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Modular Product Development for Mass Customization

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Tiivistelmä

Tuotteiden asiakaskohtaiset ominaisuudet kasvavat jatkuvasti nykypäivän kilpailussa toimintaympäristössä. Asiakaskohtaisten ominaisuuksien kehittäminen vaatii tuotekehitysprosessin ja liiketoimintastrategioiden uudelleenjärjestelyjä vastaamaan yksittäisten asiakkaiden tarpeita ja dynaamisen tuotannon vaatimuksia. Tuotteiden uudelleenkonfiguroinnissa vaaditaan tiiviimpää informationvaihtoa tuotekehitykseen osallistuvilta sekä yrityksen sisällä että huomioiden yrityksen ulkopuoliset tekijät.

Tässä tutkimuksessa kehitetään tietojärjestelmien integraatiota asiakkaiden, suunnittelijoiden ja valmistajien kesken mahdollistaen näin asiakaskohtaisten tuotteiden valmistaminen. Tutkimuksen päätavoitteet esitetään seuraavien kolmen tutkimuskysymyksen avulla:

1. Miten informaation jakamisen ohjaaminen vaikuttaa tuotekehityksen käytäntöihin?
2. Miten konfiguraatioprosesseja voidaan soveltaa tuotekehityskäytäntöihin ja niiden käyttökelpoisuuden selvittäminen asiakaskohtaisessa tuotannossa?
3. Miten eri tuotekehityksen mittarit integroidaan tukemaan markkinoilla oleva ratkaisuja ja vastaamaan yrityksen sisäisiä resursseja?

Tutkimuskysymyksiä selvitetään empiirisellä case-tutkimuksella ja tulokset on esitetty kuudessa julkaistussa artikkelissa. Tutkimus tuottaa sekä teoreettisesti merkittäviä että käytäntöä hyödyttäviä tuloksia.

Tutkimuksen tuottama lisäarvo on suunnittelumallin luominen. Suunnittelumallilla johdetaan konfiguraatioprosessia, joka kytkee yrityksen tiedonkulun hallintaprosessin ja eri tuotekehitysstrategiat yhteen. Erityisesti yritykset, jotka kehittävät tuotteittensa asiakaskohtaista räätälöintiä voivat hyödyntää väitöstutkimuksen tuloksia.

Asiasanat

Tuotteiden kustomointi, tiedonkulku, konfigurointiprosessi, suunnittelumallit, tuotekehitys, design rakenne matriisi (DSM), domain kartoitus matriisi (DMM)

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Abstract

Product customization is a growing concern in today's competitive business environment. Success in the customization process is achieved by swiftly recon–figuring the product development process and business strategies with respect to individual customer's needs and dynamic production requirements. Alongside the product reconfiguration process, a new level of information integration among product development participants is required, both within the firm and with external environments.

In this research, the integration of information systems among potential customers, designers and manufacturers is developed with a view to fabricating modular custom-built products. The overall objectives of this research are explored through three research questions as follows:

1. How does managing information exchange affect the use of product development practices?
2. How could the configuration process be implemented for product development practices and its usability in the customization principle?
3. How can different development measures be integrated to support market solutions and the internal resources of a firm?

Research questions have been analyzed with empirical case studies and the results are described through six published articles. Research provides theoretically significant results, which are also practically beneficial.

The contribution of this research is the development of a managerial framework for managing the configuration process, which purposefully bonds the information management process and specific product development strategy of a firm. Firms can use the results and findings of this thesis for the purposeful promotion of their product customization process.

Keywords

Product customization, information exchange, configuration process, design architecture, design structure matrix (DSM), domain mapping matrix (DMM)

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Vaasa, March 2010

AHM Shamsuzzoha

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List of abbreviations

PD	Product Development
RQ	Research Question
MC	Mass Customization
R&D	Research and Development
TC	Turbocharger
QFD	Quality Function Deployment
CAD	Computer Aided Design
BOM	Bills of Materials
IT	Information Technology
DIYD	Do-It-Yourself-Design
3D	Three-Dimensional
ATP	Available-to-Promise
ASDN	Agile Supply and Demand Network
APS	Advanced Planning and Scheduling
EU	European Union
CATER	Computerized Automotive Technology Reconfiguration
DSM	Design Structure Matrix
DMM	Domain Mapping Matrix
MDM	Multi Domain Matrix
IM	Information Management
SADT	Structured Analysis and Design Technique
PERT	Project Evaluation and Review Technique
CPM	Critical Path Method
IDEF	Integration DEFinition
CIM	Computer Integrated Manufacturing
CE	Concurrent Engineering
DFM	Design for Manufacturability
PDB	Product Data Base
ICT	Information and Communication Technology
ATO	Assembled-to-Order
VR	Virtual Reality
2D	Two-Dimensional
JIT	Just In Time
MPS	Master Production Schedule
MTS	Make-to-Stock
MFD	Modular Function Deployment
VOC	Voice of the Customer

List of publications

Shamsuzzoha, AHM, Helo, P., and Kekale, T. (2008). Applying design structure matrix (DSM) method in mass customizations. In: *Operations and Supply Chain Management - An International Journal,* Vol. 1, No. 1, pp. 57-71. (Supply Chain Management Forum)

Shamsuzzoha, AHM (2009). Restructuring design processes for better information exchange. In: *International Journal of Management and Enterprise Development*, Vol. 7, No. 3, pp. 299-313. (Inderscience Publishers)

Shamsuzzoha, AHM and Helo, P. (2009). Reconfiguring product development process in auto industries for mass customization. In: *International Journal of Productivity and Quality Management*, Vol.4, No.4, pp. 400-417. (Inderscience Publishers)

Shamsuzzoha, AHM, Kyllönen, S., and Helo, P. (2009). Collaborative customized product development framework. In: *Industrial Management & Data Systems,* Vol. 109, No. 5, pp. 718-735. (Emerald Group Publishing Limited)

Shamsuzzoha, AHM, Kekäle, T., and Helo, P. (2011). Aligning external varieties to internal varieties for market solutions. In: *International Journal of Innovation and Learning,* Vol. X, No. X, pp. XX. (Inderscience Publishers) [Forthcoming]

Shamsuzzoha, AHM and Kekäle, T. (2010). Platform-oriented product development: prospects and limitations. In: *International Journal of Business Innovation and Research*, Vol.4, No.3, pp. 179-194. (Inderscience Publishers)

Author's contribution

The ideas and the work discussed in this dissertation and the research papers included were mainly carried out by the author while working as a member of the Logistics Systems Research Group of the University of Vaasa under the guidance of Professor Petri Helo and Professor Tauno Kekäle. Petri Helo and Tauno Kekäle acted as the co-supervisor and supervisor and the co-author of four and three papers, respectively. They checked all the draft papers, stated the essential changes needed and made suggestions for improvement.

The author of this thesis is the principal author of all the published or accepted articles. The author carried out the required research work, testing, experiments and the problem solving reported in the articles. The basic ideas came from the Logistics Systems Research Group. The contributions from the other authors are duly acknowledged and presented as follows:

Paper1 is directly linked to the work performed by the research team in the CATER project. The author was the principal writer of the manuscript and implemented the DSM tool as the information exchange among design elements. The other authors made valuable contributions in molding and condensing the paper into a more coherent and publishable format.

Paper 2 was solely written by the author implementing better information exchange among product development participants through restructuring design processes. The author tested the applicability and limitations of different matrix-based tools for managing information dependency.

Paper 3 can be seen as a participatory approach to the product customization process. This paper represents an empirical extension of the work initiated in connection with Paper 1. The author performed the data analysis and prepared the manuscript independently. The other author provided valuable insights and comments in the preparation of the manuscript.

Paper 4 is primarily based on the initial idea of co-author Sami Kyllönen, which was then extended and formulated by the author. The author also had an important role in writing the manuscript. The other co-author, Professor Petri Helo, provided the overall structuring of the paper and valuable guidelines on the manuscript during its different phases.

Paper 5 can be interpreted as a group work from the authors and participants from the case company, Wärtsilä. The base idea was translated and implemented by the author through the matrix tool DMM. The other authors contributed to the manuscript through cross checking and reviewing to an acceptable level. Accordance with the research contract between the University of Vaasa and its industrial partner Wärtsilä Oy, representatives of Wärtsilä checked this paper in order to prevent the publishing of any confidential information.

Paper 6 was formulated and written for publication by the author. The author contributed to the paper by explaining platform strategy in terms of product variety management and mass customization. The other author had an active role in supporting and motivating the preparation of the manuscript.

1 INTRODUCTION

1.1 Background and motivation

The globalization of the business environment is exerting extra pressure on the practice of product development (PD) across a wide range of firms. In this environment, customers are more particular in obtaining individualized products or services for their essential needs. This represents a major transformation in business, where manufacturers are being forced to customize products to some degree for increasingly selective customers, or to compete in niche markets (Pine & Gilmore, 2007; Kumar, 2007; Piller, 2007). However, if products are not designed well after consulting with potential customers, this could lead to a customization process that is slow and costly (Dellaert & Stremersch, 2005; Piller et al., 2006). This might trigger possible damage to the business, which consequently incurs a revenue loss for firms.

In order to achieve a higher customization level, firms need to cooperate and coordinate better interactions with their potential customers (Berger et al., 2005). This coordination can be facilitated through managing valuable information exchanges between manufacturers and customers. With the appropriate tools or methods to access, control and formulate interactions among product development participants, this information exchange can be managed. Configuration process is nowadays widely implemented in industrial sectors for coordinating the information exchange between firms and their customers (Zhou et al., 2007; Lapouchnian et al., 2007; Yang et al., 2008; Jiao et al., 2008). This approach can ensure the design and fabrication of custom-built products with a high level of customer satisfaction (Duray et al., 2000; Salvador & Forza, 2004).

The integration of customers in the production process creates value during the course of configuration, product specification and design strategy (Piller at al., 2004). Customer involvement at an early stage of the PD cycle can be seen as a fundamental principle of product customization, which supports and enables the majority of individual customers´ needs with near mass production efficiency (Tseng & Piller, 2003; Lu et al., 2008; Buttle, 2008). Product customization is characterized by a high intensity of information flow, which is produced by using adequate configuration tools (Zipkin, 2001). Designers have to interact with customers to obtain specific information in order to define and translate the customers' needs and desires into a definite product specification.

In the product customization system, the main part of customer integration happens during the configuration phase, or even in the design phase of a product. Zipkin (2001) defines this customer involvement process as the 'elicitation' of a customization system, which is more than information exchange - rather an act of cooperation and co-creation. The co-creation between customer and manufacturer during the elicitation process, demands for required information flow in order to handle the intensity and complexity of product development process (Lee et al. 2000). For the majority of industrial firms, customizing products is among the most critical means of delivering true customer value and achieving superior competitive advantage (Gilmore and Pine, 200; Johnson & Weinstein, 2004; Singh & Ranchhod, 2004).

Product customization is the driving force to potential growth and measures of performance indices for firms. Different product development strategies such as modularity, product platform, component commonality offer several benefits for customized products such as the reduction of the lead-time and cost, increases in product differentiation, etc (Jiao & Tseng, 2000a; Kamrani & Sa'ed, 2002; Thevenot & Simpson, 2006; Fixson, 2007). Adoption of a suitable product development strategy can ensure faster and qualified responses for the specification of customized products. A number of observers have suggested that specific PD strategies such as modularity, product family, configuration process and component standardization are the key to achieving low cost customization (Sanderson & Uzumeri, 1995; Pine et al., 1995; Perera et al., 1999; Huang et al., 2005a; Guo & Gershenson, 2007).

McCutcheon et al. (1994) suggest that modular product design is the best way to provide product variety and production speed, which facilitate customization through the fulfilling of customer demand for variety and reduced delivery times simultaneously. Modular design also can reduce the number of interfaces and variety of components, while offering a greater range of final products (Duray et al., 2000). Other strategic options like component commonality (Thevenot & Simpson, 2007; Shamsuzzoha & Helo, 2009), product platform (Simpson, 2004; Huang et al., 2005), product family (Meyer et al., 1997; Jiao & Tseng, 2000), product postponement (Yang et al., 2004; Su et al., 2005) also contribute significantly to customized product design and development with lower cost and reduced lead time.

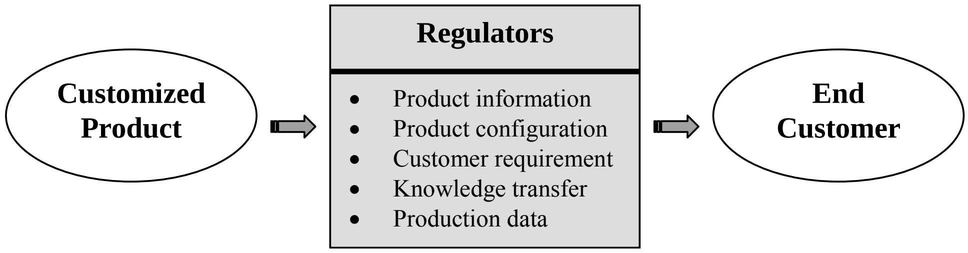


Figure 1. Product customization framework.

The motivation of this research is to elaborate on how to design customized products within the scope of manufacturers' competitive strategies. The suggestion is to offer customers the latest and best tools and technologies in order to promote co-design, which satisfies most of their needs and wishes. Up-to-date methodologies and tools support customers and manufacturers in tracking information flow among the product development participants (Söderquist & Nellore, 2000; Kiritsis et al., 2003; Finne, 2006). Figure 1 displays a customization framework, where different regulators have influence in satisfying the end customers. Along with the participatory design issue and tracking information exchange, appropriate design architecture and strategy can contribute to a successful business environment.

1.2 Research scope and objectives

The focus of this thesis is in the integration of three essential perspectives on product development, as presented in Figure 2: the informative perspective, configuration perspective and strategic perspective. Each of these perspectives includes specific research challenges and problems, which have been identified as the research outcomes from this thesis. Figure 2 displays the implementation process of three perspectives and can be explained as follows:

Informative perspective: The generic strategy behind this perspective is based on the understanding of the importance of information exchange among product development participants such as customers, manufacturers, suppliers, distributors and retailers. Information management can be viewed as a system involving input as information and output as knowledge transfer. This view is regarded as the fundamental part of strategic business management from which basic influences of innovations are evolved. Information management is considered as a complex process, which is required for knowledge transfer inside firms and in inter-firm interfaces (Macdonald, 1998; Nonaka and Teece, 2001). This thesis applies different approaches for managing valuable firm information, which is needed for developing quality products or services.

Configuration perspective: The configuration process is considered as a systematic approach of customer preferences that integrates those preferences with the firms' resources. One of the focuses of this dissertation is to articulate the configuration process, which is one of the most challenging and important issues in the customized product design and development arena. The management of the configuration principle is often considered the critical early phase of key business processes, where a firm's business activities are formed from several interacting key business participants. Critical business success very much depends on the overall interactions between customers and manufacturers, which is the base of any configuration process.

Strategic perspective: Different strategies and methodological support are needed in order to carry out customized product development in practice. This research perspective is defined and designed according to the market requirements and business targets. The strategies and methods are implemented through the priorities of design importance. For instance, the priorities might be to produce more variants of products, reduction of lead-time, custom-tailored production or mass production, etc. Individual needs are identified through unique or combined strategies for implementation purposes. A firm realizes its strategies depending on resource availability and demand aptitudes.

The research relationship between the three perspectives as discussed above is displayed in Figure 2 below. From Figure 2 it can be noticed that the informative perspective deals with the concept of information management during the product development process. The configuration perspective relates more to the interactions between consumer community and manufacturing environment, whereas the strategic perceptive integrates valuable production decisions such as mass customization, commonality, standardization, etc.

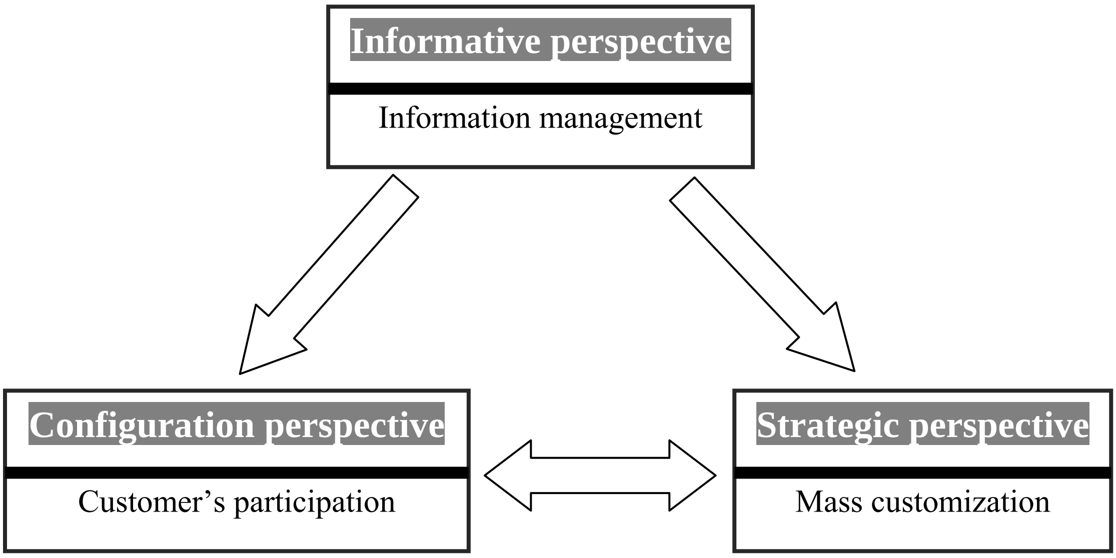


Figure 2. The interrelationship between the research perspectives.

The aim of this research is to provide new insights into and enhance knowledge in the area of product development as part of a better design approach. Valuable information flow, basic configuration principle and different design approaches are presented in this research with a view to optimizing product variants for higher customer satisfaction. Therefore, this research has three objectives:

1. To describe the importance and usability of information flow among the product development participants
2. To investigate the configuration principles to develop custom-built products
3. To formulate a specific design approach to meet diverse market demands

The objectives are derived from the observations made in different research articles as presented in this thesis. This research tries to measure the level of information dependencies and shows how this can be managed properly to develop product customization. Several configuration approaches are also stated from both the customer and manufacturer's points of view. This interest leads to the requiring of better product design and development. It can also lead to extensive management efforts trying to measure the expectations from both the manufacturers and customers.

Different developmental efforts such as modularity, platform-based product development, component commonalities etc are offered at a certain value for the design team. All these efforts follow the mass customization approach, which is based on competitive products that fit the purposes of the consumer and add value. The individual articles included in this dissertation (Papers 1–6) contribute to different aspects of the individual objectives as presented in Table 1 below.

Table 1. Presentation of research objectives in relation to the focus of each paper.

Article no.	Objective 1	Objective 2	Objective 3
Paper 1	Dynamics of mass customization Integrated framework for information flow Single case study		
Paper 2	Information flow management Single case example for matrix-based modeling		Implementation of modular design approach
Paper 3		Conceptual framework for configuration process Single embedded case study from auto industry	
Paper 4		Integration framework for product customization Implementation of interactive configuration processes for product customization	
Paper 5	Mapping among design information		Literature review Discussion of overall PD strategies Single case study from manufacturing industry
Paper 6			Framework for collaborative business strategy Development of product platform through matrix-based approach

1.3 Research questions

The basic approach that the research questions are formulated on is based on the research objectives. The research questions have been chosen to gain insight into and knowledge on how product information flow influences the adoption of a particular strategy in the product development process. Different types of information flows can be modeled and analyzed in a successful product development process. The success of new product development and competition has been analyzed through technical antecedents only and not by considering the actual information analysis among development participants (Maunuksela, 2003). Thus, the basic question addressed in this research is how we could organize better information flow for the analysis of product development practices.

It is also recognized in the literature that product configuration process nowadays plays an important role in meeting the competitive requirements. It is suggested that this issue might be related to the ways in which consumers needs are interpreted and how such interpretations are organized in firms with their existing resources. With the firms' resources, also different strategic decisions are needed to organize the customers' requirements. Absolute product development measures need to be integrated to offer distinct market solutions and enhance business growth. All the basic requirements or objectives for product development processes are formulated within three research questions (RQ), as follows:

RQ 1: How to manage information exchange so as to enhance the product development practices?

RQ 2: How to implement the configuration processes for product development practices and find out its usability in the customization principle?

RQ 3: How can different development measures be integrated to support market solutions and the internal resources of a firm?

The first research question recognizes the importance of information flow for successful product development, whereas the second research question focuses on the basic steps and requirements of the configuration principle for developing customized product. The third research question aims to find ways to integrate and improve market demands from the firm's internal resources and implement important product development strategies.

The overall contributions to the research questions are discussed and presented in the six publications. Individual question may be answered through a single publication or a combination of publications. Each of the questions are assessed and analyzed in terms of managerial contribution and implications.

1.4 Research contributions and implications

1.4.1 Managerial contribution with respect to research question 1

Information management practices were developed to support the complexity of product development processes. Both Papers 1 and 2 tried to formulate this concept with real life examples. The key trends in R & D in industrial practices influence the importance of keeping track of information variability. Some of the important parameters for information management can be summarized as follows:

- integration of knowledge transfer among developmental participants
- tracking of technology change within the business environment
- management of intellectual properties among organizations
- keeping of information sources for alternative ideas
- management of linkages between internal and external business resources

An accurate information flow is a source of competitive advantage as it initiates the development of customized product economically. Paper 1 presents a framework for customized product development, where integration among participants is achieved by information flow. Design structure matrix (DSM – also known as dependency structure matrix), which is a square matrix (i.e. it has an equal number of rows and columns), shows the relationships between elements of a system that was used to integrate this customization process. This tool also presented to keep track of design rules within the scope of Paper 1.

