competitive advantage. Our special focus is on how global firms successfully build their linkage competence. The determining factor of any firm’s competitive advantage is its unique resources or advantageous position [10], [5]. In relatively stable business environment, it is not unusual that firms can utilize their core competence for a long period once it had been successfully built over the years. However, in turbulent market environment the core competence of the past may turn out to be the reason of business failures.

After 2008 global financial shock the demise of Japanese electronics firms illustrates this point. As firms focus on incremental innovation, architectural knowledge embedded in work routines and regular work flows rarely change. As the internal innovation leaders depend on organizationally filtered information, their understanding of organizational architecture and absorptive knowledge become outdated. These firms are no longer able to face the challenges of the disruptive innovation of rival firms. In this context, researchers in 1990s present dynamic capability theory [11], [12], [13], [14], [15]. Firms lose their competitive advantage once their organizational governance is unable to create, store and explore knowledge assets through their routine work processes in the form of unique innovative capability. In this sense, dynamic capabilities are defined as "the systematic organic effort to capture the new innovation opportunities by connecting to the external network and to translate into organizational core capability that reconfigures and protect their knowledge assets for sustainable competitive advantage" [11]. Thus, the crucial elements of dynamic capability are organizational sensing of external environment, exploration of business opportunities, stretch and leverage of innovative knowledge assets [9]. In this article, such dynamic capability is referred to linkage competence which is further explained in three types of competence which are market competence associated with external environment, resource securing for enhancing technology competence, and linkage competence that combines external and internal resources [5].

First, the strengths of Japanese firms are in their technology competence that develops products with high functionality and quality. Such technology competence is based on product development capability, patent rights, multi-skilled human resources, product design and manufacturing capability embedded in organizational system and work processes. The indicators of technology competence are productivity, production lead time, time to market, number of new product projects, product integrity, and design quality [16]. Technical experts with years of experiences in manufacturing floors (e.g., heavyweight project managers of Toyota Company) can recognize the level of technology competence with their intuitive understanding and careful observation of manufacturing processes [17].

Second, in the emerging new markets relative weakness of Japanese firms lies in customer competence which is essential to inspire customers through aggressive marketing and promotional efforts which are vastly different from the advanced USA/European markets. This involves innovative methods of communicating the unique value of their products which lead them to adopt new life style patterns. Such customer competence is not for easy and quick methodical measurement. Rather, it includes comprehensive measures such as customer satisfaction ratings, repeat purchase rates, the number of new customers, market share, customer loyalty, and customer willingness to pay. Intuitively, expert managers with years of experiences in the areas of customer services would be able to estimate the extent of customer competence.

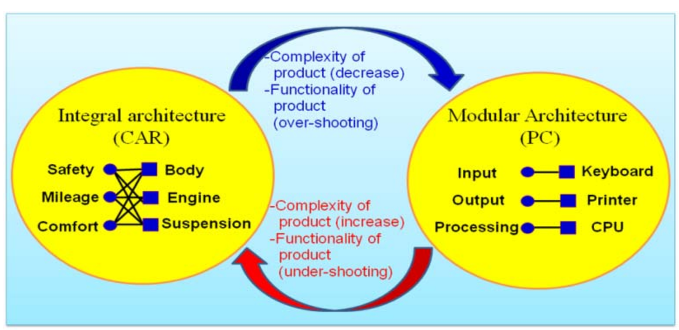
Third, the ability to transform idea into tangible substance (i.e., linkage competence or network capability) is to integrate product concept into tangible products (i.e., linking customer competence to technology competence). However, many Japanese firms are not quite familiar with this "linkage competence" concept. Japanese firms assume that their weak customer competence is the main reason for their relatively weak position in the global markets. Thus, many firms reinforce their marketing efforts and yet they do not necessarily understand the critical role of linkage competence for their market success. Linkage competence is realized as firms attain adequate market sensing ability, develop customer trend sensitive managers, implement product architecture and achieve overall product-process integrity.

B. Product Architecture and Core Competence

In this section, it is explained about the theory of product architecture and core competence. Product architecture is the basic design philosophy which is divided into modular and integral types [18], [19], [10], [5]. Modular architecture shows one-to-one relationships between product functions and product structures, and thus each component part is independently designed and combined separately. Thus, each separate and independent unit is called a module. On the other hand, integral type shows multiple-to-multiple relationships. Any changes in design influence other parts and the design details take into account the complex interrelationships within product structures.