Paper 2 discusses the different tools or methodologies to keep track of inter-organizational information. In this paper, the most valuable clustering operation among organizational sources is presented with a case example. This clustering process is essential to identify the potentials of interdependencies among business participants. Clustering helps to restructure design process according to market demands or customer preferences.

1.4.2 Managerial contribution with respect to research question 2

Research question 2 is related mainly to the results presented in Papers 3 and 4. In Paper 3, a generic configuration framework is presented, which explains the implementation possibility of different configuration processes according to business requirements. Another framework is articulated in Publication 4, where major specifications of the customization process are proposed. Both the frameworks are extensive in providing a platform for managing customization process effectively.

The configuration process, which is applied from customers' participation to the product delivery process, integrates all the participants during the product customization process. This process connects the internal and external business domains of a firm. The configuration tool termed as 'configurator' provides a linkage with critical design knowledge and information sources among manufacturers, suppliers and customers for the purpose of customized products or services.

It needs to be noted that the traditional product design process is not always suitable for competing in today's business environment. It has also been discovered that the dynamic nature of a design process needs consumers' involvement from the very beginning of the product design and development process. This conception is outlined in both of the publications, where designers can narrow down their design themes to achieve highly customized products.

The integration of different design rules with the respective configurator is highly demanding in today's business arena. This methodology ensures a cost effective design process and enables collaboration with manufacturers, the supply chain network, distributors and consumers. Integration of both front-end and back-end product development process enables advanced planning and scheduling, available to promise, and visualizes the complete production scenario for potential consumers.

1.4.3 Managerial contribution with respect to research question 3

Papers 5 and 6 answer this research question, where both developmental strategy and integration between external market demands and internal resource contents are formulated. Firms generally face certain common challenges such as how to collaborate standard market demands with existing resources or capabilities and what are the critical components needed to identify the majority of market demands. These issues emerged when we analyzed the case company, as discussed in the empirical research section. From the analytical perspective, we observed the lagging of information structure between two domains, which can be solved by implementing an appropriate tool or methodology.

The use of the domain mapping matrix (DMM) tool contributes to the balance and focus between firms' capabilities and their offerings or solutions. The modeling approach used in Paper 5 builds an idea of where to locate between a design approach and competitive solutions. The possibilities of design uncertainties and developmental risks are minimized through proper communication pattern among the respective domains. Different performance dimensions related to product development practices need to be analyzed critically before their implementation. This research reveals the dependencies among product structure, design process and design goals.

Further research on internal design process could be initiated when different domains are collaborated through information structure. This informative structure guides firms in initializing certain product development strategies in order to satisfy consumers. The strategic options of modular principle and platform-based product designs are elaborated within the boundary of this research approach. These approaches contribute to a basis for R & D in customization processes. A framework is presented in Paper 6, where the concept of globalization is integrated with a platform-based strategy. A distributed platform approach is adapted with a case example, where base modular design is implemented for creating product varieties.

The following general outcomes can be concluded:

- Information intensive architecture promotes product innovation
- Information exchange is poorly managed in companies
- The configuration paradigm is strategically important for product customization
- Production flexibility is supported by a collaborative design approach
- Formal processes are important to keep track between firms' resources and their offerings
- A customization process needs to be opened up between internal resources and external demands
- A unique product development strategy may not be suitable for a competitive business environment

The research questions led to the selection of research methods with a view to capturing the issues that are not observable just by reading documents. The methods have been chosen based on the need to understand information flexibility, product configuration and the integration of consumers´ needs with the development stages.

1.5 Selection of research methods for the research question

For the purpose of the research themes, qualitative research methods were chosen due to the practicality of their implementation. The collection of real-life data was a valuable foundation for carrying out this research. To validate the fit between theoretical models or frameworks and technical implications, research data was collected from two case companies with a view to generalizing the research themes.

The participatory technique was adopted to gather the research data. Valuable data was gathered from two case companies, namely Wärtsilä Oy and Volvo Trucks (from the CATER project) through this participatory approach. A major amount of data was collected from Volvo Trucks (from the CATER project). This data was used to justify and generalize research questions 1 and 2. The data from Wärtsilä Oy was gathered through interviews, facilitated sessions and dialogues with a variety of people, and was used to answer research question 3.

In the case of Volvo Trucks (from the CATER project) the data was based on empirical findings. The data was mapped through the design structure matrix (DSM) tool to study the dependencies among the design elements. The interdependencies between design participants and technical systems were analyzed for different design goals in the case company. The research on Wärtsilä Oy was carried out with a view to integrating the information dependencies between design architecture and customer preferences. This integration was mapped by implementing the domain mapping matrix (DMM) tool. Both the case companies were studied with a view to monitoring and analyzing the existing information delivery processes.

1.6 Structure of the thesis

The structure of this thesis is divided into five sections and can be presented as follows: Section 1 contains an overall introduction to and motivation for this research, where a general description of the work is presented. The research scope and objectives, along with the three research questions, research contributions and implications and the research methods are also presented in this section.

Section 2 presents theoretical descriptions of the work, where three study perspectives are presented theoretically. In this section, there are general explanations of information exchange and the configuration phenomenon and basic product development strategies are discussed.

Section 3 summarizes all six publications included in this thesis. It provides an overall summary of each of the publications.

Section 4 is devoted to the empirical research, where a case study is presented and analyzed critically. An approach for the rule of modular design is proposed in this section. The generic experiences and research outcomes are also presented.

Section 5 presents a general discussion and conclusions of the findings. The theoretical implications, research limitations and recommendations for further research are also presented in this section.

1.7 Definition of key terms used in the thesis

Information management (IM) – Information management can be considered as organizing, retrieving, collecting and maintaining information. Information is collected from one or more sources and that information is distributed to one or more audiences. The basic goal of information management is to have the right piece of information in the right place, in the right form and of sufficient completeness and quality to meet the specific need. IM is a field of wider scope, which is also related to other fields such as information systems, computer science, information science, artificial intelligence, amongst others (Rao, 1999). IM requires an understanding of the patterns of information flow within an organization and then it demands a systematic means of mapping and monitoring of such flows (Anand et al., 1998; Kekäle, 1999).

Product development process – The product development process can be defined as set of steps and tasks such as strategy, organization, concept generation, planning, evaluation and commercialization of a new product. It is therefore a set of procedural steps, from which an innovative firm routinely converts ideas into commercially viable goods or services (Belliveau et al., 2002). The steps include analyzing the market, targeting potential buyers, understanding the productive capacity of the organization, developing a product to fit market needs, distributing it to the marketplace and analyzing customer feedback.

Configuration process – Generally, this is a relative arrangement of parts or elements in a particular form, figure or combination. In computers and computer networks, a configuration process often refers to the specific hardware and software details in terms of devices attached. In networks, it often means the network topology.

Configurator – A configurator is a software tool applied to the designing of products exactly matching customers' individual needs. It is used to help the customer or seller to carry out purchases and the user gets the opportunity to choose a product based on the combined parts and their characteristics. The configurator ensures that the parts that are chosen are compatible with each other. It is often used to replace the need for human customer service or live intervention during the checkout process.

Matrix-based information flow –This provides a useful information flow among different design-related elements that are required for mangers to have control over the entire product development activities. Matrix-based tools such as design structure matrix (DSM), domain mapping matrix (DMM) and multi-domain matrix (MDM) are used successfully to exchange information among product development participants. DSM exchanges information within one domain, DMM exchanges information within two different domains, while MDM accepts more than two domains for information flow.

Modularization – Modularization refers to a methodological principle that develops as a set of small modules and later composes them into a form to be used as one modular strategy. Its application in industry has evolved architectural changes in product, production and supplier systems, which emphasize different purposes and aspects. Modularization offers many advantages such as the possibility of producing product variations, limited proliferation of parts, reduction of throughput times, greater productivity and quality from automation (Wilhelm, 1997).

Product customization – Product customization can be defined as a controllable and strategic variable. Product customization is a critical component of manufacturing and product flexibility, which is significantly related to financial and marketing performance (Gerwin, 1993; Krajewski & Ritzman, 1990; Vickery et al. 1997). It emphasizes the differences between products or their uniqueness. This product differentiation naturally results in the continuous accretion of varieties and thus may engender unfavorable design variations and process changeovers, which attracts customer satisfaction through aesthetic principles and ergonomic criteria.

Design Structure Matrix (DSM) – This is a compact, matrix representation of a project network tool (Steward, 1981). The matrix contains the information flow among product or project development participants. The DSM provides insights into controlling a complex project and highlights issues of information needs and requirements, task sequencing and iterations (Yassine, 2004).

Product architecture – Product architecture is the description of a scheme which arranges the functional elements of a product or system into physical chunks by which they interact (Ulrich, 1995; Whitney, 2004). It can also be defined as the specification of the interface between the components; in other words, how the components are going to interact together in the product as a system. The specification of the interface is critical to the design of flexible architectures that allow product designers to substitute component variations within product boundary without having to make adjustments in other components (Sosa et al., 2004). Architecture has profound implications for how the product is designed, made, sold, used and repaired.

2 THEORETICAL FRAMEWORK

2.1 Management of information exchange in product design and development

2.1.1 Theories of information exchange and strategic perspective

Global competition and a distributed business environment make product development processes much more complex than ever (Salminen et al., 2000; Ming et al., 2005; Eppinger & Chitkara, 2009). This complexity does not arise simply from a technical point of view but also from the managerial perspective. Technical complexity can be managed through deconstructing the designing process into more manageable smaller engineering tasks and assigning these tasks to individuals or teams (Kusiak & Park 1990; Steward 1991). On the other hand, managerial complexity, which has evolved from the information gap between organizations and different engineering disciplines, can be managed through project management tools, which interface the dependencies between design tasks and the departments of an organization (Yassine, Falkenburg & Chelst 1999).

The proper execution of a design plan and the structuring of various information dependencies normatively suppress design complexities. Information dependencies are modeled according to the design plans, which shows the order in which design tasks are performed (Yassine et al., 1999; Hung et al., 2008). This planned execution order reduces the product design risk and magnitude of iteration between design tasks, which in turn explore opportunities for reducing the overall project cycle time. The numbers of design iterations, which cause a lengthy cycle time, occur due to the information gap between design elements (Eppinger et al., 1994; Ha & Porteus, 1995; Yassine et al., 2003).The development of appropriate information modeling approach bridges the gap between design processes. The exchange of design information can be fragmented and released on a timely basis during the development process.

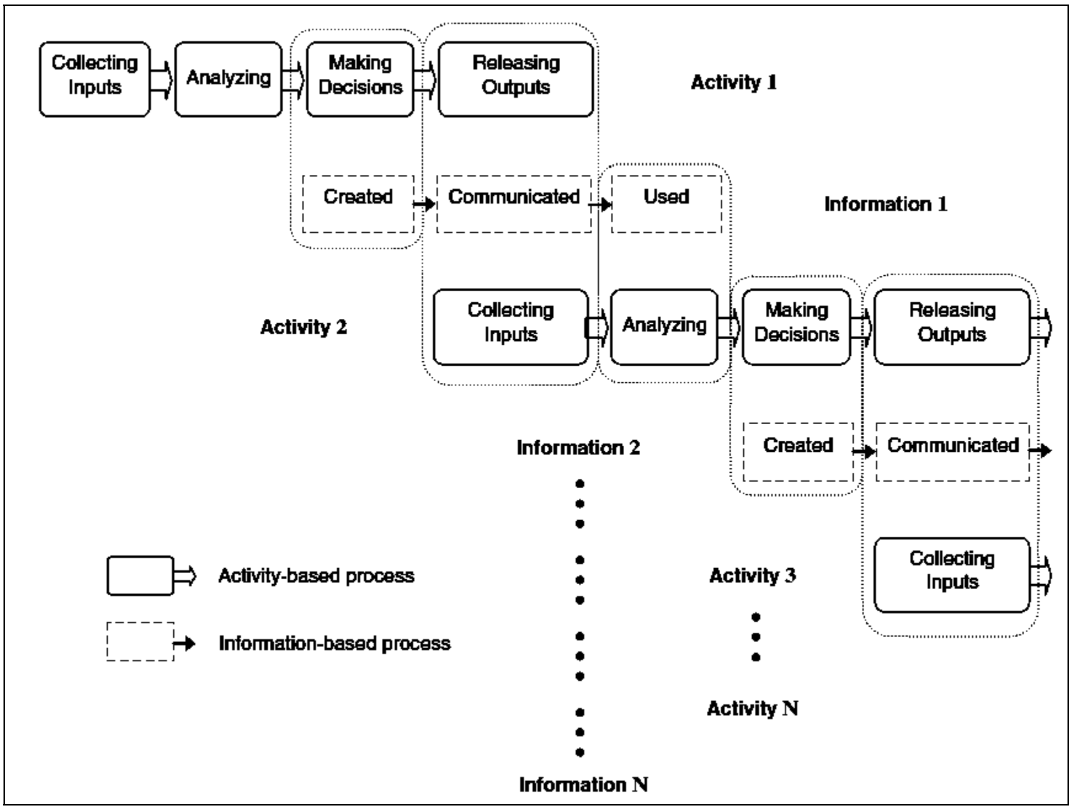


Figure 3. Product development process from an information processing perspective (Yassine et al., 2008).

Information processing among design elements eases the decision-making process as the information is considered as input while the decisions are released as output. Each design activity collects the required information as input, which is analyzed internally for specific decision-making before being released as output (Zhu et al., 2004). Figure 3 outlines this analogy, where the available information accelerates the development process when decisions are made. Before exchanging information among design elements, it is worth studying how information is created, communicated and implemented during the development process and what might be the possible impacts on design activities. Through understanding the possible impact and risk of information, better decisions can be made to develop quality products with higher efficiency.

2.1.2 Information management tools and approaches

There are many tools or methodologies available to manage the information flow among design elements. Lawler (1976) introduced the directed graph approach, which is most popular for presenting the precedence relationships among design tasks. In this approach, nodes present different tasks and their dependencies are displayed through directed lines connecting these nodes. Ross (1977) presented a graph-based technique known as the Structured Analysis and Design Technique (SADT), where design information is captured through intra-task complexity. The information dependencies among tasks or components can also be presented by using a matrix-based tool such as the Design Structure Matrix (DSM) introduced by Steward (1981, 1991). This matrix-based information exchange approach uses a binary form of dependency representation.

Spinner (1989) presented the Project Evaluation and Review Technique (PERT) method, which is a digraph representation of a project information flow where the tasks or nodes are arranged along a time line. In the PERT method, three probabilistic times, namely optimistic, pessimistic and most likely are presented in order to reflect the uncertainty in task duration. Another technique, critical path method (CPM) which is a variation of the PERT method applies deterministic task duration and minimal uncertainty in the project completion time.

The US Air Force developed the Integration DEFinition (IDEF) method, which originated from SADT to perform information modeling activities to support Computer Integrated Manufacturing (CIM) and Concurrent Engineering (CE) (Mayer et al. 1992). The IDEF3 is a method that provides a mechanism for collecting and documenting processes (Belhe & Kusiak 1995). IDEF3 descriptions can determine the impact of an organization’s information resource on the major operation scenarios of an enterprise. It captures all temporal information, including precedence and casualty relationships associated with enterprise processes. IDEF3 builds structured descriptions, which capture information about what a system actually does or will do and provide an organization’s system views.

The DSM representation is used and proven by many researchers (Eppinger et al., 1990; Steward, 1991; Kusiak & Wang, 1993) and can be implemented successfully for system architecture, engineering and design, project scheduling, organizational design, etc. The dependency representation through matrix-based approach provides a concise and systematic mapping among components or tasks, which is clear and easy to read whatever the sizes are. It details what pieces of information are needed to start a particular activity and displays where the information generated by that activity leads. This approach overcomes the problems of size and visual complexity, which generally occur in graph-based techniques. These matrices are amenable to computer manipulation and can be stored conveniently for further use.

The DSM approach has two main strengths. Firstly, it can accommodate a large number of system elements and their interdependencies in a compact format, which highlights iterations or feedback loops and clusters or modules. Secondly, it is presented in matrix format, which can be used to improve the structure of the system and to manage the effects of change. For instance, if the specification of a component needs to be changed, it would be possible to identify all the processes or activities, which are dependent on that specification. This phenomenon provides insights into how to manage complex systems or projects, highlighting information flows, task sequences and iteration together, which is not possible in any other information driven tools or methodologies.

Although the DSM tool is considered to be powerful and versatile, it is not a remedy for all design related problems. Firstly, the representation power and the decision capacity of DSM are limited in various ways in comparison with other methods, e.g., rule-based, graph-based, etc. Secondly, not all information related to product development is suitable for DSM representation, e.g., product hierarchy and commonality. The manipulation of this tool such as in partitioning, clustering, and banding can provide some design advantage but is limited to an adequate analytical ability for decision-making process.

The information structure among product architecture, development organization and the required resources could provide a useful approach in the basic product development process. This approach is intrinsically investigated through case examples as presented in Papers 1 and 2, where specific requirements, methodologies and tools are outlined to realize the importance of information flow among product development participants. The research methodology presented in this dissertation provides an information-processing network, which contributes to the inter-functional and inter-organizational terms that answer the first research question.

2.2 Configuring the business process information system

2.2.1 Defining the configuration process

The complete configuration process can be described as the interactions between the bundle of configurators such as product configurator, sales configurator, production configurator, etc and the human and organizational resources that interact with these (Forza & Salvador, 2002). According to Brown & Hellerstein (2004), configuration is the process whereby components are assembled or adjusted to produce a functional system that operates at a specific level of performance. It guides sales people and users through a given set of rules to find a valid and desirable configuration of the product. It plays an important role in the support of the mass customization paradigm (Pine et al., 1993).

The configuration process can be seen informally as a set of design activities, where the configured products or processes are built from a predefined set of rules and components or process types. Additionally, various constraints are used to restrict the number of legal product or process constellations (Felfernig et al., 2001). There are a variety of application areas in a configuration system such as in the computer industry (PC configuration), automotive industry (sales configuration), manufacturing industry (production configuration) etc. Based on the requirements of a given application, a configurator, which is a tool for the configuration process, chooses the required services from a component database by following a set of rules that govern the configurator.

Through the configuration process different goals of customizations are achieved. In this process general sequences of actions are performed by human operators which could be explained as deterministic sequences with no branches or decision points. The configuration process can be divided into five domains, i.e. the customer domain that relates to customer requests; the functional domain that interacts with the solution-neutral design requirements versus the functional requirements (FRs); the design domain that relates to the set of design parameters describing all the product attributes; the physical component domain that interacts with the set of physical components; and the appraisal domain that relates to the set of overall index setups for appraising the configuration result (Lu et al. 2008).

2.2.2 Purposes of the configuration process

In today’s business environment, competition between engineering firms has become much harder. In order to prevail over the competition firms need to deliver highly customized products or services as fast as possible that meet customer requirements and firms´ constraints. Along with reduced time-to-market, firms also need to offer many product variants to customers to stay competitive in the markets. This challenge has lead to a scenario where firms are losing track of the generic functionalities of their products. Efficient tools or methodologies are needed to tackle the increasing complexity of products or processes. Appropriate tools and methods can ensure a higher level of customer integration with the complete product development process.

The configuration processes are such classes of tools or methodologies that are given a set of rules to define the set of valid configurations of the products or processes. The increasing complexity of manufacturing processes requires the provision of advanced methods to support the configurator development process as well as the actual configuration process. Different developed configurators guide the customers, sales people or engineers to make it possible for firms to shorten the product development time and sales-delivery process. The term sales-delivery process represents all the stages necessary to sell, design, order, manufacture and finally deliver an individual product or service to a customer.

In large distributed systems where it may not be possible or economic to stop the entire system, a dynamic configuration system can be implemented, which has the ability to modify and extend a system while the system is running. It is also useful during the production phase of the system to aid incremental integration of component parts and during operation to aid system evolution (Kramer & Magee, 1985). Any configuration process should be designed in such a way that customer preferences or selections do not affect the previous selections in order to achieve design flexibility (Helo, 2006). The configuration process is generally implemented as the source of a knowledge management platform, where important design process information is stored and retrieved as necessary.

2.2.3 Influence of the configuration principle on inter-firm coordination

The cooperative strategies among firms, both domestic and foreign, have become an important component of the business environment. Different forms of inter-firm alliances are transforming and redefining the general nature of the competitive situation among business communities. There are different reasons for alliances or partnerships such as geographical proximity, economic advantage or the fact that governments have created an enabling environment. In such business environments, the configuration process can play an important role at the strategy level of the firm, e.g. mission, resources, markets, etc (Kotter, 1996; Miller, 1996; Mintzberg et al., 1998). This process addresses coordination among business partners for production agility, operational efficiencies, troubleshooting, etc (Srai & Gregory, 2008).

The configuration process clusters product development partners based on their origins and links them according to operational dynamics (Adobor, 2006). Inter-firm systems can be configured in multiple ways such as one-to-one as in a typical buyer-seller system, one-to-many as in a marketing or purchasing system, or many-to-many as in electronic markets, based on the transactional patterns between the participants (Konsynski, 1993). Inter-firm coordination can also be configured according to the type of interdependency existing between the firms joining in a network (Kumar & van Diesel, 1996). Configuration issues are clearly related to aspects of location, which is a major issue in the multinational business environment (Dunning, 1995).

Firms are being forced constantly to squeeze the time between different stages of customization and increase responsiveness in product development. To cope with this challenge, implementation of the configuration process needs to be extended between firms rather than confined only to a firm's specific boundaries. The configuration process can therefore be seen as an instrument that not only just improves internal working practices, but also improves inter-firm coordination by aligning working practices between firms involved in the bidding-tendering process. Finally, the configuration process presents to potential customers a design dialogue that drives it as far as possible towards the specification of product or process variants. This custom feature tends to improve a firm's operational efficiency (Forza & Salvador, 2002).

2.2.4 Developing configurable products

The term configurable product is one level forward from customized product, which is very much related to customize marketing. Hart (1996) explains mass customization as "using flexible processes and organizational structures to produce varied and often individually customized products and services at the price of standardized mass-produced alternatives". Whereas configurable product is generally one of a kind of product, which is formulated, designed and manufactured directly from the customer's experience and desire. Both customized and configurable products are IT-intensive, where, customization is IT-based on the production side and configuration IT-based on the marketing side.

Configuration process enhances one-to-one marketing and personalization, the aim of which is to serve individual customers' unique needs. This is a buyer-centric strategy, which is focused on helping customers' — identify their desires and wishes in a digital marketing environment. In the configuration process, a product or service is sold before it is actually produced. In this approach, customers directly interact with the firm's existing design architecture, suggest or modify the architecture according to their requirements and obtain the costs of their products or services. To accommodate such customer needs, more than customized products and services are required; firms need also to customize their internal processes and supply chain partnerships in order to more fully meet the differing needs of their customers (Wind and Rangaswamy, 2001).

The applicability of the overall configuration process is implemented within the scope of this dissertation. Papers 3 and 4 formulate the conceptual configuration framework, applicable for ascertaining the customers' expectations through guided questionnaires in which customers could express their desires and needs appropriately. The specific case examples are presented with a view to demonstrating the applicability of different configuration tools known as 'configurators' for enabling the connectivity and direct interaction possibilities among customers, manufacturers and suppliers. This network relationship should iteratively generate and refine customer-focused product variants according to specific customer needs that answer research question 2.

2.3 Product development strategies in the business environment

2.3.1 General perspectives on strategy

Shorter product life cycles and increasing global competition have made firms to select an appropriate strategy for their business environment. The success of industrial firms depends on the price of their products, differentiation, competitive positioning, and quality (Lee & Zhou, 2000; Jiao et al., 2007a; Calantone & Benedetto, 2007). In this business environment, a firm that possesses a higher clock speed can enhance its existing product development strategies to hedge against market competition. Adopting particular strategies such as customization, gaining market share, technology enhancement, risk management, etc are the key options for business success (Broekhuizen & Alsem, 2002; Slater & Mohr, 2006; Amoako-Gyampah & Acquaah, 2008). Negotiable strategies could support firms in dealing with uncertainty and business risk in such a competitive market.

In today's customization era, firms cannot focus on mass production strategy, but rather provide products, which are better adapted to individual customers' aesthetic and functional preferences (Piller, 2007; Franke & Schreier, 2008). To fulfill the requirements of mass customization, firms need to consider several development strategies such as modularity, product family, platform, standardization, etc (Karandikar & Nidamarthi, 2007; Antonio et al., 2007; Zacharias & Yassine, 2008). All these strategies need to be implemented according to the objectives and goals of individual firms based on their customer requirements, production complexities and volumes. Individual firms might adopt and implement a single strategy or multiple strategies according to their market requirements.

2.3.2 Modularization and module drivers

Modularization can be defined as the opportunity for mixing and matching of components in a modular product design in which the standard interfaces between components are specified to allow for a range of variation in components to be substituted in the product architecture (Mikkola, 2000). In this process, the module, which is a structurally independent building block of a larger system with well-defined interfaces, provides flexibility without changes to the overall design (Eicsson & Erixon, 1999; Baldwin & Clark, 2000). Through product modularization, firms can create many product variants by assembling different modules within a short product development lead-time (Simon, 1962; Sanchez & Mahoney, 1996; Baldwin & Clark, 1997; Salvador et al., 2002).

A modular system boosts the rate of innovation, as it reduces the time to respond to competitors and can spur innovation in design as firms can independently experiment with new products and ideas (Baldwin & Clark, 1994). The modularization process reduces the cost of developing product variety through combining the old and new versions of modules or sub-assemblies within a firm. This process of mixing and matching can be a source of learning for firms and allows firms to specify the required rules for inter-module interfacing. Modular architecture allows the customers to take advantage of interchangeable components or modules rather than accepting a complete package that is preselected by the manufacturer.

There are several drivers to convince manufacturers to adopt modular phenomena in their respective firms. These drivers may vary according to the requirements of individual firms. Generic module drivers can be identified as technology evaluation, planned product changes, styling, after-sales service, separate testing, etc (Ericsson & Erixon, 1999). For instance, if a firm offers after-sales service for its customers, it will then be encouraged to adopt modular architecture, which facilitates its smooth operation. Another example of the module driver is separate testing. If a firm wants to test some of its important subassemblies separately, it could then proceed towards the modular principle.

2.3.3 Platform-based product family

Product platform, which evolved from product architecture, encompasses the design information and components shared by a set of products. It offers general interfacing between modules that share specific features and functionality (Meyer & Lehnerd, 1997). Platform development offers candidate design for the product family, where modules are shared across multiple product variants. The benefits of product platforms are similar to modular products, as the developed modules are usually used for creating modular platform. This modular platform acts as the base architecture for developing different product variants (Ulrich & Eppinger, 1999; Hölttä-Otto, 2005). This method, if properly executed, can result in economies of scale through producing larger volumes of the same modules, reduced design cost and many other advantages evolving from the sharing of modules (Gonzalez-Zugasti & Otto, 2000; Pekkarinen & Ulkuniemi, 2008).

Using platforms allows important family design savings, distributed manufacturing and easy maintenance (Marion et al., 2007). It offers manufacturing firms the opportunity to reduce overall production costs and development time, while satisfying diverse customer demands (Meyer & Lehnard, 1997; de Weck & Chang, 2003). The main contribution to a successful product family is the product platform from which it is derived by either adding, removing or substituting one or more modules to the platform or by scaling the platform in one or more dimensions to target specific market niches (Simpson, 2004). Many products are developed based on platforms; include airplanes, computers, power tools and automobiles. Although we have discussed the many advantages of a platform approach, however it has some limitations, too. For instance, if the degree of commonality is too high, each variant evolved from the product platform might not be competitive in its specific market segment due to inferior performance caused by sharing components (de Weck & Chang, 2003).

There are two distinct approaches to create product family from platform-based architecture. Firstly, an integral platform, where individually designed portions are add-ons: a single, monolithic part of the product to create variant design. This type of platform is very much restricted in use as it resists product differentiations in certain limits (Meyer & Lehnerd, 2000; Simpson, 2004; Mikkola & Skjott-Larsen, 2006). The second most commonly implemented platform is the modular platform, where the product is divided into modules that can be interchanged to create variants based on different size and functionality (Gonzalez-Zugasti & Otto, 2000; Muffatto & Roveda, 2002; Sosa et al., 2003; Jose & Tollenaere, 2005; Slevinsky & Gu, 2005). This type of platform constitutes a set of modules that are reused repeatedly across the product family.

There are many model-based approaches to formulate platform-oriented product development. Steward (1981) presented the DSM approach to the formation of platform from which product family could be created. Different approaches have been designed by Martin and Ishii (1997), Wheelwright and Clark (1992), and Robertson and Ulrich (1998) to plan for commonality and to execute the management of platforms and varieties. Krishnan et al. (1998) presented a network model to obtain an optimal platform-based family. Dai & Scott (2007) used sensitivity analysis and cluster analysis to improve the effectiveness of a scale-based product family through multiple-platform product family design. Chen & Wang (2008) proposed a quantitative method for scale-based multiple-platform design using clustering analysis and Shannon's Entropy theory. Baldwin & Woodard (2008) describe three ways of representing platform architectures, namely network graphs, design structure matrix and layer maps.

One of the focuses of this research is to present an effective way for developing modular product from which it is quite easy to develop customized products. In order to reduce product development complexities, this modular approach is very much essential to cope with changing customer perceptions, customizing product and developing product variants. In Paper 5, the idea of modular design approach, justification of commonality among modules and platform-based product development process are presented. This article also demonstrates the mapping between external varieties (e.g. customer requirement) and internal varieties (e.g. component/module) that answer research question 3. Various prospects for platform-based product development and their limitations are outlined in Paper 6. This research also contributes to formulating aspects of module development and the formation of product platform from those developed modules.

3 SUMMARY OF ORIGINAL MANUSCRIPTS

This section summarizes all the six publications. The interconnectivity and information flow among all six publications are displayed in Figure 4 below. In this section, all the six papers are summarized according to their contributions in the respective fields of product design and development. Specific relationships among these papers are also outlined accordingly.

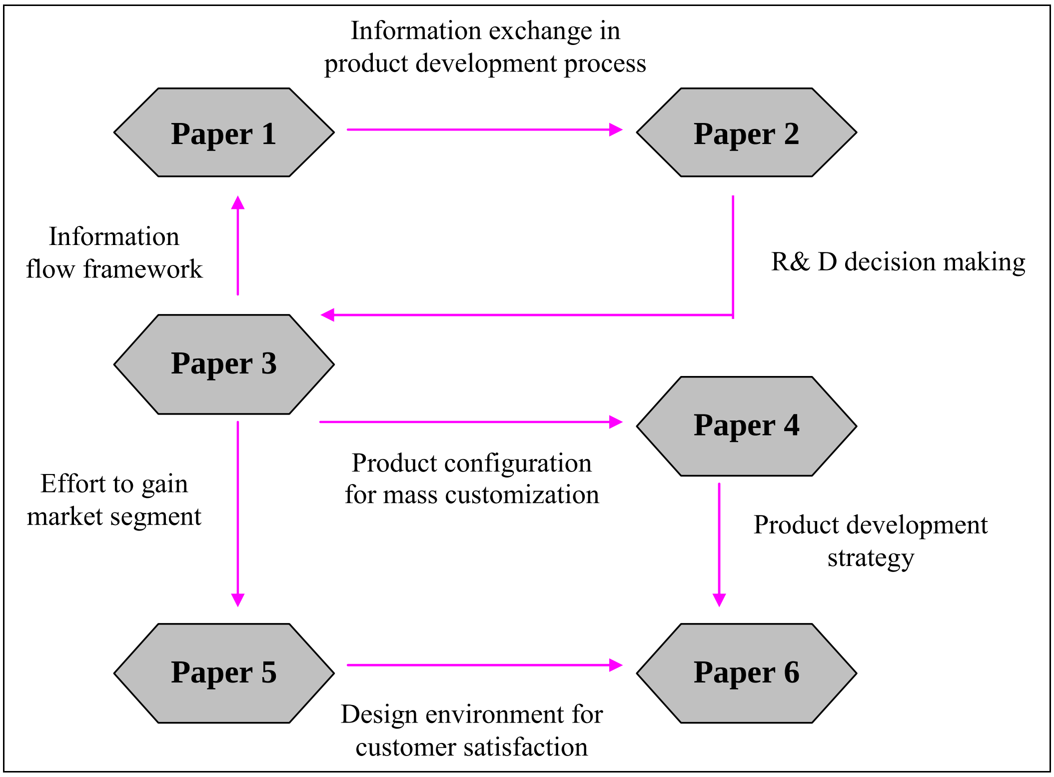


Figure 4. Overall dependency and information flow among the publications.

Paper 1: Applying design structure matrix (DSM) method in mass customizations (Shamsuzzoha, A., Helo, P. and Kekale, T. 2008).

The paper introduces an integrated framework and design structure matrix (DSM) tool that could be applied for customized product development process. The framework displays the applicability and appropriateness of various product development participants such as CAD model, product database, DSM tool, part family, etc. Each of the participants are illustrated and discussed in detail. General mass customization features such as configuration, modular design, relationship mapping among customers, product architecture and departments are emphasized in terms of gaining competitive market share and reducing production costs.

The second part of the paper highlights the influence of the DSM tool on the customization process. In this part, the applicability of the tool is tested on Volvo design rules, and the rules were collected from the Volvo Company Truck Division. The goal was to display different design restrictions appropriately. Along with design rules, information dependencies among Volvo's design elements are also presented through DSM methodology, which helps to develop modules in the assembly process. This module formation is nowadays an attractive business strategy to achieve success.

There is also a proposal for mapping customer requirements, product architecture and various departments within an organization. This methodological approach allows managers to coordinate their tasks among departments and design teams to prioritize their customers' choices and desires. This philosophy also reflects the dynamic of product customization and enables the transformation and traceability of information from one domain to another.

Paper 2: Restructuring design processes for better information exchange (Shamsuzzoha, A. 2009a).

This paper introduces the importance of information exchange among generic product development participants. Successful firms always prioritize the speed of transfer of their information from one place to another. Increasing the response rate allows the firms to reduce product development lead-time while maintaining higher quality and reduced cost. Firms always look for suitable tools or methodologies to speed up information exchange among its product development participants such as designers, engineers, supply chain network, managers, etc. This coordination of information transfer therefore becomes a crucial responsibility for management personnel.

It is emphasized how efficient information exchange can reduce complexity and uncertainty in the product development process. The matrix-based tools DSM, domain mapping matrix (DMM) and multi domain matrix (MDM) are used to visualize and interpret the information exchange of the same or different domains. These tools have been applied with their unique features and functionalities. These matrix methods are applied extensively to identify and develop modular product design. A comparison among different matrix-based approaches is also presented according to specifications within the scope of this paper. An example is formulated to explain three matrix-based approaches used for maintaining information exchange.

Through information exchange, valuable knowledge among resources is transferred in the early development phases, which helps to fabricate quality product or services. A clear and concise flow of information among different design actors enables the improvement of design projects. This information management reduces non-important dependencies and, where possible, clusters the valued dependencies together according to their closeness and/or tightness to each other. Although the usefulness of a matrix-based approach is described in this research article, nevertheless various limitations of their implementation are also discussed. The aim of this paper is to identify the factors influencing the communication pattern of a product development project and to clarify such factors for better information exchange.

Paper 3: Reconfiguring product development process in auto industries for mass customization (Shamsuzzoha, A. and Helo, P. 2009b).

This paper outlines the basic configuration process framework applicable to bridge the gap between customers and product development processes. There is focus especially on how the citarasa, product and production configuration system can be applied in global manufacturing industries for placing an order for custom-ized products efficiently and economically. This design philosophy starts from obtaining the customers' expectations, which are guided through pre-developed questionnaires collected by potential companies.

The presented framework helps to ease the order-making process from customers and to transfer these orders to the internal operations of the company through three configurators, namely the product configurator, production configurator and sales configurator. Through the framework, customers have to answer some basic questions as to where they can choose their products of choice. The guided principles of the framework established require BOM, sales price and controlling logistics network to manufacture a product.

The configuration framework is verified through an example extracted from the Volvo Company's truck configuration system. Here, different design rules were integrated with the configurator. The basic principle of the configuration process as explained in the paper is to formalize customer requirements with interactive guidance for designers and engineers to fulfill those requirements. Without detailed knowledge and expertise in terms of specifications of the planned product, it is not possible to apply this configuration process successfully.

The goal of the paper is to find a way to faster order development process through proper utilization of IT tools and methodologies, which could be helpful in developing a strong relationship with customers, and the business process. Another goal is to integrate the DSM tool with the production configuration process with a view to optimize operational sequences of the firm's design tasks. This tool also guides the dependency pattern within the production configurator and restructures them for possible improvement.

Paper 4: Collaborative customized product development framework (Shamsuzzoha, A., Kyllönen, S. and Helo, P. 2009c).

This paper is a continuation of Paper 3, where collaboration among three configurators and DSM tool are elaborated and discussed. Different configurators and software tools are used to connect the back-end and front-end module of customized product development process. The DIYD (do-it-your-design) configurator is introduced where customers can directly participate in the design process, view their products through 3D view and quote them for the final order. The information required for the DIYD configurator is fed by the citarasa configurator, which is passed towards the production stages for the required BOM, supply network and scheduling.

The presented collaborative framework communicates between citarasa, DIYD configurator and BOM at the front-end, and ATP, ASDN and APS system in the back-end to visualize the complete production scenarios of custom-tailored product development. This idea was not only to develop customized product but also to ensure the availability, planning, scheduling and control of the complete supply chain network. Usually, very few firms use such a sophisticated configuration process and other tools to develop customized products.

The goal of this research was to show firms how to practice and control the product customization process with a higher level of agility and flexibility and to offer integration possibilities with all the product development participants. The integration process is applied in Volvo Trucks, Sweden in its truck customization process, where basic design features such as cabin size; cabin and other equipment, the sales configuration process and the supply chain network were integrated successfully in developing customized trucks. It is observed that the discussed collaborative framework needs greater cooperation between customers and suppliers in order to improve the overall consumer value within product development arena.

Paper 5: Aligning external varieties to internal varieties for market solutions (Shamsuzzoha, A., Kekäle, T. and Helo, P. 2011).

This paper is additional to the previous paper (Paper 4), where influential factors of the product development process, both external and internal, are explained with a view to better market solutions. External varieties or features such as customers' requirements and internal varieties like the task or component list are mapped with a view to developing better solutions or offerings for potential customers. The mapping was done with the help of DMM software for the betterment of information exchange among external and internal varieties.

The mapping between the internal and external varieties shows the possibility of a modular approach to communicate between customer requirements and the component/module list. This interaction exposes the possibility of finding any errors that could be improved through simultaneous iterations. The mapping offers several guidelines for the designers to go for a modular, integral or platform based problem-solving approach.

The basic goal of this research is to control the customers' requirements through available internal resources. The research shows that in order to control the customers' requirements, it is necessary to accommodate all the available resources; for instance, the component or module list, to fulfill as many requirements as possible. Appropriate tools can help to display this mapping visually to show where firms could take any necessary initiation like the proper utilization of available resources or to subtract or add new resources to fulfill the requirements.

The paper also briefly discusses general product development strategies such as modular design concept, prospects of commonality among modules and the applicability of product platform within the area of product design and development. Two distinct types of modular design approaches, namely bottom-up and top-down are explained, together with their specific advantages and limitations. A conceptual framework for customized product development process is presented, where the effects of both external and internal varieties are illustrated.

Paper 6: Platform-oriented product development: prospects and limitations (Shamsuzzoha, A. and Kekäle, T. 2010).

This paper is an addition to the previous paper (Paper 5) that outlines the basic principle of platform-based product development process. A general review of recent works on platform approach comprising prospects, risks, and limitations are discussed and analyzed critically. The goal of this approach is to elaborate different perspectives of platform development in order to enhance customer satisfaction through producing many variants of products quickly and economically.

Within the scope of the paper, a framework is presented where generic issues between globalization and a platform-based approach are discussed with a view to developing collaborative business strategy. Here the objective is to interpret the business issues involved in a distributed product development strategy. This approach places greater demands on collaboration, especially geographically distributed collaborators and organizational groups for sharing and reusing knowledge and information about developing product platforms.

Along with the prospects and implementation issues, the formation of product platform is also presented with the help of the DSM tool. The specific focus is on how this tool can be applied and contributes to platform development. Systematic guidance and support for developing the expected platform of a case example is explained and displayed by using the DSM tool. This developed platform brings flexibility among design elements, which can be used for creating variety. Successful platform development initiates an overall reduction in product development lead-time.

The key objective of this research article is to identify the pros and cons of product platform and formulate the operational procedure to develop it. The balance between collaborative business strategy and a distributed platform approach is investigated and discussed with a view to achieve gain in market segment. The suitability and influence of platform on product differentiation and product family approach is also presented in order to achieve a higher customization level.

4 EMPIRICAL RESEARCH

This section describes the empirical research that has been carried out in a case company named Wärtsilä Oy, Vaasa, Finland. Wärtsilä is a global leader in complete lifecycle power solutions for the marine and energy markets. By emphasizing technological innovation and total efficiency, Wärtsilä maximizes the environmental and economic performance of the vessels and power plants of its customers. In 2009, Wärtsilä's net sales totaled EUR 5.3 billion, with 18,000 employees. The company has operations in 160 locations in 70 countries around the world (Wärtsilä, 2010).

This case study research conducted in Wärtsilä Oy, Vaasa delivery centre, Finland, was formulated with a view to justify the research questions and to display how these could be implemented for the benefit of the case company. This research was justified through intrinsic investigation and implementation of the research issues, namely information perspectives, the configuration principle and design strategies applicable for developing customer specific product.

Various research perspectives were tested and verified through real data taken from the case company. Due to the issue of confidentiality, mostly sample data or data sets were implemented for this study purpose. The empirical research was conducted through an ongoing 'Modulmetrics' project at Wärtsilä. The brief background of the case company, methods for the research aspects, with examples, experiences and research outcomes are discussed in the following sub-sections.

4.1 Background

The basic principle of this empirical research is to address the research questions of the study. All three research questions and the related underlying theoretical aspects of the study are addressed within the scope of this case study. Both theoretical and practical analysis and interpretation have been developed in an iterative manner within the empirical research process.

In the case company Wärtsilä, several technology meetings, mainly weekly/biweekly, were arranged to discuss the existing technology strategy within the case company. The goal of these meetings was to discuss and decide on the strategic initiatives into which the business unit should be directed from the technology point of view. The very first review meeting was mostly used to brief the status of the production floor, problems, challenges and trends in the competitive environment.

The generic target of the technology review meetings was much more ambitious: the discussions between managers could lead to fruitful innovative decisions. The benefits from these review meetings were observed to be worthwhile in revealing various problems and weaknesses to the case company. Therefore, specific improvements in engine architecture and the necessity of interface between customers' needs and design architecture were suggested in order to cope with existing problems or bottlenecks.