In particular, complexity is apparent in highly functional mechanical products with many parts. The design process of such complex products and associated organizational structures are closely related to the types of product architecture [20], [21], [18], [22], [23], [24], [25], [26], [27], [28], [10], [25], [5].

Figure 1 depicts how firms change product architecture—either from integral to module or modular to integral [29]. As we mentioned, integral architecture (e.g., a car) shows highly interrelated relationships between product functions and body parts. As integral product processes are not easily divisible, products with an integral architecture may switch to a modular one as product complexity decreases. On the contrary, products with a modular change into an integral one if product complexity increases.



Source: Adapted from [29]
Figure 1. Types of Product Architecture

However, this product architecture concept has not included relationships among customer needs, function and structure and only focuses on relationships between function and structure. In this article, we suggest the framework about relationships between product architecture and core competences. In general, speed is the key for modular products. In contrast, integral products may pursue high degree of product complexity through coordination functions so that closed technology accumulation is more valuable for integral architecture with tacit knowledge and expertise. Thus, to keep competitive advantages, product development relating to core competences must be done with integral architecture internally. But product development of non-core area should be outsourced with modular architecture for cost reduction. Based on this competitive structure with product architecture, our architecture analysis method suggests portfolio analysis to identify and manage core competences, and to determine the optimum allocation of resources concerning core competences [30].

C. Integrated Manufacturing Information System and Architecture Analysis Method

It is expected that consumer needs will become more sophisticated and the trend towards stricter environmental, energy, and safety constraints conditions will continue in the future [28]. To cope with these trends, it is necessary to conduct various countermeasures, such as IT system and modularity of product architecture and standardization of parts, and construction of organizational capability for team development. Complex products with an integral architecture, their mechanical sides in particular, may fit well with coordinative (i.e., teamwork-oriented) organizational capabilities, as well as with design processes emphasizing detailed structural designs at relatively early phases of product development. Such integral-coordinative processes will also need the support of team-oriented IT. Therefore, to analyze the complex processes for product development, we have developed an architecture analysis method as IMIS that integrates design information [30]. This architecture analysis method shows the relationships among customer needs (voice of the customer), function, structure, process and organization. Based on this analysis, the companies can concentrate on their own core competence, and outsource non-core areas, while still maintaining integral product architecture for quality standards and product integrity as a core competence area.

Figure 2 explains the concept of architecture analysis methods. This is based on interviews on customer needs and construct architecture matrix. IMIS implementation requires vertical integration of design information which translates customer needs information into new product design and development, manufacturing processes and final finished products delivery. This entire process involves value chain process in the form of customer needs-production functionality performance-product architecture-product process-supplier matrix. Take automotive product functionality-product architecture as a matrix example. All the customer requirements on functionality items are listed in the horizontal rows and corresponding component parts details are specified in the vertical columns. Such item by item specifications are prepared according to the firm's design standards and QFD methodology. This is to transform implicit product development knowledge into explicit product design knowledge and IT system provides the practical tool to share relevant design information to all the related participants of the value creation and delivery processes. For the effective communication among diverse organizational participants, the matrix details are saved in Microsoft Excel spreadsheets.

Figure 3 shows diverse architecture analysis applications. First, sorting tool is to define priority sequence to overcome product design constraints arising from design information complexity shown in the vertical columns and horizontal rows of architecture matrices. If particular product design constraints are handled in the backend process, too often retrogression (backtracking) occurs. Thus, it is important to put forward the items that might cause design information glitches.

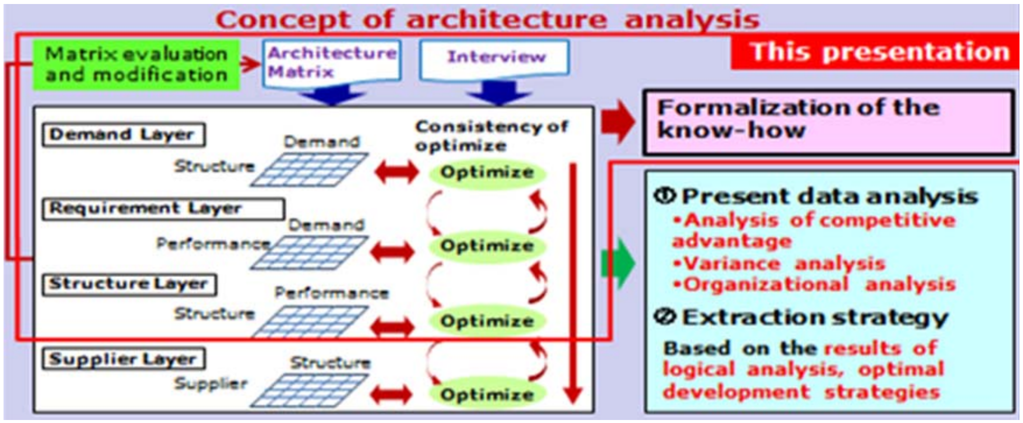


Figure 2 Concept of Architecture analysis methods

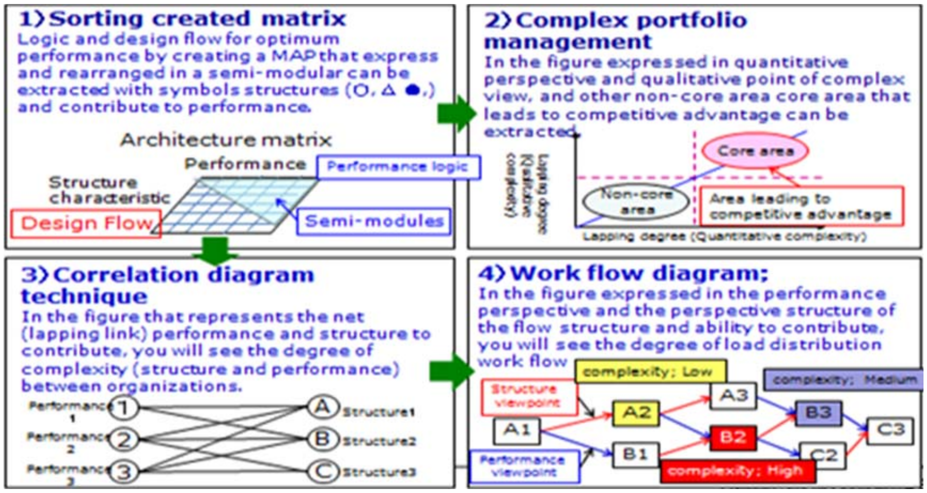


Figure 3. Diverse Architecture Analysis Applications

Figure 4 presents the similar solution logic for matrix equations. Here, the details are stated in certain symbols. In real product development applications, all the specific items are expressed in numbers (e.g., 1,5,9) of matrix equations. Thus, the finding solutions might be comparable to finding determinant solutions for YN among corresponding Xn.

Second, based on the data obtained by sorting method, portfolio analysis shows the matrix complexity rules. The rules search for questions such as "What particular design details require focused attention?" and "What design items are related to core competencies?" Portfolio analysis is to scientifically search for effective solutions in design matrix complexity. Figure 5 shows the key aspects of portfolio analysis concept. The horizontal columns of portfolio analysis indicate MS(Matrix Score) and vertical columns are IS(Interface Score). The results of portfolio analysis are derived based on the combination of vertical and horizontal matrix columns. Take portfolio analysis map of product functionality-product architecture matrix as an example. From the product functionality perspective, we may obtain MS (Matrix Score) and IS(Interface Score). On the other hand, from product architecture perspective, MS (Matrix Score) and IS(Interface Score) are also derived. The MS (Matrix Score) from product architecture is the cumulative points translated from imbedded knowledge scores which suggest the complexity degree between component parts functionality and architecture patterns. This is also compared with IS (Interface Score) which indicates the component parts inter-relationship complexity. Thus, from architecture matrix, MS (Matrix Score) can recognize which particular design pattern items impact specific component parts in terms of complexity requirements. In the portfolio map, the upper right section suggests great deal of design complexity. Thus, particular design items positioned in the upper right section require special attention for resolving design complexity challenges.