4.2 Wärtsilä modulmetrics project

The Wärtsilä Modulmetrics Project was initiated in March 2009 and is still running. The specific objectives were to develop and implement appropriate methods and tools, which could support scanning of the competitive environment. Wärtsilä Oy, Vaasa, Finland and the University of Vaasa organized the Modulmetrics Project through their corporate research programs. The project started up with a technology-oriented pre-study, in which the existing product development technologies were reviewed and analyzed for possible bottlenecks and further improvements.

In the beginning, the overall requirements of this study were discussed and target goals agreed with the case company. The potential methodology and tools to be implemented for this study were selected. The objectives of the research study were to investigate the possibility of integration among information flow perspectives, customers' preferences and design strategies within the company. All these research issues were investigated within the case company with a view to possible customized product development. The basic objectives of this research study can be summarized as follows:

- To investigate existing design architecture and display component dependency or information flows
- To examine the possibility for suitable clusters/modules and recommend potential design improvements
- To display and balance dependencies between internal resources (e.g. components) and external offerings (e.g. customer requirements)
- To identify clusters between resources and offerings and investigate critical components

All the objectives mentioned above are formulated within the scope of the Wärtsilä 32 engine family, designated as W32. This engine family is a comparatively large group with a high level of customer demands.

4.3 Technical details of the studied engine

The research mainly concentrated on the Wärtsilä W32 engine family. Here W32 represents W for Wärtsilä as a brand name and 32 the diameter of the cylinder bore, which is 32 cm or 320 mm. The W32 engine, is used both for marine and power plant engines. The main technical data for the W32 engine used for both marine and power plant engines can be seen in Table 2 below.

Table 2. Main technical data of W32 engine family [adapted from Wärtsilä, 2009].

Wärtsilä 32 Main Technical Data		
Specification	**Marine engines**	**Power Plant engines**
Cylinder bore	320 mm	320 mm
Piston stroke	400 mm	400 mm
Engine speed	720-750 rpm	720-750 rpm
Piston speed	9.6-10 m/s	9.6-10 m/s
Mean effective pressure	24.9 bar	22.9-23.3 bar
Output per cylinder	480/500 kW	450/460 kW
Available cylinder configurations	6L, 7L, 8L, 9L, 12V, 16V, 18V	6L, 7L, 8L, 9L, 12V, 16V, 18V, 20V

The W32 engine family has many types, with different rated power as displayed in Table 3 below. From Table 3, we can observe different engine types with revolutions per minute (rpm), output power per cylinder (kW/cyl), engine output (kW) and generated output (kW). Here, the engine type '6L32' represents the six cylinder line (parallel) engine with 32 cm cylinder bore; '12V32' represents the twelve cylinder V-engine with 32cm cylinder bore, and so on.

Table 3. Rated power of W32 engine family [adapted from Wärtsilä, 2009].

Rated Power Wärtsilä 32 Engine Family				
Engine Type	**480 kW/cyl, 720 rpm**		**500 kW/cyl, 750 rpm**	
	Engine kW	**Gen. kW**	**Engine kW**	**Gen. kW**
6L32	2880	2760	3000	2880
7L32	3360	3230	3500	3360
8L32	3840	3690	4000	3840
9L32	4320	4150	4500	4320
12V32	5760	5530	6000	5760
16V32	7680	7370	8000	7680
18V32	8640	8290	9000	8640

4.4 Methodological aspects of the research

The empirical research was conducted through active participation in the daily assembly operation of the Wärtsilä Pilot Plant at Vaasa, Finland. The objectives of this study were to investigate the suitability of the current engine architecture and to suggest or guide designers or managers in adopting appropriate design strategy. In order to fulfill these objectives, existing interfaces between components to components, modules to modules or components to modules were studied and mapped. These interfaces or dependencies can be transformed to accommodate and enable the clustering process within the existing engine architecture and external environments.

With a view to carrying out the research objectives, the existing dependency pattern and required information flow of the W32 engine family was collected through face-to-face interviews with engineers, designers, workers and managers, and from the Wärtsilä 32 standard register. Several review meetings were also conducted with managers in Wärtsilä in order to discuss the existing engine architecture, customers' preferences, the company's business strategy and current bottlenecks or problems. These discussions led to the making of recommendations for possible improvements for the existing design architecture and configurations issues within the company.

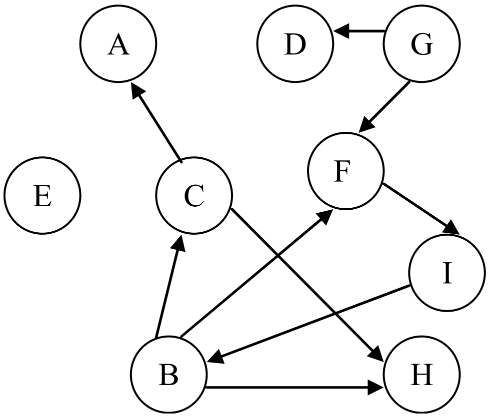
Several issues were identified within the scope of the modulmetrics project. Among them, the suitability of modular architecture, rules for modularity, product configurations and information flow between potential customers and the company's internal resources were formulated and analyzed. All these study issues were examined and iterated through matrix-based tools, namely design structure matrix (DSM) and domain mapping matrix (DMM). These tools were used to model the required information flow among design elements and customer preferences.

In this study, two software tools, namely 'PSM32' and 'Multiplan' for DSM and DMM, respectively were used to codify, visualize and analyzing the information dependencies. The DSM tool 'PSM 32' is provided by a company named Problematics, USA, and the DMM tool 'Multiplan' by RedTeam, Sweden. Both tools were implemented due to their simplicity in use. Brief explanations of the matrix-based tools DSM and DMM are outlined in next sub-section.

4.5 Matrix-based tools: DSM and DMM

4.5.1 Design structure matrix (DSM)

The design structure matrix (DSM) tool can be outlined as a tool or methodology to display compact, matrix representation of design architecture or a project network (Steward, 1981). Four types of DSM are commonly available, namely activity-based, parameter-based, team-based and product architecture or component-based DSM (Browning, 2001). This tool is implemented for tracking the information flow dependencies among design elements or project tasks. The DSM provides insights of a complex design structure and formulates clustering for developing modules. Figure 5 displays a simple graph of component interdependencies and its equivalent DSM representation.



	A	B	C	D	E	F	G	H	I
A			X						
B									X
C		X							
D							X		
E									
F		X					X		
G									
H		X	X						
I						X			

Figure 5. (a) Component interdependencies graph; (b) DSM representations of component interdependencies graph (unclustered).

Figure 5 (a) displays nine components of a product namely A, B, C, D, E, F, G, H, I and their interdependencies. For instance, component C needs information from component B, while components A and H need information from component C to be completed. This is presented in a matrix format (shaded area) in Figure 5 (b). All other information exchanges or interdependencies among components are also displayed in Figure 5 (b). In order to reduce the iteration time, the upper diagonal marks need to be brought as close to the diagonal line as possible. This is done by clustering, where the rows and corresponding columns are rearranged to get clusters or modules. Figure 6 shows two overlapping clusters or modules.

	A	C	B	F	I	G	H	D	E
A		X							
C			X						
B					X				
F			X			X			
I				X					
G									
H		X	X						
D						X			
E									

Figure 6. DSM representations of component interdependencies (clustered).

In DSM analysis, both partitioning and clustering operations are done with different perspectives. Partitioning is the sequencing (i.e. reordering) of the DSM rows and columns in such a way that they do not contain any feedback marks, thus transforming the DSM into a lower triangular form (Steward, 1981; Yassine & Falkenburg, 1999). The reason behind this transformation is the significance of the upper-diagonal marks, which represent feedback information flows. Partitioning is used for activity-based or time-based DSM and parameter-based DSM. On the other hand, when the DSM elements represent design components or teams, the goal of the matrix manipulation changes significantly from that of partitioning algorithms. The new goal becomes finding the subsets of DSM elements (i.e. clusters or modules) that are mutually exclusive or minimally interacting. This process is termed clustering (Yassine, 2004). Clustering is done for team-based DSM and component-based DSM (Browning, 2001).

4.5.2 Domain mapping matrix (DMM)

The domain mapping matrix (DMM) is similar to the DSM which was introduced by Danilovic (2001). It is a rectangular two-dimensional matrix tool used to represent and analyze dependencies and relationships between two different domains and not a single domain as in DSM (Danilovic and Börjesson, 2001). This tool provides a clear representation of complex systems and visualizes the interactions across two different domains, where the rows represent the nodes of one domain and the columns represent those of another domain. For instance, rows might represent product architecture or component lists, and columns different departments in order to fabricate the complete product.

Component versus Department/unit (DMM)	Engine manufacturing	Gear box supplier	Repair and maintenance	Purchasing unit	Customer service	Raw materials supplier	Wheel supplier	Rim manufacturing	Cabin assembly	Chassis manufacturing	Marketing and sales	Stationary supplier	Research & development	Electronics and lighting	Transmission & wiring	Painting & decoration
Truck model	X	X			X					X	X		X			X
Engine model	X	X	X				X						X			
Transmission	X	X	X				X						X	X	X	
Gear box	X	X	X										X			
Chassis	X		X	X		X	X		X	X		X	X		X	
Comfort level					X				X		X			X		
Color theme				X	X				X		X					
Kitchen unit				X		X			X		X	X		X	X	
Front wheel			X				X	X								
Front rim			X				X	X								
Rear wheel			X				X	X								
Rear rim			X				X	X								
Cabin type (model)	X		X						X	X						
Cabin body						X			X						X	X
Cabin equipment				X		X			X							
Cabin interior				X		X			X		X	X	X	X	X	X
Entertainment				X	X				X		X	X	X	X	X	
Office package				X	X	X			X		X	X		X		X
Resting package				X	X				X		X					X
Storage section				X	X	X			X			X		X		
Rear axle	X	X	X	X			X			X			X		X	

Clusters/ Modules

Figure 7. DMM representations of components versus departments (clustered) [Fig. 4 in Paper 2].

Figure 7 displays an example DMM where the rows represent the components of a truck and the columns represent the supporting departments in order to assemble the complete truck. The interactions between these two domains are clustered in order to get suitable clusters or modules. There are four clusters or modules formed which could be collocated and worked together to save costly time.

4.6 Deployment examples

4.6.1 Example 1: modular phenomenon

From the dependency pattern as collected through the interviews and from Wärtsilä standard register, the definitions of the required information flows are extracted for analytical purposes. For the sake of simplicity in explanation, only higher-level components and modules were considered to display within a network analysis, as shown in Figure 8. Different dependencies or interactions among the components or modules are presented through a generic network diagram. From Figure 8 we can observe the overall complexity of the W32 engine architecture.

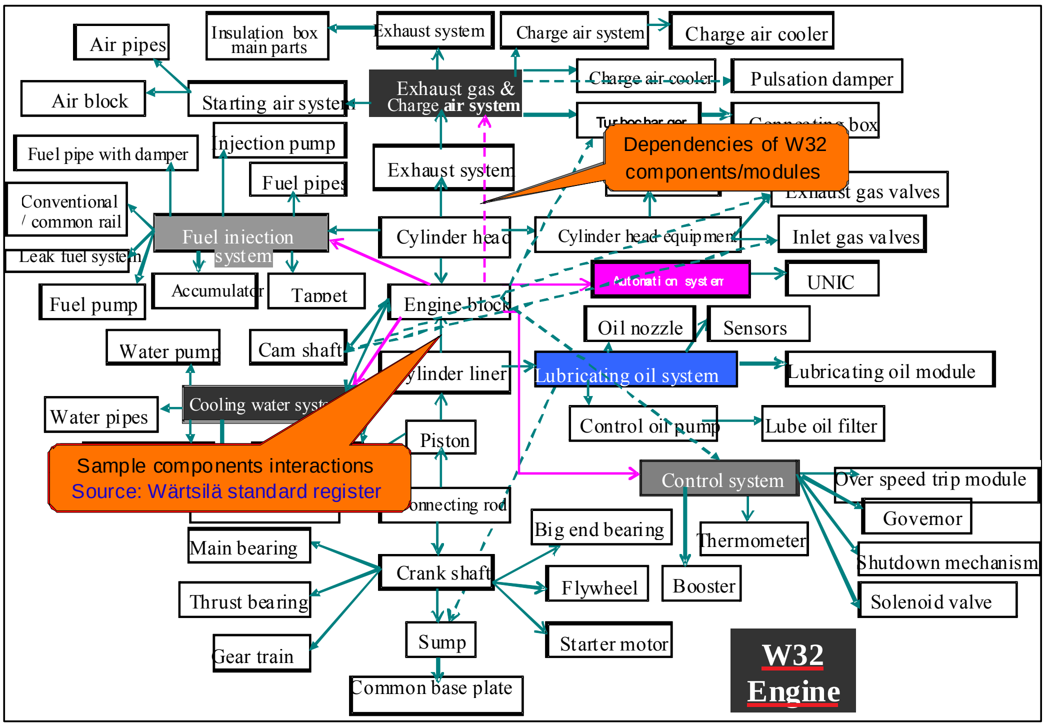


Figure 8. Generic network of component architecture in W32 engine.

The network representation in Figure 8 may be manageable at the higher level of interdependencies, but what happens if we consider these dependencies in the lower level of component architecture? It is therefore of prime concern to represent these interactions in a more formal way before moving towards any study or investigation for updating or improvement. To examine these information dependencies, we have implemented a component-based DSM tool 'PSM32' for presenting the interdependencies among different components.

This DSM tool can accommodate a large number of design elements and their interdependencies in a comfortable way. It can be used quite easily to display the iterations or feedback loops within the design architecture. It manages the design architecture through clustering, which results in optimum clusters or modules that are required for smoother assembly process. These clusters provide insights into how to manage complex architecture through increasing interactions within modules and reducing interactions between modules. Figure 9 displays the matrix representation of the W32 engine component architecture, which was presented in Figure 8.

Component versus component (DSM)		Crankshaft	Main bearing	Thrust bearing	Lubricating oil system	Fly-wheel	Cylinder liner	Piston	Piston ring set	Connecting rod	Big-end bearings	Camshaft	Cooling water system	Valve tappet	Cylinder head	Inlet gas valves	Exhaust gas valves	Cylinder head equipment	UNIC	Starting air system	Leak fuel system	Engine block	Fuel injection system	Overspeed trip device	Starter motor	Water pipes	Pulsation damper	Fuel pump	Spash guard	Injection pump	Turbocharging system
Crankshaft	1		1	1		1				1	1														1						
Main bearing	2	1																													
Thrust bearing	3	1																													
Lubricating oil system	4						1																								
Fly-wheel	5	1																													
Cylinder liner	6							1	1				1																		
Piston	7								1	1																					
Piston ring set	8						1	1																							
Connecting rod	9	1						1																							
Big-end bearings	10	1																													
Camshaft	11															1	1					1									
Cooling water system	12						1															1				1					
Valve tappet	13																	1					1								
Cylinder head	14																	1				1	1								1
Inlet gas valves	15											1						1													
Exhaust gas valves	16											1						1													
Cylinder head equipment	17														1	1	1														
UNIC																															
Starting air syster																															
Leak fuel system																							1								
Engine block												1	1		1								1								
Fuel injection sys														1	1						1	1					1	1		1	
Overspeed trip device	23																														
Starter motor	24	1																													
Water pipes	25												1																		
Pulsation damper	26																														
Fuel pump	27																						1								
Splash guard	28																														
Injection pump	29																														
Turbocharging system	30																														

Component dependency by DSM tool

1 indicates that 'Inlet gas valves' have a dependency over 'Camshaft'

Figure 9. DSM representation of W32 component architecture (unclustered).

This way of presentation extracts the valuable feedback or iteration that is responsible for higher developmental lead-time. The iteration number and/or dependency pattern can be minimized through the clustering operation, which is done as displayed in Figure 10. Figure 10 also outlines the different modules required for updating of existing modules or developing newer modules according to the dependency level. The formation of modules guides designers towards improving the existing design architecture and initiates the possibility of different strategic options such as, component commonality, standardizing components or platform-based product architecture.

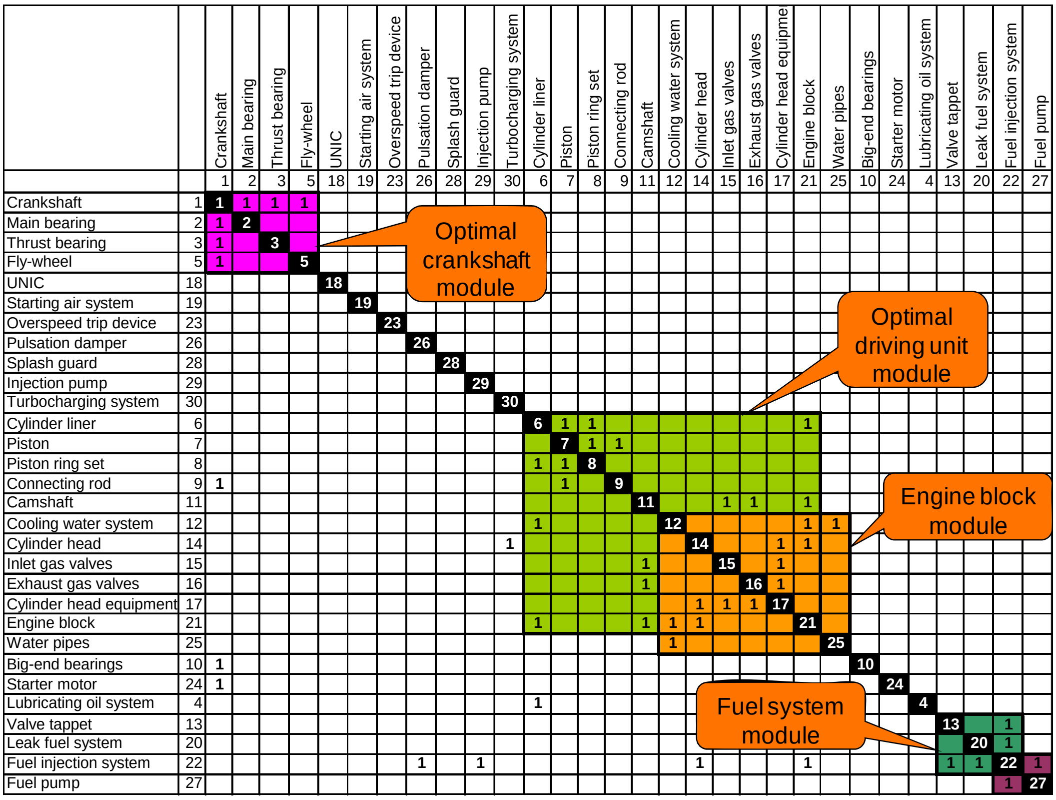


Figure 10. Proposal for modules with optimal interaction (clustered).

For analytical purposes, we have modeled all the 218 components of the Wärtsilä W32 engine, and the DSM tool in Figure 11 displays their interactions. All the component interactions are modeled according to the dependency strengths, where ‘1’ represents the highest, ‘2’ is medium and ‘3’ is the lowest dependency level. In Figure 11, red, green and yellow colors denote the highest (1), medium (2) and lowest (3) dependency level respectively. In order to investigate the modular principle, we have clustered all the components in Figure 11 and the resulted matrix is shown in Figure 12.

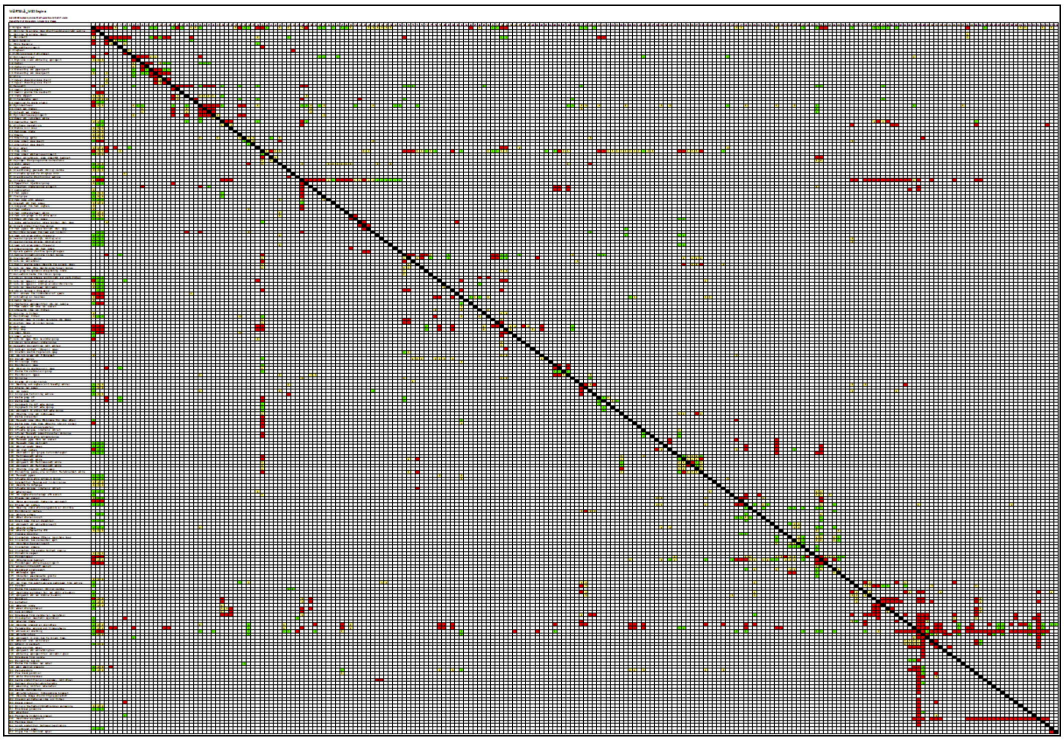


Figure 11. Wärtsilä W32 engine component dependency (unclustered).

From Figure 12, we can observe four clusters/modules, with the biggest consisting of 75 components, the second biggest of 7 components and the last two modules of 2 components each. It is noticed that the biggest module, known as the 'Basic module', displays highly integrated design architecture, which needs to be broken down into smaller manageable modules. This integrated architecture evolves due to the specific feature of the engine. Some specific components such as engine block, sump, crankshaft, etc are responsible for this highly integrated architecture. An effort is needed to sort out these specific components and where possible de-compose or split them into manageable sizes, modify or redesign and replace some of the components with a view to breaking down this highly integrated de-sign architecture.

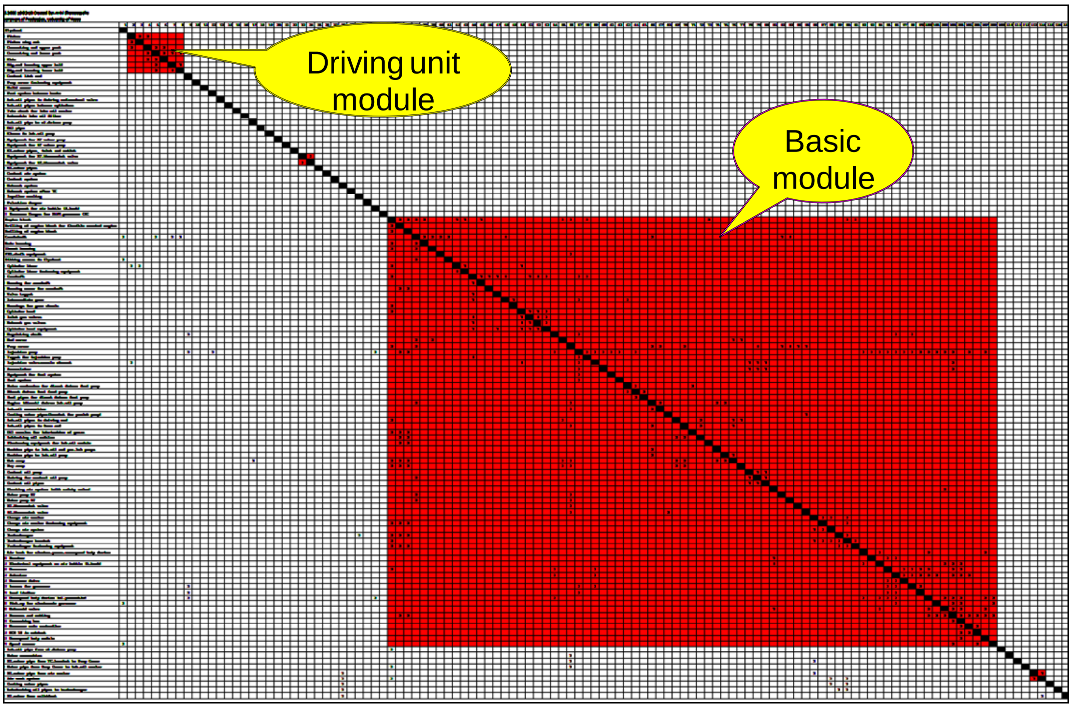


Figure 12. Wärtsilä W32 engine component dependency (clustered).

The second largest module, known as the ‘Driving unit module’, appears consistent with the existing W32 engine architecture, where the components are fully matched with the existing driving unit module at Wärtsilä. The DSM tool therefore shows its implementation reliability in the area of design engineering. Figure 13 and 14 display the matrix-based information flow between the components of the driving unit module and its equivalent physical module at Wärtsilä.

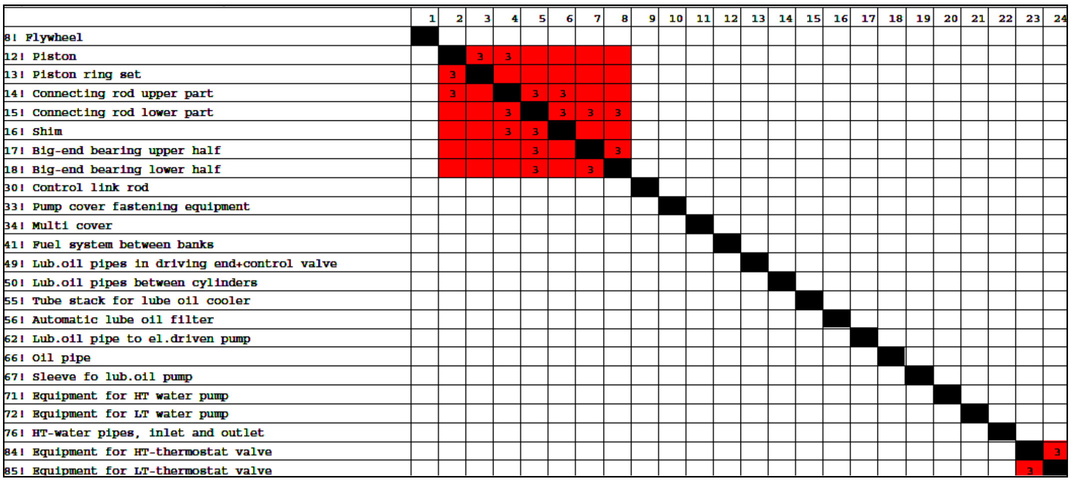


Figure 13. DSM representations of driving unit module in Wärtsilä W32 engine.

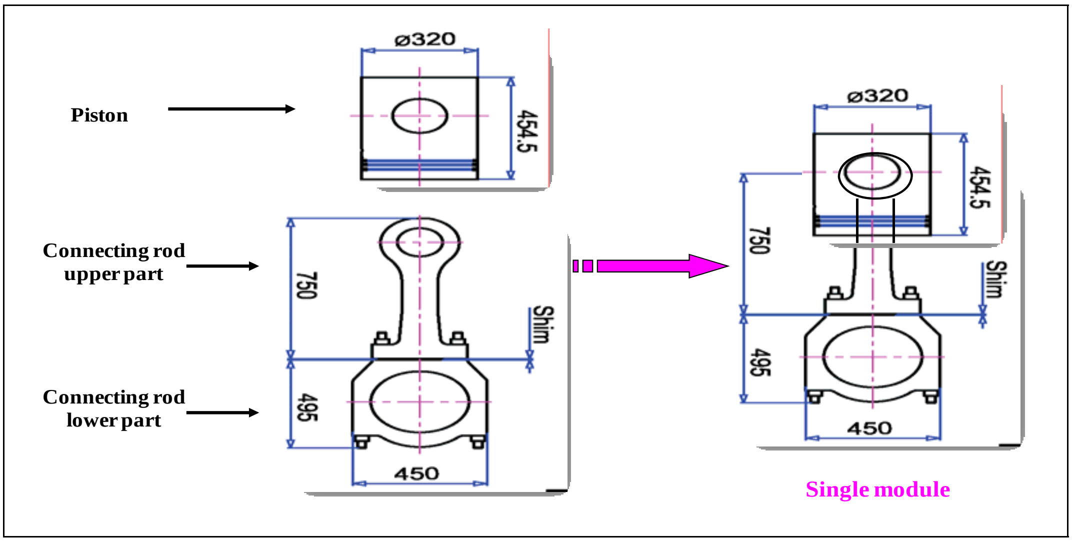


Figure 14. Driving unit module in Wärtsilä W32 engine.

4.6.2 Example 2: clustering between resources and offerings

This example analyses the dependency pattern or information exchange between Wärtsilä's customer requirements (offerings/solutions) and existing component architecture. In this example, we have used the domain mapping matrix (DMM) software 'Multiplan' with a view to presenting the required dependency pattern between solutions/offerings and components list. This is partially displayed in Figure 15 below. There were 70 solutions/offerings or customers' requirements and 218 component lists as displayed partially in Figure 15. In Figure 15, all the dependencies are marked as number '3' (highest); however, it might be graded as '1' for lowest and '2' for medium dependency, too. The objective of this approach is to screen out the most critical component(s) among others, which covers the most important solutions/offerings by the firm.

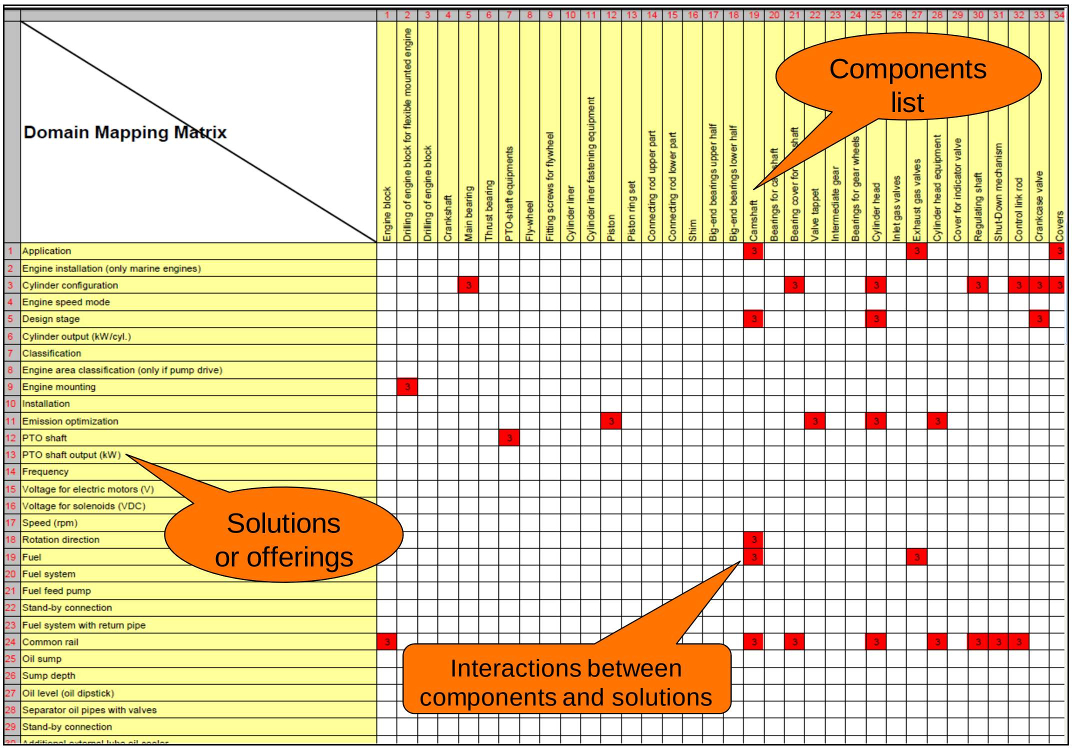


Figure 15. Screen shot of W32 engine dependency matrix between components and solutions (unclustered).

In order to find out the critical component (s), the DMM software 'Multiplan' clusters the interdependencies between solutions/offerings (customers' requirements) and components list. The clustered DMM is displayed partially in Figure 16 below. In this example, two clusters were formed after clustering operation. These clusters were developed based on the closeness or interdependencies between components list and solutions/offerings (customers' requirements). Figure 16 displays one cluster partially. This cluster displays the list of most important components that satisfies the top order solutions/offerings by the firm.

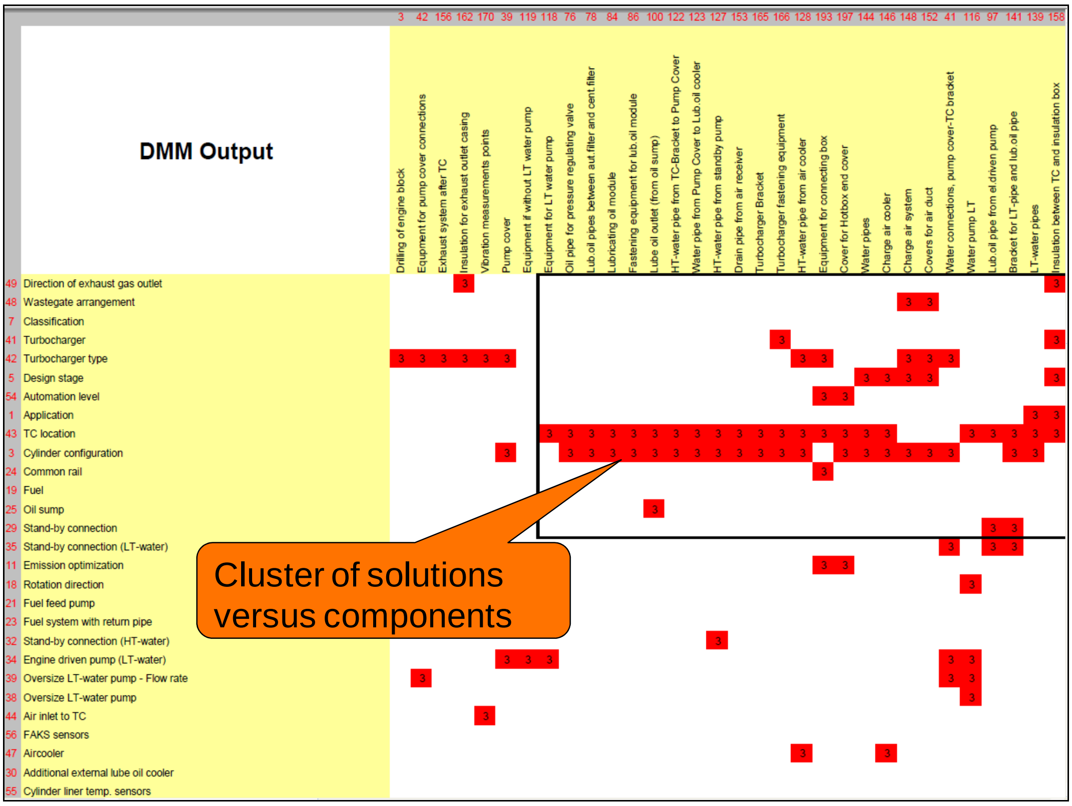


Figure 16. Screen shot of W32 engine dependency matrix between components and solutions (clustered).

It is therefore, a valuable guideline for the designer to identify the critical compo-nent(s) before offering any solutions/offerings for potential customers. From this approach, designers would be able to sorting their components list based on the level of importance and planned the product architecture in a way that will satisfy most of their customers' desires or needs. This methodological approach will con-tribute to industrial firms for achieving a balance between their existing resources and their market offerings (customer needs).

4.7 Rule for modular design: an approach

Modularity, which is an expanding design strategy in the industrial community, requires specific rules or methodology to form the required modules. The DSM (Steward, 1981), as discussed, is one such tool to formulate the module, based on compo-nent dependencies or interaction with each other. Stone et al. (2000) introduce a heuristic method for identifying modules. Ericsson and Erixon (1999) imple-mented QFD-based methodology to formulate a module, while Hölttä and Sa-lonen (2003) assess three methods of module formation, namely DSM-based physical interaction, the heuristic method and QFD-based methods. Gershenson et al. (2003, 2004) offer an overview of modularity metrics and methods. An extension of the classic DSM by adding flow interactions between components to form a module is proposed by Alizon et al. (2006).

In this study, we propose a rule for the formation of modules that can be explained through a network diagram consisting of six components of a turbocharger (TC) installation bracket, as shown in Figure 17. This bracket is used as a support to install the TC on the engine block. Figure 17 displays six higher-level components, namely TC support, bracket, distance sleeve, hexagonal screw, blind flange and the O-ring of the TC installation bracket. The numbers from 1 to 9 display the dependency strength within the components. Number ‘1’ represents the highest dependency strength, while number ‘9’ is the lowest.

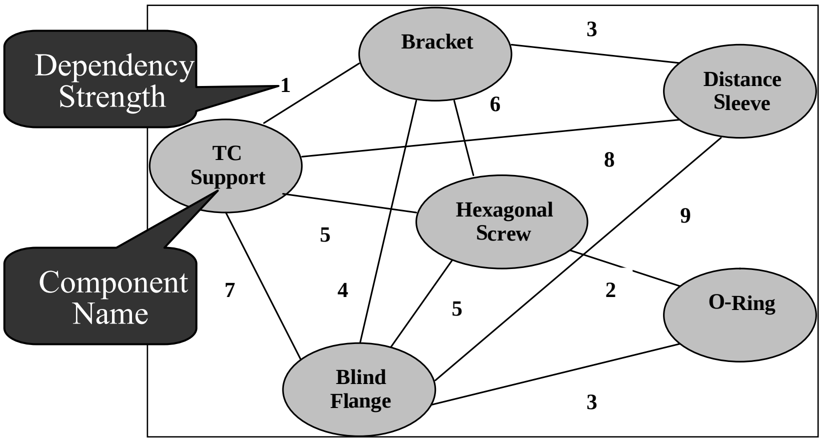


Figure 17. Display of component interactions and dependency strength of a TC bracket.

In order to form a module, let us start with the component ‘TC Support’, from which the components ‘bracket’, ‘distance sleeve’, ‘hexagonal screw’ and ‘blind flange’ have dependency strength of 1, 8, 5 and 7, respectively. According to the dependency strength, the interdependencies between the components ‘TC support’ and ‘bracket’ are considered the highest, and we proceed towards the first module as displayed in Figure 18.

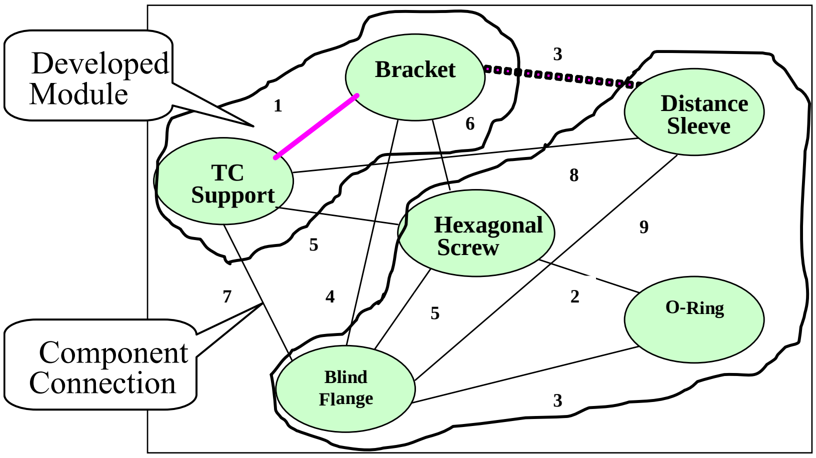


Figure 18. Formation of a module according to the dependency strength of the components of a TC bracket.

With a view to extending the first developed module, we could check the dependency strength again from the components 'TC support' and 'bracket'. It is noticed from Figure 18 that from the component 'TC support' the remaining dependency strengths are 8, 5 and 7 with the components 'distance sleeve', 'hexagonal screw' and 'blind flange', respectively. Whereas, from the component 'bracket' the dependency strengths are 3, 6 and 4 with the components of 'distance sleeve', 'hexagonal screw' and 'blind flange', respectively.

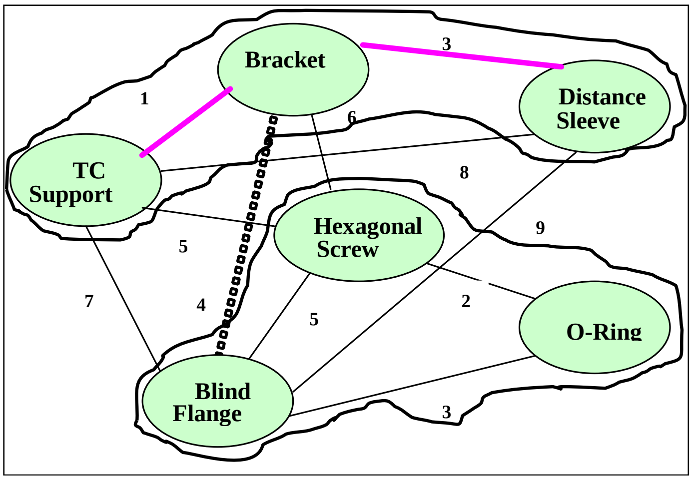


Figure 19. Formation of an extended module (three components) according to the dependency strength of the components of a TC bracket.

It is therefore clear that the component 'bracket' should be connected with the component 'distance sleeve' according to dependency strength in order to extend the previous module. The new extended module therefore consists of three components, namely 'TC support', 'bracket' and 'distance sleeve', as depicted in Figure 19. In the following fashion, other extended modules can be formulated according to the method as explained. Another extended module consisting of four components can be seen in Figure 20 below. The other remaining component(s) within a product can be connected as a separate module or part during the assembly process according to specific functionalities or requirements.

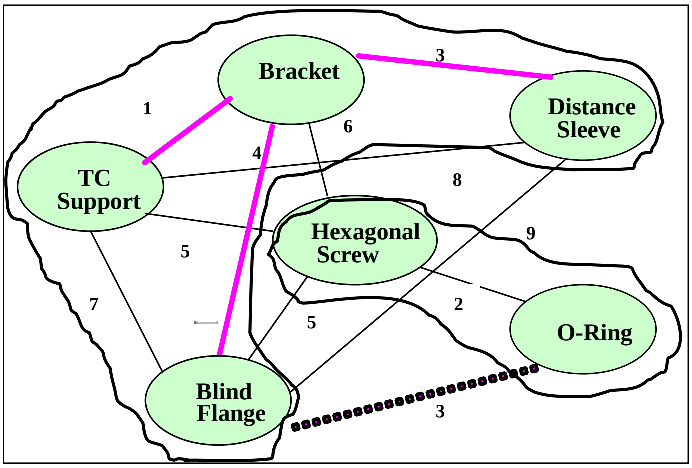


Figure 20. Formation of an extended module (four components) according to the dependency strength of the components of a TC bracket.