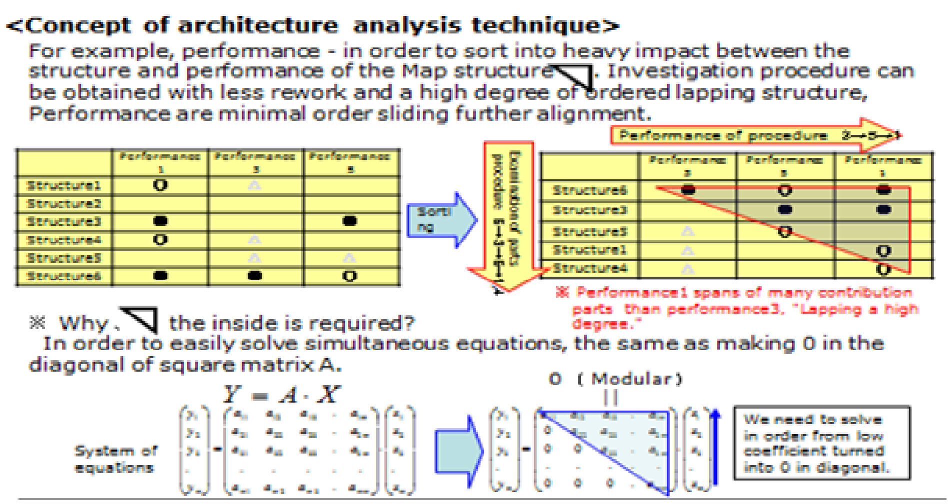


Figure 4. Sorting for architecture Matrix

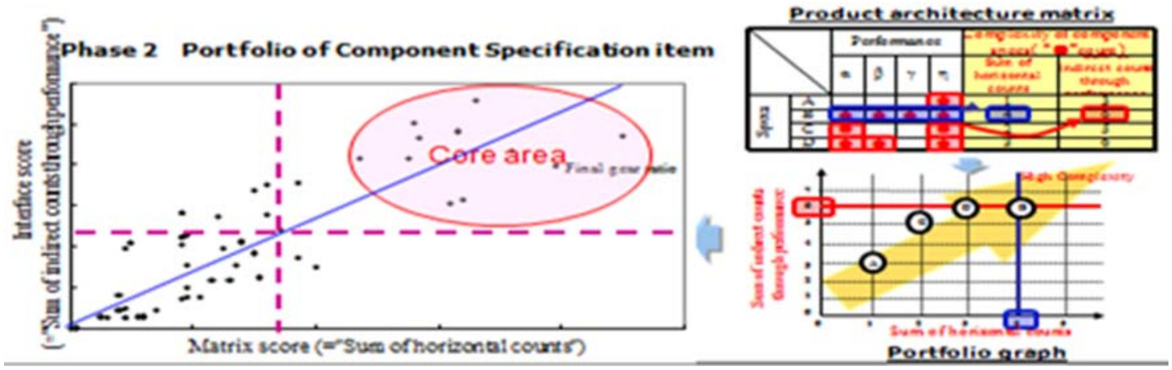


Figure 5. Complexity portfolio analysis

Third, correlation diagram tool shows the correlation between columns and rows. Portfolio analysis is to quantify the degree of design complexity and correlation table shows visual relationship extent of items in particular columns and rows.

Fourth, work flow diagram defines in sequence steps for the product development after determining the optimum product development processes. This can easily pinpoint any bottleneck in product development process.

Finally, Figure 6 shows Organization graph and PERT chart. Correlation diagram tool helps to determine the complexity level between column-row inter-relations. The greater complexity of interrelationships, the greater need for coordinative mechanism. Thus, highly experienced engineers usually assume the responsibility to deal with such design complexity challenges. In this sense, Organization graph is useful to identify the right engineering experts to particular design tasks and reduce the probability of product development retrogression (backtracking) and accordingly minimize the product development failures.

Another planning and controlling tool is the Program Evaluation Review Technique (PERT). This is to manage product development project. This tool can also be referred to as the Critical Path Method (CPM). Both PERT and CPM can be used interchangeably, but for the purposes of this lesson, only the PERT term will be utilized. Primarily, the PERT chart identifies the critical path for the project. The critical path is the sequence of tasks where there is no slack time. In other words, if any task on the critical path takes longer than expected, the end date of the project will be affected. This only applies if there are tasks that can be completed in parallel. For example, all of the tasks in Figure 6 occur sequentially and therefore every task is part of the critical path. Both PERT chart and Organization graph are useful to achieve effectiveness in product development projects.

In the following sections, we further examine the details of case study based on the research framework of this architecture analysis method.

III. CASE STUDY

Case study of two firms is presented here to illustrate the research model of product architecture. This two year case study project (2011-2012) examines the results of applying product architecture model. The project team members are all senior engineers who are the leaders of new product development project leaders. Because of propriety nature of the product development projects still in progress, the names of firms are not disclosed.