The methodology as proposed above can be applied successfully in manufacturing firms for developing the required modules. This approach is comparatively simpler than other existing methods such as DSM, clustering algorithm, etc for module formation. It differs from conventional approaches in a way that this methodology depends on the level of interdependency strength between components to components or components to modules. Another difference is that in this proposed approach the module size is not fixed and can be extended or shortened according to the functionalities or requirements. It offers higher flexibility since the dependency strength can be tracked from each component and the highest one is chosen according to the functionalities and requirements.

This method has many limitations, too. For instance, the levels of dependency or interface among components or modules are measured by interviewing designers, engineers or workers, which could be biased from person to person. Particular dependency strength can vary between designers and engineers or engineers and workers, and so on. This approach is lagging behind the selection criteria for including or excluding a component in a module. There is also no appropriate technique to choose one when there are several dependencies with the same level of strength from a component or module. This approach cannot limit the size and number of the modules required within a product if it is not predefined.

The size and number of the modules are generally formulated based on the specific requirements or functionality of the developed modules or products (Zamirowski and Otto, 1999a, b; Gonzalez-Zugasti et al., 2000; Kimura et al., 2001; Asan et al., 2004). The formation of modules is also dependent on various strategies such as assembly line design (He & Kusiak, 1998), decomposition of manufacturing systems (Kusiak, 1990; Kim et al., 1993), mass customization (Jiao & Tseng, 1999), product platform and family design (Erens & Verhlust, 1997; Gonzalez-Zugasti & Otto, 2000; Muffatto & Roveda, 2000). Each of the strategies needs to be investigated before finalizing the suitability of a modular approach for a specific firm.

4.8 Experiences and research outcomes

The study conducted within the case company Wärtsilä Oy was very fruitful in terms of research perspectives. The main target of this study was to investigate the information flow within the company with respect to design architecture, customers' preferences and business strategies. In order to model this information flow, we implemented DSM and DMM tools to measure the level of information dependency and to investigate how this issue affects the overall company's objectives. In terms of design architecture, we studied the existing product architecture within the company and the overall information dependencies among components and modules. These dependencies were modeled to formulate the current practice and to look for possible bottlenecks.

After analyzing the company's present engine architecture, it was observed that the architecture is mostly an integral one with limited forms of modular architecture, too. This is due to the main part of the engine being 'engine block'. Almost all components or modules being tightly fitted to the engine block results in a highly integrated structure. This is also displayed in our analysis (Figure 12), where the major portion of the components is tightly clustered due to strong interdependencies. This is one of the major bottlenecks in the case company. In order to overcome this bottleneck, splitting the engine block into several pieces or modules and joining them together based on power demands (number of cylinders) is suggested. This might mean needing to rearrange or redesign some of the components or modules to improve design flexibility in the engine assembly process.

Another bottleneck found during this study was that Wärtsilä is using different turbocharger (TC) brackets to support different TCs, which creates problems for them. This is happening due to having different suppliers and turbocharger designs. Most often, this creates interface problems with the engine block during assembly. We investigated different architectural designs of different TC brackets and proposed that Wärtsilä should consider the possibility for developing a universal supporting bracket. This structure as suggested would be fabricated in a modular structure, which would be suitable for interfacing with the engine block easily and accommodating most of the supplied TCs comfortably. The information dependency of the components for designing this modular universal TC bracket needs to be modeled by the DSM tool in order to develop this proposed structure.

With respect to customer preferences, we studied the interactions or dependencies between Wärtsilä's design architecture and its offerings for potential customers. All the interactions between these two domains were modeled by the DMM tool (MULTIPLAN) with a view to grouping the dependencies in terms of closeness of relationships. The objective of this approach was to cluster the dependency pattern in order to find the critical components or modules responsible for most of the important offerings or customer preferences. In this study, two clusters were identified where most of the customers' requirements were accommodated. The advantage of this approach is that designers can concentrate more on these specific modules, which cover most satisfied customers. This study was conducted within the marine engine division of Wärtsilä, where the company offers more varieties for customers.

In conducting this case study, we faced some limitations. For instance, the information dependencies between offerings/solutions (customers' requirements) and component lists (engine architecture) are considered the highest level, which may not be true in real applications. This happened due to the confusion of dependency strength among the design staff. This might skew the study output from the actual figures. Another limitation can be the lack of a complete list of components within the case company. We considered only higher-level components and their interactions in order to investigate the design architecture. This might not reflect the true clustering process within the case company, which may then confuse the actual results from this study.

5 DISCUSSION AND CONCLUSIONS

This section comprises a discussion and conclusion of the work carried out in the study. The research gap and the overall findings in relation to the original research questions are identified. This section also includes the basic contribution of the research, its limitations, and finally further research ideas and directions are suggested.

5.1 Research gap and findings from this study

This research provides new insights and enhances knowledge in the field of managing product design for customization. The main objective has been to understand the management of information flow by combining the configuration principle and product design strategies such as modularity, product platform and customization for developing customized products. The objectives of this study were transformed into three research questions:

1. How does managing information exchange affect the use of product development practices?

2. How could configuration processes be implemented for product development practices and used in the customization principle?

3. How can different development measures be integrated to support market solutions and the internal resources of a firm?

It is observed in the literature that the information management process in firms is not properly managed or stored (Vickers, 1983; Vickers, 1984; Entsua-Mensah, 1996). Firms mostly look for expert knowledge to stay competitive in the market; however, this knowledge or information is not properly stored for future use. There is a lack of proper tools or methodologies to store valued information and to exchange information among product development participants (Browning et al., 2002; Eppinger & Salminen, 2001). The first research question tries to answer this dilemma within the boundary of product design and development. Practical problems for information exchange are considered and expected solution approaches are formulated within the scope of this research. Papers 1 and 2 discuss this information flow aimed at the improvement of the product development process.

In the present study, we have attempted to answer the second research question, which addresses a major concern in manufacturing organizations. To cope with today’s customization or individualization trends, the configuration process functions as a dynamic way to build relationships among customers, designers and manufacturers. Researchers also validate its suitability and applicability in business success (Tseng & Du, 1998; Myung & Han, 2001; Forza & Salvador, 2002). However, the implementation of a configuration process is very much confined to certain types of industries such as automobiles, the shipbuilding industry, textiles, etc. Through answering the second research question in this study, the implementation issues of the configuration principle and its competitive market values are evaluated. Papers 3 and 4 examine the concept of configuration process with practical examples.

From this research, we have noticed that along with the information and configuration perspectives, firms are also lagging behind in terms of appropriate product design and development measures, which are the base requirements for enhancing productivity and customer satisfaction. Available measures such as modularity, product platform and postponement are widely used by firms, although there are limited rules or methodologies to justify its usability. Specific measures such as modularity and product platform are discussed and evaluated in this thesis, which addresses the third research question. A trade-off between these development measures and firms´ internal capacity are also highlighted in this study. Papers 5 and 6 elaborate the modular design concept and platform-based approach for developing customized products.

In the literature there are few specific rules or methods available to formulate modular product development strategy. Firms are facing common challenges such as; Which component needs to standardize? Which section of a product is needed to modularize? In addition to, what are the ways to modularize? These questions emerged during the study of the case company. An approach has been proposed to formulate modules from certain numbers of components according to their level of dependency on each other. The formulated approach is also explained with an example, which might be a new strategic option for modular design architecture.

5.2 Theoretical implications

This thesis contributes to the growing field of research on product customization and its impact on industrial establishments. The issue of information transfer during product development process is considered as an asset for firms, where progressive information is exchanged between the participants. The generic information perspective is discussed within the periphery of this study. This line of research is followed up through information management as a source of firms’ resources. This thesis contributes to developing a pathway of information exchange between internal resources and external markets.

A large number of industrial organizations are lagging behind in terms of their communication pattern with their customers, an issue which is also elaborated within this research through the configuration process. There are several formulations and interconnectivity, which require integrating this process with the generic business environment. In order to implement the configuration process successfully, a generic platform is required, which is also discussed in this thesis. This approach establishes a balance between external pressures, such as — customers' demands, product costs and quality issues with internal resources, such as — capacity constraints, resource availability and production timing.

Along with information exchange and configuration perspective, the general outlines of different product development strategies are discussed and presented in this thesis. The presented lists of different strategies, such as modularity, component commonality and product family are commonly applied in the mass customization process. Through the implementation examples in the six articles, different types of strategies and ideas are captured and modeled for the product customization process. The issue of which specific strategy might be suitable among these alternative strategies is also presented and discussed in this study.

5.3 Research limitations

The research work presented in this thesis was limited due to the level of confidentially. This work could not be presented in detail due to the terms of confidentially in the case organizations. In such a perspective, a broad coverage of the thesis has clearly been a challenge. The thesis has mainly focused on the organizational level and does not consider networks between firms. This constraint limits the interpretation of the results and may not be applicable in a generic format.

The information drive as depicted in this study is not well managed when organizations are dealing with customers' demands. In the empirical part of the study, the information dependencies are not analyzed financially, but rather on a theoretical basis only. Any strategic decision always needs to be financially validated before considering its applicability. This limitation can be overcome by taking firms' financial capability as a strategic point of view. The empirical part of the research considers information dependencies among product components, i.e. the physical components domain only. This research could contribute more significant and comprehensive results if we considered information exchange also among other domains such as design teams, resources, functions etc.

The research has been a qualitative study, which has several limitations. The research outcomes are based on two case studies, which contribute several theoretical illustrations. Due to this, the results should be interpreted cautiously and too much generalization needs to be avoided. More case studies might be useful to validate the methodologies presented here. In the empirical part of the thesis, it is mainly focused on the possibility of modular design strategy rather than considering also the importance and feasibilities of platform-based engine development, component commonality, product family, etc. The implementation of DSM and DMM tools were limited due to their inadequate analytical ability.

In this thesis, six publications are presented, which all have their own objectives and methods independently. All the publications had their own data and methods as described within the summary of the article section. It can be concluded that all the publications have their own identity and it is quite difficult to consolidate them into one dimension. Each of the publications is considered as a sub-project of the research.

There are some limitations and misconceptions in the published papers, which need to be updated for further research. For instance, in Paper 1 the concept of the terms partitioning or sequencing and clustering was mixed up, which was a typological error and needs to be corrected for further research. Paper 2 is based on both component-based and team-based DSM, which needs to be clustered to make them into clusters or modules, not partitioning as stated in the article, which was a typological error. Paper 3 appears to be the average development loss, which would be better if the loss is proven somehow. The suitability of the proposed configuration framework also needs to be compared with available ones in the market.

In Paper 4, the authors proposed an integration framework for both front-end and back-end modules of the customization process, which needs to be compared with the available frameworks in the existing production process. This configuration framework also needs to be generalized after implementing in real life. Paper 5 lacks essential resources (references) in the field that could be updated in future research. The application of DMM could be elaborated for more readability. There are also limited resources in Article 6 and the implementation issue of the product platform was a bit complicated. The overall limitations of the published papers need to be considered carefully for further research in this specific area.

There are also limitations to the presentation of this thesis. This is an article-based thesis, which enables the use of several research sub-processes for the purposes of different publications. This makes the research process more flexible in respect to dependability, but it requires careful coordination of the whole research process. In comparison to a monograph thesis, the consistency level between the publications is not as high. This is common in an article-based thesis, where the process is more adaptable, and changes in the research plan can be made more flexible during the research process.

5.4 Recommendations for further research

There are several important issues that could be continued in further research based on the findings of this study. First, would be tracking knowledge transfer at the organization level, which is considered an important step towards achieving business success. This knowledge transfer needs to be organized and stored in an appropriate structure so that it can be used further. Few firms maintain their own individual methodology to store valuable knowledge or information, and there is no generic tool or methodology for it. Further research could be carried out to develop a generic tool to store and retrieve information structure. The possibility of intra-net and/or internet-based information management systems may also be investigated with security options.

In order to achieve customization, firms need to examine several strategic options but there is a lack of methodology to select the optimal one. There are potential research areas, where researchers could find tools or methods for selecting the best strategic option suitable for a firm. The dynamic of the product customization process is required based on product design and development strategies. In this study, most of the customization strategies are dependent on assumptions, which could be formulated or modeled with real case studies in order to develop the empirical research. The scope of R&D in the strategic context of the firm’s effort can also be investigated with respect to fulfilling customer satisfaction.

Another issue for further research might be to integrate the configuration process not only with product design and development but also with a larger area of this field. This collaboration might be with marketing or advertizing, logistics and distribution systems, etc. It would be good business practice to evaluate firms’ production strategies based on the configuration process. The development of a multi-purpose configuration process could be a good solution for enhancing a firm’s success.

In today's business, modularity is widely used by many leading firms globally. There are many ways to formulate specific module functionalities, but none of them is obviously appropriate for business success. To date there have been no specific rules or metrics to form optimum numbers of modules for a certain product or product family. There is potential scope to extend this research in this particular area and especially to focus on the issue of modular rules. Finding specific metrics appropriate for modular product or process development also needs to be investigated.

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Applying Design Structure Matrix (DSM) Method in Mass Customizations

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Abstract

Growing demand on product individualization forces manufacturing organizations to react quickly and reducing the cost at the same time. To meet individual customers' need, competitive enterprises have to adopt both strategies of customer-driven and cost efficient product development. This can only be achieved by raising designers' awareness of market information, which includes both customer, and competitors' information. Sharing market situation among concurrent design teams is critical to provide customized products. This paper discusses mass customization approach using Design Structure Matrix (DSM) methodology, which is a valuable tool for producing different product variety quickly and economically. Our focus in this paper is to demonstrate how product-customization could be done efficiently by using DSM. A case example taken from Volvo Company trucks is also included with this paper in order to show how different design rules could be implemented successfully by using DSM, which may be helpful for customization process too.

Keywords: *product customization, Design Structure Matrix (DSM), integrated manufacturing, product variety*

1. Introduction

Today's intense competitive market place, mass production of identical products is not sufficient to survive rather producing products for specific customer need is essential. The only way to gain in business is to adopt customers driven strategy, which delivers products and services to meet customer expectations (Wallac, 1992). Mass customization recognizes each customer as an individual and provides each of them with "tailor-made" product. The role of customer demand information is therefore extremely critical to the success or failure of new product introduction (Ottum & Moore, 1997). Yet, customers requirements are seldom gathered and it is even rarer that this valuable information is shared between marketing and R&D or made available to design engineers (Omar et al. 1999). The prime goal of any enterprise is to make profits and this can be achieved through producing the right products and services in right time, which in turn reduce cost, design and implementation times.

Adoption of mass customization principle helps companies to reduce the costly inventory and gain market segment. However, to really deliver products that the customer wants in an appropriate way requires design engineers to focus on market demand throughout the design process. This includes consideration of what customers want and how design parameters satisfy customer needs. Besides the customized design, the product has to be cost effective because modern mass production ensures low cost product (Mitchell et at. 1998). If it is cost effective, mass customization strategy then gaining over competitors through new customers and achieving higher market revenues.

Product design and development is directly connected with customization. Product customization has recently attracted interest due to the growing demand of 'mass customization'. In industrial organization, however customization is not new and has always been predominant. In customizable products, customers select products from various alternatives that meet most of their needs at one time. Customization of product is an attempt to summarize many recently developments strategies in flexible manufacturing system such as commonality, modularity, standardization and so on. These features accumulates emerging manufacturing paradigm with the aims of satisfying individual customers needs (Pine, 1993).

This paper presents an approach of mass customization using DSM. Section 2 discusses mass customization features those are commonly adopted by the companies. In Section 3 a framework for mass customization approach using DSM are presented with brief explanation of its features while Section 4 illustrates an example and explains how DSM can be implemented to represent different design rules of Volvo Company trucks for customization. Section 5 outlines the importance of relationship mapping among customer requirements, organizational implications and design elements whereas Section 6 explains the influence of DSM methodology in terms of mass customization. Finally, Section 7 outlines some managerial implications while Section 8 concludes the key points, and discussed how DSM can be implemented successfully further for mass customization.

2. Mass-customization Features

Nowadays, market environments are shifting rapidly from identical products concepts to individualized products. Mass customization is now becoming the challenge for the manufacturing organization to stay competitive. To survive in this competitive environment, enterprises must be shifted from producing mass identical products to mass customized products as much as possible without compromising with cost and quality. Product individualization or variety brings enterprises to face the competition and offers more choices to customers (Sanderson & Uzumeri, 1997). This concept helps companies to deliver customized products with reduce costing and higher quality (Jiao, Zhang and Pokharel, 2005). The principle of mass customization lies in maximizing the correlations among manufacturer's technical capabilities to target market niches and in a timely manner to meet diverse customers' needs. To capture the target market niches, manufacturers need to concentrate on appropriate development of production capabilities to keep production costs low, quality high and quick response. Three criterions are therefore essential for mass customization such as; time to market, product variety and economics of scale (Tseng and Jiao, 1998).

To fulfill individual customer needs, manufacturing companies have to adopt several strategies in their business goal such as; common product platform or proliferation, product configuration, production configuration, part commonality/reusability, modularization in design etc. Resulting from these approaches, the main challenge is to develop a customer-focused and product-driven business portfolio for managing varieties. The product cost must be designed out of the production processes as it is very difficult to reduce the cost through 'cost-reduction' measures after the product has been designed. The product design cost accounts for 80% of the lifetime cumulative cost of a product and is difficult to remove later (Anderson, 1997). Any change in design in order to reduce cost may cause other changes too. Tools like 'design for manufacturability' (DFM) can be applied for easier products design and less costly to manufacture. This approach is known as concurrent engineering where the processes are concurrently designed with the product to ensure lower processing cost. The cost of quality also can be reduced in mass customization through adopting robust product design techniques (Taguchi methods, design of experiments) and then built into the product with process controls instead of the more expensive inspection paradigm.

Product platform or configuring the products, which denotes the collection of elements shared by several related products are the base of making product varieties. Meyer and Lehnerd's (1997) defined product platform as "a set of subsystems and interfaces developed to form a common structure from which a stream of derivative products can be efficiently developed and produced". The success of producing product varieties depends on maintaining and selecting of product platform from which the associated product family is derived (Simpson, 2004). The product family may be considered as a differentiation process of a base product or in an aggregation process of distinct products. It has substantial influences on a firm's ability to deliver large product variety efficiently and has important implications for subsequent product development activities. An effective platform design can allow a variety of derivative products to be produced more rapidly and easily that saving costs and times (Zha and Sriram, 2006).

In mass customization strategy, product and production configuration process plays crucial role to fabricate sales and order processing of products (Hyam, 2006). Configuration software known as 'configurator' contains all of the features and information such as dependencies, rules, constraints and resources necessary to develop a product. Advanced product configurator consists of solid model and graphics of the products that the customers have chosen from different alternatives. The customers are able to request multiple "what if" scenarios during their choices. The use of configurator reduces technical tasks required in sales phase of any product and helps to develop platform based products with rapid pace of time (Franke, 1998). The use of product configurator enhances developing substantial varieties without significant reductions in productivity of any firm (Helo, 2006). Production configurator also acts like product configurator, where manufacturers could choose different operational scenarios to manufacture products according to customers' choice and need.

Competitive market pressures forcing manufacturing firms to reduce cost, which could be possible through reducing the cost of components/ parts and making components/parts as common as possible. Parts commonalities also defined in literature as to reflect the extent of similar products elements (Farrell & Simpson, 2003). The part commonality approach determines the minimum numbers of parts required for new product design and developments and is not focused to remove parts used on existing products unless the common parts are functionally equivalent in all respects (Anderson 1997). It is a very effective technique to minimize the number of different parts by standardizing on certain preferred parts. This technique generally applies to purchase parts but could also be applied to manufactured parts too. Manufacturing organization realized today that the use of common parts could greatly facilitate the custom product design and production process in a way that provides competitive advantage. Parts commonality actually shortens the product design and production process. Fewer types of parts simplifies assembly, part procurement and distribution logistics. Greater commonalities also reduce the complexity of production system, lower costs of assembly, quality and material overhead (Sheu & Wacker, 1997).

Globalization and market segmentation forcing manufacturing firms to diversify their product development processes. Firms are generally not designed for variety management, thus the challenge is to create the desired product variety economically while maintaining the cost and quality. Modularization has been proposed as a tool to split the product structure into smaller, more manageable segments, which makes mass customization easier. Product modularization defines the commonality among products or in other wards it brings standardization among functional independence. It could be a single part or a combination of many parts with certain functionality. Modular products which are the combination of separable modules can be manufactured, assembled and serviced separately and may be recycle, reuse or remanufacture after product retirement (Slevinsky et al. 2005). Modularization enhanced product variety management through creating commonality among components/parts, which can be reused for different products (Baldwin, 1997). Traditionally, modularization has been determined by several factors such as cost, ease of manufacturing, ease of maintenance etc. All the product parameters discussed above can accommodate and geared towards the efficient production of individualized items.

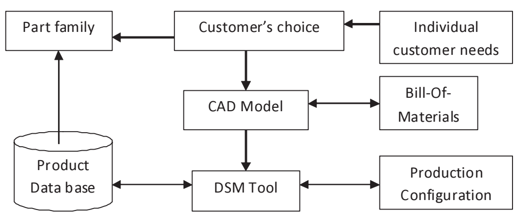
3. Integration of DSM Tool for Mass Customization

The design and development of customized product is very important phase in an organization. In order to response quickly to the customer needs, product development process needs to be integrated with automated interactive framework, which enhances product development (PD) activities. The concept of integrated framework is shown in Figure 1.

From Figure 1 we can observe that individual customer needs mobilize customer's choice process, which has a direct link with CAD model and part family. Part family that needs required information for different parts specifications is connected to product data base (PDB), which is also inter-woven with DSM tool. CAD model gets the required information about a custom-designed product from customer's choice and communicate with Bill-of-materials (BOM) to produce that. Production configuration allocates different resources efficiently for manufacturing the specified product after getting the required tasks sequence from the DSM tool.

From the above framework, it is seen that to order or design for a product, a customer has to try for the required parts/components from existing part family; otherwise to configure it from CAD model. Part family takes the required information/ specifications from PDB which is populated with product data information. If the customer configured his/her product of choice from CAD model, it has to communicate with BOM for the available parts or necessary tasks information required to produce those parts. When the parts are required for manufacturing, all necessary tasks will have to be delivered to DSM tools via CAD model

Figure 1. Integrated framework for customized product



for obtaining optimum tasks ordering. The DSM tool tries to schedule the required sequence for the parts to be manufactured. This tool also helps to minimize the iteration or feed back loop as minimal as possible, which reduces the costly parts lead time essentially. When the sequencing completed through DSM tool, it is then passed over to the production configuration for required resources allocation. In this way customized product/parts can be manufactured more quickly, economically and efficiently. The different components of the integrated framework are explained in brief below:

Product Database: Customization principle emphasizes the uniqueness and variety of the products, which requires design variations and manufacturing changeover (Tseng, Jiao & Su, 1997). To maximize productivity, it is important to reuse previous design data as much as possible in order to keep customization in mind. This will also maintain the integrity of the product families and the economy of the manufacturing investments. It is therefore, important to maintain a product database for the development of customized articles. This data base system is employed to manage manufacturing resources effectively and efficiently so that an appropriate resource can be found out to reuse when needed. In this system, the manufacturing resources are classified according to their content and usage.

CAD Model: To develop custom-built parts/ products, Computer Aided Design (CAD) model is necessary. CAD model contains different software's which are essential for the customers and manufacturers to configure a product or service. It produces the required geometry to design a part. Initially customers are designed in 2D geometric format, which is later converted to 3D solid parts and then applying physical properties such as color, texture etc.

Bill-Of-Materials (BOM): A Bill-Of-Materials consists of list of the parts, materials and tools required to manufacture products. It is an essential part to design and manufacture of a product, as without the basic knowledge and understanding of how many parts a product requires, there are no way to know how many units of those parts we need to buy or manufacture. When customers select the design through CAD model, it needs to communicate with BOM for the required parts/components necessary to make the products. These parts may be order to purchase from outsource or fabricate in-source.

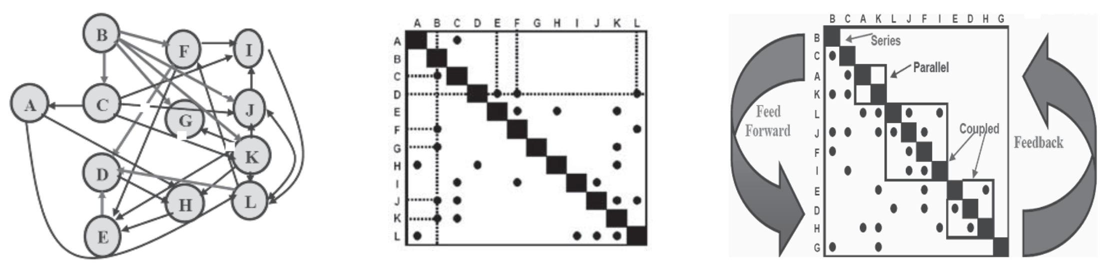
DSM Tool: The DSM is a powerful tool for representing and analyzing task dependencies of a design project (Steward, 1981). It is a compact representation of the information flow structure of any design project. This method differs from conventional project-management tools such as PERT, Gantt chart, CPM method etc. in that it focuses on representing information flows of a design project rather than work flows (Eppinger, 2001). These tools permits modeling of sequential and parallel tasks or processes but fail to interpret interdependency or feedback processes, which are common in complex PD projects. To tackle this consequence, a matrix based method known as DSM has evolved. This method provides the representation of complex tasks (or teams, components etc.) interrelationships in the view to obtain a sensible sequence (or grouping) for the tasks (or teams, components etc.) being modeled.

A DSM is a square matrix with identical rows and columns. The rows and columns are named and ordered identically, although generally the rows contain the complete names list of the tasks while columns follow the corresponding tasks numbers. All the tasks of a project are assigned along rows and corresponding columns by using DSM. A task's dependencies on other tasks are represented by placing marks in the corresponding tasks columns on which it depends upon to complete. Reading across a row reveals all of the tasks whose outputs are required to perform the task while reading down a column reveals which tasks receive information from the task corresponding to that column. The diagonal cells within DSM are usually filled in with dots or the task number, which are meaningless but are included to distinguish between diagonal, upper diagonal and lower diagonal marks of the matrix.

For the demonstration of DSM principle, we have considered an example given in Figure 2 (a), (b) and (c). From Figure 2(b), it can be seen that task B passes input information to tasks C, F, G, J, and K, while task D requires output information from tasks E, F, and L in order to be completed. All marks above the diagonal are considered to be feedback marks while the marks below the diagonal are feed forward marks. Feedback marks correspond to required inputs that are not available at the time of executing a task. In this case, the execution of the dependent task will be based on assumptions regarding the status of the input tasks. As the project unfolds, these assumptions are revised in light of new information and the dependent task is re-executed if needed (Yassine, 2004). It can be now be observed here how easy it is to represent the feedback relationships using DSM compared to the graph as shown in Figure 2(a).

In order to eliminate or reduce the feedback marks from Figure 2(b), we can manipulate the rows and columns to bring back upper diagonal marks to lower diagonal one as much as possible, which is known as partitioning (Steward, 1981; Yassine et al. 1999). After partitioning, a transparent tasks

Figure 2. (a) Tasks representation & their interactions using Spaghetti Graph (b) A binary DSM before partitioned [Figures adopted from (Eppinger, Whitney, Smith & Gebala, 1994)] c). A binary DSM after partitioned [Figures adopted from (Eppinger, Whitney, Smith & Gebala, 1994)]



(a) (b) (c)

structures are evolved which allows better planning to any product development project. Figure 2(c) shows the same matrix as in Figure 2(b) but after partitioning which illustrates the tasks as in series, parallel and coupled or iterative. Tasks in series can be executed sequentially while parallel tasks are executed concurrently. Coupled tasks require advance planning by determining which task should start the iteration process based on an initial estimate or guess value of a missing piece of information. For example in Figure 2(c), the block consists of tasks E, D and H can be executed as follows: task E starts with an initial guess value on H's output, then E's output is fed to task D and D's output is fed to task H and finally H's output is fed to task E . Up to this point, we have to check how far the initial guess value of H deviated from the latest value received from task H. This iterative process continues until convergence occurs. Same process has to be considered within a design project for other coupled blocks too.

Production Configuration: Production configuration is a planning tool intended for manufacturing and selling complex products according to customer's choice and need. It helps true mass customization through increased part commonality, enabling assembly-to-order and requiring less sales personnel (Helo & Kyllönen, 2007). It contains different manufacturing databases needed for operational activities for product development. A production configuration defines and manages all aspects of manufacturing a product. Production configuration can be populated according to the requirements of customized products. The configuration itself collects necessary task sequences or schedules from the DSM tool and passes to the production department for necessary operations to fabricate the products. In this way, product development lead time will be decreased substantially. A badly designed production configuration system leads to decrease customer satisfaction that results low sales ultimately.

4. The Application of DSM in Managing Volvo Design Rules: An Example

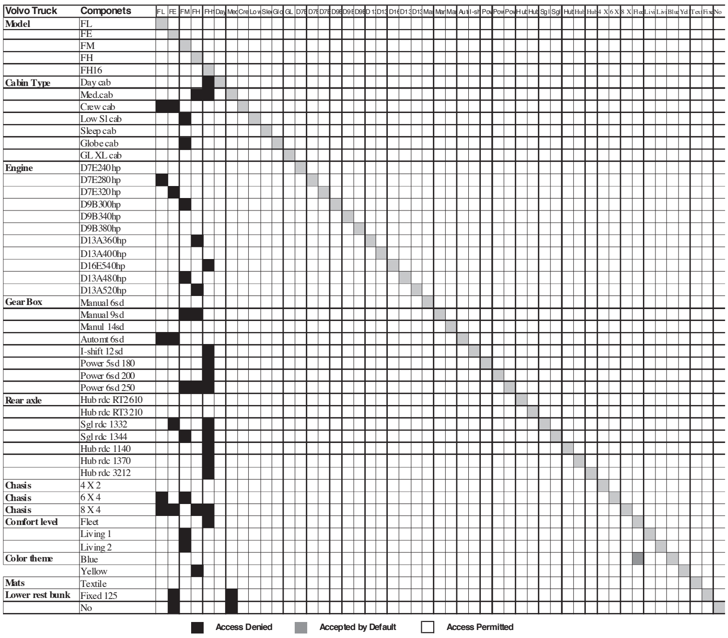
The example stated below is taken from the ongoing CATER project, an EU funded project aiming at networked business and mass customization in the automotive industry. The world leading automobile company Volvo is one of the partners of the project from which this example is taken from. AB Volvo / Volvo Group is a Swedish company dealing with motor engine manufacturing founded in 1927. Its customers are active in more than 180 countries worldwide, mainly in Europe and North America as well as to a considerable extent in Asia too. During 2006, the Group's workforce rose to more than 90,000 employees in 58 countries. The majority of employees are based in Sweden, France and US and its sales increased to nearly SEK 250 billion in 2006. Volvo Company produces cars, buses, trucks, marine engines, aero engines and construction equipment. This example is taken from the Volvo trucks configurator where different models of trucks can be customized according to customers' choice with some predefined restrictions.

This configurator was developed within CATER project by collecting answers resulting from interviewing of truck drivers and truck owners from their choices and preferences for the different expected features and parameters within a truck (Kyllönen & Helo, 2007). This configurator maintains different design rules from which customers have to choose their own model according to specific functions and design parameters. From this configurator, customers are also able to see the costing of their chosen models. The whole configurator consists of 268 design rules among which 24 are presented in Table 1 (see appendix) as an example. These rules can be presented in a more simplistic and compact visual way by using DSM as shown in Figure 3 below.

The DSM in Figure 3 delicately representing the various design rules necessary for manufacturing the Volvo Company's different models of trucks. From Figure 3, we can easily find out the different restrictions of choosing a model according to customers' requirements. This figure also demonstrates how DSM can be used as an organized tool for representing the design rules contains in Volvo Company trucks. The black color boxes within the DSM represent the denial of a particular feature of an engine model, whereas deep gray boxes are the set value by default and white boxes indicates the acceptance of the rules.

For example, let us consider rule 1 which explains that if model FM is selected by any customer, he/she won't be able to get Globetrotter type of cabin and upper rest bunk of narrow-1. In a similar fashion if

Figure 3. Application of DSM for representing the design rules of Volvo company trucks



anyone select model FH 16 for instance, he/she could not be able to get comfort level 'fleet', 'day cab' and 'medium cab' type cabin; but he/she can be able to choose from other available alternatives such as comfort level of 'ease', 'comfort', 'living 1' etc. and cab type of 'crew', sleeper etc. from the data base. In this simplistic way, DSM can be used to represent these rules in a brief matrix format rather than maintaining pages of documents. A designer or customer will be able to choose among different alternatives; being in mind too that he/she may not be able to choose all but with some restrictions. In this brief representation among alternatives help manufacturers to customize their products in a nice and easy fashion. The DSM in Figure 3 represented only few design rules among many as an example of Volvo Company trucks manufacturing.

The Volvo trucks configurator contains 268 design rules for customers' choice. These rules restricted the choice of the customers from various alternatives. These rules can be demonstrated in compact way by using DSM. The main problem arises here to figure out all the necessary design features/components in a single DSM. There are 188 different parts or components presents in Volvo trucks configuration, which are interrelated with various design rules or restrictions. These rules are also connected with Bills of Materials (BOM) that contains 190 components or parts.

In product customization, customers' choice may be guided for their benefits and saving time to choose the products efficiently. For example, in Volvo trucks configuration if a customer choose a truck model of FH16 without knowing the available features for it, he/she may be in trouble. To avoid this cumbersome, it is better to have a guideline or sequential steps to choose a product. For example, in Volvo trucks configuration, after selecting a particular model brand, the customer need to follow the sequence such as: engine, gear box, chassis, cabin type, front axle, rear axle, resting, storage etc. respectively to save time and energy. Otherwise, the customer may be failed to choose that particular model as some type of cabin he/she has chosen for, may not fit for that model according to design specification.

Along with the application of Volvo design rules, DSM could also be used to organize the information dependency among design elements. For the demonstration purpose, we have taken different design elements and their information dependencies from Volvo trucks configuration, which are presented in a matrix format in Figure 4. These data were collected after interviewing among Volvo design teams and populated in Volvo trucks configurator. Figure 4 shows the inter-dependency among different components/parts of the Volvo trucks. These dependencies are expressed in terms of number '1' but also could be presented by 'X' as the symbol. For example, the first task 'truck model' depends on information from cabin type, engine type, assembled chassis and assembled cabin which are presented by marks '1' along row while 'truck model' also passes information to cabin type, engine type, rear axle, chassis, transmission, assembled chassis, assembled tire set, resting package and assembled cabin that presented by marks '1' along column. From Figure 4 it is counted that there are 59 feed forward marks above diagonal that causes costly iterations or feedbacks and need to eliminate or minimize as much as possible by moving them from above diagonal area to lower diagonal area. This can be done by changing individual rows and columns accordingly, named as partitioning (Eppinger et al., 1994).

After manual partitioning, the feed forward marks above diagonal area are reduced from 59 to 37, which show an improvement in design architecture and presented in Figure 5. From Figure 5, we also observed the presence of five clusters or modules, which indicate the possibilities for formation of cross-functional, integrated teams to facilitate the most intensive coordination among components/parts. For instance, cluster with cabin body, transmission, front tire, front rims, rear tire, rear rims could fabricate together as all the components are closely related with each other. Formations of such clusters help designers to concentrate with the specific area in design and visualize the dependencies in more compact format.

5. Relationship among Customer Needs, Design Elements and Organizational Implications

From managerial perspective, it is realized that product development process is a way of handling complexity, uncertainty and ambiguity. There are no easy and exact answers to design and organize cross-

Figure 4. A DSM showing different design elements and their relationships of Volvo Company trucks (before sequencing and clustering)

Name		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
Truck Model	1	1	1	1																					1							1
Cabin type	2	1	2															1					1				1					1
Engine type	3	1		3		1											1								1							
Gear box	4			1	4	1																										
Rear axle	5	1		1	1	5																										
Color theme	6						6	1						1									1									
Comfort level	7		1				1	7			1																		1			
Mats	8							1	8														1				1					
Office	9		1							9													1					1				
Resting	10		1								10												1				1		1			
Storage	11											11											1							1		
Kitchen	12												12										1				1					
Entertainment	13						1				1			13										1								
Other	14														14																1	
Chassis	15	1	1													15									1	1						1
Transmission	16	1		1	1												16															
Cabin body	17		1															17	1				1		1		1					1
Front tire	18		1													1		1	18		1				1							1
Rear tire	19															1				19		1			1	1						
Front rims	20															1			1		20				1							
Rear rims	21															1				1		21			1	1						
Cabin interior	22		1				1	1	1	1		1	1					1					22				1	1	1	1		1
Audio package	23		1											1									1	23			1					
Assembled chassis	24	1														1									24	1						1
Assembled tireset	25	1														1		1	1	1	1	1			1	25						
Cabin equipment	26		1																				1				26		1	1		1
Office package	27		1						1	1													1					27				1
Resting package	28	1		1							1												1						28			
Storage parts	29											1											1							29		
Other equipment	30														1																30	
Assembled cabin	31	1	1							1	1		1			1							1	1	1			1	1			31

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Figure 5. A DSM showing different design elements and their relationships of Volvo Company trucks (after sequencing and clustering)

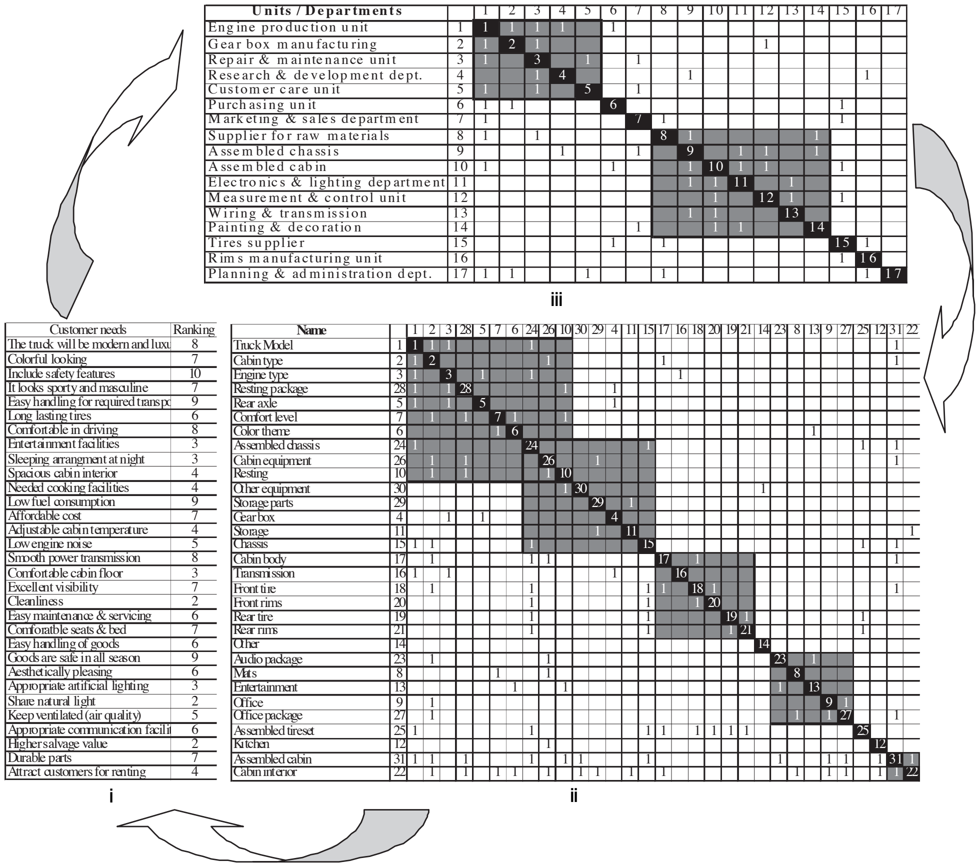
Name		1	2	3	28	5	7	6	24	26	10	30	29	4	11	15	17	16	18	20	19	21	14	23	8	13	9	27	25	12	31	22
Truck Model	1	1	1	1					1																						1	
Cabin type	2	1	2							1							1														1	
Engine type	3	1		3		1			1									1														
Resting package	28	1		1	28						1			1																		
Rear axle	5	1		1		5								1																		
Comfort level	7		1		1		7	1			1																					
Color theme	6						1	6																		1						
Assembled chassis	24	1							24							1													1		1	
Cabin equipment	26		1		1					26			1																		1	
Resting	10		1		1					1	10																					
Other equipment	30										1	30											1									
Storage parts	29												29		1																	
Gear box	4			1		1								4																		
Storage	11												1		11																	1
Chassis	15	1	1						1							15													1		1	
Cabin body	17		1						1	1							17		1												1	
Transmission	16	1		1										1				16														
Front tire	18		1						1							1	1		18	1											1	
Front rims	20								1							1			1	20												
Rear tire	19								1							1					19	1							1			
Rear rims	21								1							1					1	21							1			
Other	14																						14									
Audio package	23		1							1														23		1						
Mats	8						1			1															8							
Entertainment	13							1			1													1		13						
Office	9		1																								9	1				
Office package	27		1																						1		1	27			1	
Assembled tireset	25	1							1							1	1		1	1	1	1							25			
Kitchen	12									1																				12		
Assembled cabin	31	1	1		1				1		1	1				1								1			1	1		1	31	1
Cabin interior	22		1		1		1	1		1		1	1		1		1								1		1	1		1	1	22

functional teams, components and tasks structuring in a concurrent engineering environment. However, coordination and continuous flow of information among different departments, product architecture and customers help to reduce managerial hierarchy and developmental complexities. DSM methodology provides inter-domain communication in a structured way to meet the schedule of the entire development program. This could guide managers to give special attention to complex sectors of the developmental program and enhanced prioritization of the coordinated work for on time delivery.

For any product development project, the interrelationship among design elements, organizational departments and customers' preferences are very much essential to have a holistic approach to solving problems. Before launching any product/service in market, it is essential to identify and prioritize customers' taste, planning managerial implications and product architecture accordingly to satisfy those customers. There is often a poor connectivity and lack of information exchange especially in multi-disciplinary design environment among customers, management personnel and designers. An improved capability of information exchange provides organizational managers with highly improved decision support system and visibility among developmental teams, which facilitate the reduction of uncertainty and ambiguity in product development projects.

To demonstrate the information exchange and dependency among inter-organizations and customers preferences, we have taken an example from Volvo company trucks manufacturing which is shown in Figure 6 below. Here a dependency mapping among customer needs, design tasks and departments in the functional organization are presented using DSM methodology. Figure 6 (i) illustrate the customers' requirements matrix with a ranking of 1 to 10 where 1 indicates lowest and 10 as highest level of priority. Figure 6 (ii) shows a product architecture DSM where five clusters (shaded area) exits with highly related components. These clusters indicate five modules, which creates cross-functional integration teams. For instance, first cluster/module contains truck model, cabin type, engine type, resting package, rear axle, comfort level, color theme, assembled chassis, cabin equipment and resting are highly dependent on each other for information and could form single developmental team to reduce lead-time and the same principle is applicable to other modules too.