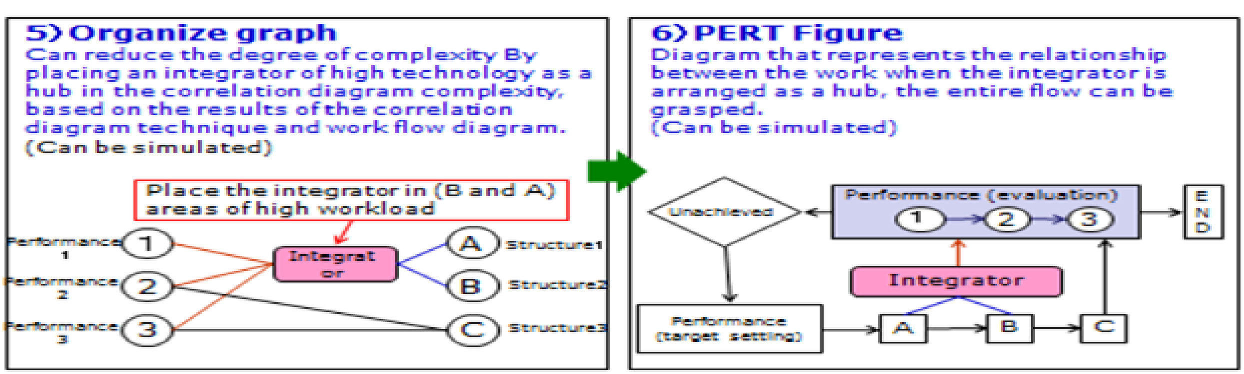


Figure 6, Organi graph and PERT figure

A. N-firm case

N-firm case involves component parts of drive train from 2011-2012. Automotive drive train is series of power delivery mechanism from main engine to tire, which includes transmission, transfer, propeller shaft and differential drive shaft. This type of driver train system is related to power performance, strength reliability, vibration, heat performance, 4 wheel drive performance, and layout performance. Because of competitive pressure cost reduction requirements for these component parts are quite serious. Thus, the focus of drive training system design is to develop component parts which satisfy multiple performance dimensions and maintain low cost standards.

By applying architecture analysis, this project team could identify their core competences through portfolio analysis method and define future product development issues based on correlation analysis and task dependence analysis. During the one year project period this project team could reduce retrogression (backtracking) in total product development process. Besides, organizational role change requirements and design floor challenges are also discovered. In particular, the reason for inadequate information sharing within the cross-functional teams further impact glitches in the upstream supplier network relationship as well.

B. O-firm case

O-firm case is related to power window switch development project. This is about switch functionality for opening and closing windows using electricity or air power. Power window has been applied since 1930s in USA. After 1980s popular usage also remind consumers the potential risk for body damage (e.g., hand and neck) by the sudden operation of power window functions, additional safety features need serious considerations. For a safety example, in the course of switch operation, detection the presence of any objects would automatically stop the intended opening or closing function.

The time period of O-firm case is during the year 2011. Architecture model was applied to power window switch for mid-end model and premium brand model cars. Based on element-functionality matrix analysis, competitive advantage factors through value added and core competence are identified. Functionality-architecture matrix analysis indicated the necessary of constructing common platform for mid-end and premium models. Size and design elements require most frequent changes and modular design is proper. Total saving of the development cost was 2.24 million (yen) plus additional labor cost saving of 1.130 million (21.8%). Common platform tasks are better defined as well. In case of design changes focusing core area of customization also resulted in saving of development cost (e.g., reducing the number of design processes) and coordination costs with suppliers (e.g., determining the mixture of component parts).

IV. CONCLUSION

This article aims to present Integrated Manufacturing Information System (IMIS) that fulfills multiple objectives simultaneously in the form of timely responses to the customer specific requests, design capabilities for products with high customer value, and excellent translation competence of embedded tacit knowledge into explicit applicable system knowledge. For this goal, this new IMIS should be able to evaluate entire business strategy based on internal product development information data base. IMIS implementation requires vertical integration of design information which translates customer needs information into new product design and development, manufacturing processes and final finished products delivery. This entire process involves value chain process in the form of customer needs-production functionality performance-product architecture-product process-supplier matrix.

We suggest that Integrated Manufacturing Information System (IMIS) is potentially very useful in achieving multiple performance requirements simultaneously in the form of timely responses to the customer specific requests, design capabilities for products with high customer value, and excellent translation competence of embedded tacit knowledge into explicit applicable system. We also provide an architecture analysis framework as a specific IMIS implementation tool. From 2011 to 2012, our research team has conducted two relevant case studies to examine the usefulness of IMIS in the real business contexts. Future research may further apply this theoretical concept into diverse industry settings.

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