Figure 6 Relationship mapping among (i) customer needs (ii), product architecture and (iii) organizational departments



The DSM in Figure 6(iii) shows a departmental interdependency among organization that sorted for two major clusters. These clusters indicate the possibilities for developing cross-functional, integrated teams to facilitate the most intensive interdepartmental coordination. After sorting out the dependencies among functional departments, product architecture and customers requirements, an integrated mapping was developed as shown in Figure 6 to meet the schedule of entire development program. From this relationship mapping, a concise format of inter-dependencies are obtained, which provide managers to coordinate their tasks among departments and design teams to prioritize customers choice and desire. In terms of managerial perspective, some areas could be identified through this relationship mapping where special attentions might be needed for efficient problem solving. This also reflects the dynamic of product development process and enables transformation and traceability of information in one domain to another.

6. Influence of DSM on Mass Customization

Growing trends towards globalization of markets, increasing demand on customized products and services have influenced firms to manage properly the complexity of product development processes.

Manufacturing firms are facing continuous challenges for producing customized products that contributed mass customization. This changing strategy forcing them to offer as many product varieties as possible in order to earn more revenue and higher customer satisfaction. However, to manage product variety is especially costly and time consuming. To mitigate this complexity and cost, firms can adopt several strategies such as modularity, component commonality, standardization and so on. Among them modularity can be useful to reduce the time, cost and complexity of manufacturing.

Application of DSM methodology provides formulation of modules creation after analyzing the strength of interactions or dependency among components/parts. These modules create smaller sub-systems, designed and developed independently and able to function properly when assembled and tested with the end product. Formation of modular based design and development enhances customized products, as it is easy to assembled different modules together to form a final product or model according to customers' own choices and preferences. Modular design can then be helpful to bring varieties among product development activities through shorten lead-time, reduced cost and increased performance. Using available DSM tools, it is quite accurate and fast to form optimum numbers of modules/clusters within a design project, which in tern helps to manufacture custom-built product.

Not only for modular design, DSM also helps to standardize components/parts by investigating product architecture within a family of products. After analyzing different tasks within a product family by using DSM tool, it is quite easy to identify the common components, which could be fabricated as standard ones. These standard components facilitate product development process by reducing lead-time and increasing product variety. Standardization enhances customization approach through allowing highly differentiated products within short span of time and with reduced cost, that brings higher customers satisfaction.

In recent days, applicability of DSM is ever increasing on several fields of industrial and service sectors. Industries are benefited from this methodology by taking consideration of information exchange among various tasks, which is very much crucial to develop product with higher quality and increased satisfaction. This pattern of information exchange guides designers to understand the functionality of product architecture that customers want. It is also ensures early customers involvement in any product design and development process and organizes various developmental activities in proper order or sequence.

7. Managerial Implications

From a managerial perspective, this paper pointed out the dynamics of mass customization and presented a framework for analyzing different design elements that guide managers to give special attention on customized product development activities. The framework presented here is broadly based on the integration analysis of customized products. It focuses basically with the integration of sophisticated method DSM for customized product design and development, which also increases the visibility of design dependencies that enables more efficient problem solving. DSM provides a more quantitative and analytical approach for mass customization and product design strategies.

In business, product customization can be aided by giving attention to product modularization, part commonality, product family architecture (Tseng & Jianxin, 1998). The inherent nature of mass customization lies in maximizing the suitability of manufacturer's capabilities and correspondingly develops its technical capabilities to meet diverse customers' choices. The integration between design and manufacturing produces a better and simpler product, which is easier and cheaper to manufacture and in the meantime maximizes customers' value with gaining competitive challenges. The requirements of mass customization depends on three aspects such as; time to market, variety and mass efficiency to keep the manufacturing cost low (Tseng & Jianxin, 1998).

This paper also outlines the application of different design rules of Volvo company truck by using DSM, which help customers to guide their choices and shows an integrated customer oriented mapping for truck manufacturing. This mapping illustrates how to coordinate among different customers' priority, design components and logistics departments. It puts focus on inter-dependencies and need for information exchange between customers, organizational units and design teams. This cyclic information exchange facilitates project managers to get an insight view before implementing any PD projects.

8. Conclusions and Future Research

Mass customization (MC) has become an important manufacturing reality in today's business environments. Agile product development and quick responsiveness to changes have become very important for manufacturing firms due to market globalizations, rapid technological innovations and intense competitive pressures. MC is a manufacturing and supply chain management strategy that allows individually designed products and services to customers. It is very important to know the preferences of customers, as customers are more or less inclined toward different types of customized products or services (Guilabert and Donthu, 2006). In mass customization approach, customers participate directly/indirectly into the product design and development phase, taking advantages of design-to-order scenarios. It guides a designer in a more negotiable way and directs the selection of component /parts of products smoothly.

In this paper, we have presented an integrated framework using DSM as an advanced product development tool for manufacturing customized products. This framework depicts the relationship mapping among customers' participation and different design elements required to produce tailored end customized products. In this framework, DSM tool plays a critical role in reducing developmental lead time. DSM is a tool that is used for not only sequencing or reordering different design tasks but also clustered tasks, depending on tasks closeness and dependencies. This clustering phenomenon facilitates building blocks termed as modules. The creations of modules are the critical design elements necessary for making customized or individualized products or services rapidly and economically. Along with DSM tool, this framework also accommodates Bill of Materials (BOM), CAD model, product data base, production configuration which are necessary for quick responsiveness to customers demand. Besides this framework, different mass customization features such as; product platform design, parts commonality, modularization, configuration for products and processes, product family are also briefly explained.

In mass customization, customers participate actively in product developmental phases, which create value for the products itself. In this respect, manufacturing firms are increasingly engaging in mass customization and offering customers a menu of choices of alternative features and options for configuring their own products and / or services they needed. A Volvo company configurator for different trucks models has been provided in this paper as an example, from which customers can choose their models accordingly with price list too. This configurator is populated with different design rules necessary to customize a specific model or brand. These rules have been presented in this paper in a more simplistic and compact visual way through using DSM tool. Along with the configurator, the presentation of various design rules using DSM, would guide customers for their choices with some restrictions.

MC is highly dependent on well designed information structure, which creates direct link between customers, manufacturers and management personnel. This relationship mapping is crucial for any development organization to produce customized products. To demonstrate this information exchange, a relationship mapping among customer requirements, organizational implications and design elements are presented in this paper to identify and prioritize the interdependencies among them. This integrated relationship mapping presents the situational visibility to the management organization. This mapping leads to minimize the product development lead time through better coordination and control among design teams, developmental groups and customers priorities. The idea behind this information flow mapping is to facilitate the customized product developments, which are facing challenges of keeping mass producibility and profitability with higher quality.

Further research could be carried out to upgrade the presented integrated framework by adding more design modules such as supply chain management systems, production planning and control strategy etc. to make it more flexible and user friendly. It is also observed that in this paper we could not able to accommodate all 268 design rules for Volvo trucks configurator using single DSM but only 24 due to the constrain in DSM design. In future research, an extension could be done to accommodate all these design rules in single DSM by developing suitable programming software to overcome this problem. Another extension could be done by investigating how DSM tool can be applied for designing common platform for a family of products. The management of platform technology evolves for creating more product varieties which enhances mass customization approach. Components commonality or standardization also could be studied further by applying the DSM methodology. It would be helpful for minimizing or reducing components used for several products within a family.

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Appendix

Table 1 Design rules of Volvo Company for manufacturing trucks

1.	IF Model < FM - FM ==> DENY Cabin type >= Globetrotter Cab - Globetrotter Cab AND DENY Upper rest bunk = Narrow – 1
2.	IF Model != FL - FL ==> DENY Cabin type = Crew Cab - Crew Cab
3.	IF Model > FE - FE ==> DENY Cabin type = Crew Cab - Crew Cab
4.	IF Model = FL - FL ==> DENY Chassis = 6X4 - 6X4 AND DENY Chassis = 8X4 - 8X4
5.	IF Model = FE - FE ==> DENY Chassis = 8X4 - 8X4
6.	IF Model = FM - FM ==> DENY Chassis = 6X4 - 6X4
7.	IF Model = FH - FH ==> DENY Chassis = 8X4 - 8X4
8.	IF Model = FH16 - FH16 ==> DENY Chassis = 8X4 - 8X4
9.	IF Model != FM - FM ==> DENY Side document box = Yes - 1 AND DENY Front document box = Yes - 1
10.	IF Model <= FE - FE ==> DENY Air Conditioning = Automatic - Automatic
11.	IF Model <= FE - FE ==> SET DEFAULT Air Conditioning None - 0
12.	IF Model != FM - FM ==> DENY Comfort level = Living 1 - Living 1 AND DENY Comfort level = Living 2 - Living 2
13.	IF Model = FH16 - FH16 ==> DENY Comfort level = Fleet - Fleet AND DENY Cabin type = Day Cab - Day Cab AND DENY Cabin type = Medium Cab - Medium Cab
14.	IF Model != FM - FM ==> DENY Cabin type = Low sleeper Cab - Low sleeper Cab
15.	IF Model = FH - FH ==> DENY Cabin type = Medium Cab - Medium Cab
16.	IF Comfort level = Fleet - Fleet ==> SET DEFAULT Interior colors Blue - Blue
17.	IF Model < FH - FH ==> DENY Mats = Textile - Textile
18.	IF Comfort level = Fleet - Fleet ==> DENY Instrument panels = Wood - Wood AND DENY Instrument panels = Metal – Metal
19.	IF Model = FE - FE AND Cabin type = Medium Cab - Medium Cab ==> DENY Lower rest bunk = Fixed 125 - Fixed 125 AND DENY Lower rest bunk = No – 0
20.	IF Model = FL - FL ==> DENY Engine > D7E 280hp - D7E280 AND DENY Gear box > Automatic 6-Speed - Automatic 6 AND DENY Rear axle > Hub reduction 1140 - RSH1140
21.	IF Model = FE - FE ==> DENY Engine > D7E 320hp - D7E320 AND DENY Gear box > Automatic 6-Speed - Automatic 6 AND DENY Rear axle < Single reduction 1332 - RSS1332 AND DENY Rear axle > Hub reduction 2180 - RTH2180
22.	IF Model = FM - FM ==> DENY Engine < D9B 300hp - D9B300 AND DENY Engine > D13A 480hp - D13A480 AND DENY Gear box < Manual 9-Speed - Manual 9 AND DENY Gear box > Powertronic 6-Speed 250 - Powertronic 2506 AND DENY Rear axle < Single reduction 1344 - RSS1344 AND DENY Rear axle > Hub reduction 3212 - RTH3212
23.	IF Model = FH - FH ==> DENY Engine < D13A 360hp - D13A360 AND DENY Engine > D13A 520hp - D13A520 AND DENY Gear box < Manual 9-Speed - Manual 9 AND DENY Gear box > Powertronic 6-Speed 250 - Powertronic 2506 AND DENY Rear axle < Hub reduction 1370 - RSH1370 AND DENY Rear axle > Hub reduction 3212 - RTH3212
24.	IF Model = FH16 - FH16 ==> DENY Engine < D16E 540hp - D16E540 AND DENY Gear box < I-Shift 12-Speed - I-Shift 12 AND DENY Gear box = Powertronic 5-Speed 180 - Powertronic 1805 AND DENY Gear box = Powertronic 6-Speed 200 - Powertronic 2006 AND DENY Gear box = Powertronic 6-Speed 250 - Powertronic 2506 AND DENY Rear axle = Single reduction 1125 - RSS1125 AND DENY Rear axle = Single reduction 1132 - RSS1132 AND DENY Rear axle = Hub reduction 1140 - RSH1140 AND DENY Rear axle = Single reduction 1332 - RSS1332 AND DENY Rear axle = Single reduction 1344 - RSS1344 AND DENY Rear axle = Hub reduction 1370 - RSH1370 AND DENY Rear axle = Hub reduction 2180 - RTH2180 AND DENY Rear axle = Hub reduction 2110 - RTH2110 AND DENY Rear axle = Hub reduction 2610 - RTH2610 AND DENY Rear axle = Hub reduction 3210 - RTH3210 AND DENY Rear axle = Hub reduction 3212 - RTH3212

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Restructuring design processes for better information exchange

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Abstract: Today's competitive business environments are changing dramatically owing to growing customer demands and higher technological innovation. The success or failure of any enterprise depends fully on how quick it can respond to customer demands and adapt to newer technology. The adoption of matrix-based tools such as design structure matrix, domain mapping matrix, multi-domain matrix could enhance the information exchange among product development (PD) activities that are required for rapid deliver to market. In this paper, one example is presented in order to demonstrate the applicability of different matrix tools to control information dependencies among PD processes.

Keywords: communication pattern; design structure matrix; domain mapping matrix; enterprise development; information exchange; multi-domain matrix; product development.

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1 Introduction

Because of globalised economy and fierce competition, business firms are forcing nowadays to market their products quicker than ever. This is owing to the shorter product life cycle and growing customers' tastes and aspirations. Faster product development (PD) process can provide a source of competitive advantage (Meyer and Utterback, 1995). To response quickly with this changing environment, it is crucial to reduce PD lead-time while maintaining higher quality and reduced price. Managing PD process is a challenge for the manufacturing industry owing to the unpredictable nature of engineering design, where design iterations are a pervasive phenomenon. Such complexities also arise depending on its functional requirements, forms and integration to different development tasks, people, teams and organisations and with their inter-relationships (Danilovic and Browning, 2007). Managers find it very hard to control these complexities and uncertainty during PD phases.

Today's manufacturing firms are working hard to reduce PD lead time and they are facing a growing number of concerns such as production complexity, resource consumption, future up-gradation, maintenance and recycling (Smith and Eppinger, 1997). Generally, PD project consists of large number of complex activities and interdependencies that might require coordination among hundreds or even thousands of resources from various disciplines. The tasks or activities from one resource pull could affect many other developmental decisions throughout an organisation. As complexity increases, it becomes very difficult to manage the interactions among various developmental resources. It may be even impossible to predict the impact of single design change throughout the development process (Eppinger et al., 1994). The engineering complexity of a design is simplified by decomposing the design process into smaller engineering tasks and the assignment of these tasks to individuals (Kusiak and Park, 1990; Steward, 1991). Coordinating design decisions have therefore become a crucial responsibility for engineering management.

PD processes are generally characterised as information flow among different development activities. This information flow creates complex loops that can be viewed within a complex system. Information creation and exchange is the lifeblood of a PD process. A powerful way to increase the understanding of the PD process is to look at its information exchange among tasks/activities and their inter-relationships. Information is an important resource for any manufacturing firm to develop its product successfully. Firms must rely on their ability to use accurate and timely available information effectively. The more accurate and on time the information is, the less time that is needed to develop a product with reduced cost. This research deals with the management of information flows among product design and development-related activities by using matrix tools such as design structure matrix (DSM), domain mapping matrix (DMM) and multi-domain matrix (MDM) developed by Steward (1981), Danilovic and Börjesson (2001) and Maurer (2007), respectively. These tools can be used for showing dependencies among PD tasks, components and resources in compact and visualise the matrix format that is widely applied in the fields of aerospace, automobile, service industries and so on.

Complex PD project often requires hundreds of participants from diverse backgrounds that result in critical relationships among both people and tasks. Traditional project management tools such as PERT, Gantt, CPM, etc. do not address this problem stemming from such complexity (Ross, 1977; Spinner, 1989). These tools allow project and organisational managers only to model sequential and parallel tasks or activities but not suitable for coupled or interdependent tasks, where a set of tasks is dependent on each other for information to be executed. They provide a simplified view of project activities using precedence network models but are unable to capture the iterative or feedback nature of the development processes, which are common in complex PD projects (Browning, 1998). In this situation, matrix-based tools such as DSM, DMM and MDM are developed, which could provide this coupled representation in a simple and elegant way. These matrix-based techniques have proven to be effective tools for planning and managing complex PD projects through information flow analysis (Maurer, 2007).

The objective of this research paper is to identify and demonstrate the management of information flows among PD activities and resources in order to develop quality products more quickly and economically. Such an improved way of information flow could offer the opportunities to speed up PD processes through enhancing better coordination and communication among different design elements. The paper is organised as follows: Section 2 outlines the overview of matrix-based modelling approach while Section 3 discusses the research theme and methodology. An example of information flow is cited in Section 4 and some limitations of the matrix-based approach are expressed in Section 5. In Section 6, several managerial implications are discussed while the paper concludes in Section 7 with some research outcomes.

2 Overview of matrix-based modelling approach

Manufacturing firms are facing growing complexity and uncertainty locally and globally owing to newer technologies and increased variation of customers, markets and organisations. It is therefore, crucial for firms to develop efficient problem-solving methodologies in order to organise their developmental tasks and corresponding resources to complete their end products. PD process is considered as a dynamic system where there are strong dependencies among domains such as product specifications, architectural designs, manufacturing processes, customer's requirements and suppliers' integrations. Each domain contains its own architecture and information dependencies that are glued within and between domains. It is therefore, highly important to manage these information flows in order to solve problems such as organising cross-functional teams, designing product architectures and manufacturing processes.

There are always interfacing and dependencies among product architecture, departments in the organisation, different on-going projects and so on where various information need to be shared with one another in order to solve problems (Danilovic and Browning, 2007). The information is the glue that holds any development process together and need to follow up this information exchange for a firms' success. Several information-driven tools such as DSM, DMM and MDM can be used to focus the interdependencies between items or different domains such as components in the product architecture, tasks in the processes and people in the cross-functional teams. These matrix-based tools help to focus on result analysis on interdependencies, interactions and exchange information within and across domains. Each of the tools is discussed in brief in the following and their comparisons are also presented in Table 1.

2.1 Design structure matrix (DSM)

The DSM is a compact representation of the information structure of a design process. This method differs from conventional project management tools in that it focuses on representing information flows of a design project rather than the work flows (Eppinger, 2001). It is a useful method for the analysis of a design process and for minimising the feedback loops that create time-consuming iterative subcycles. This methodology demonstrates how the sequence of design tasks could be represented as a network of interactions (Steward, 1981).

Table 1 Comparison of matrix-based tools

Specifications	*DSM*	*DMM*	*MDM*
Dependency type	Single domain	Two domains	Three or more domains
Matrix type	Square matrix	Square and rectangular matrix	Square
Directional dependency	Single directional	Bi-directional	Tri-directional and more
Application technique	Sequencing, clustering	Clustering	Clustering
Partitioning algorithm	Triangularisation, clustering of blocks along the diagonal	Clustering of items	Clustering of items
Integration analysis	Sequencing, minimising feedback loops, clusters of items	Clusters of items, dependencies or interface identification	Clusters of items, dependencies or interface identification
Representation	Information flow between components vs. components, organisations vs. organisations, etc.	Information flow between components vs. specifications, product architecture vs. operational processes, etc.	Information flow among components vs. architecture vs. operational processes, etc.

Figure 1 shows an example of a DSM presentation where 'X' symbols represent the information dependencies with each other. Reading across a row shows the tasks whose outputs are required to perform the task corresponding to the row. Reading down a column indicates the tasks that receive information from the task corresponding to the column. For instance, from Figure 1, it is seen that the component 'cabin body' needs information from the 'cabin equipment' and 'cabin interior' to be completed and it passes information to the components, 'final assembly', 'chassis', 'cabin equipment' and 'cabin interior'. Upper diagonal marks indicate feedback while lower diagonal marks indicate feed forward.

Figure 1 Example of a DSM (without partitioning)

Truck Components		1	2	3	4	5	6	7	8	9	10	11	12
Final assembly	1		X	X	X								
Cabin body	2					X	X						
Chassis	3		X		X			X		X			
Engine	4											X	X
Cabin equipment	5		X										
Cabin interior	6		X										
Front axle	7								X				
Front wheel	8							X					
Rear axle	9										X		
Rear wheel	10									X			
Transmission	11				X								
Engine equipment	12				X								

Figure 2 Example of a DSM (with partitioning)

Truck Components		5	2	6	11	4	12	8	7	10	9	3	1
Cabin equipment	5		X										
Cabin body	2	X		X									
Cabin interior	6		X										
Transmission	11					X							
Engine	4				X		X						
Engine equipment	12					X							
Front wheel	8								X				
Front axle	7							X					
Rear wheel	10										X		
Rear axle	9									X			
Chassis	3		X			X			X		X		
Final assembly	1					X	X					X	

Modules

In order to minimise the feedback marks or loops, rows and columns of Figure 1 are rearranged (known as partitioning) as displayed in Figure 2 (Steward, 1981; Eppinger et al., 1994). In Figure 2, the feedback marks are reduced from 12 to 6 and 4 iterative modules or clusters are formed. These modules indicate the interdependencies among the components within a module and could be performed together separately that reduces complexities and development time.

2.2 Domain mapping matrix (DMM)

DMM is a rectangular two-dimensional matrix tool used to represent and analyse dependencies and relationships between two different domains (Danilovic and Börjesson, 2001). This tool provides a clear representation of complex systems and visualises the interactions across two different domains where the rows represent nodes of one domain and the columns represent the nodes of another domain. Combination of both DSM and DMM methodologies offer enriched result and provide an expanded view of any system (Danilovic and Sandkull, 2005). Figure 3 shows the example of a DMM after partitioning or clustering where rows indicate the different components and columns represent the various departments. There are four clusters or modules formed that could be collocated and worked together to save time.

2.3 Multi-domain matrix (MDM)

The MDM methodology is an extended version of DSM and DMM methods that includes three or more different domains and multiple relationships (Maurer, 2007). It can store multiple relations in the same matrix, that is, the matrix is not flat like DSM or DMM. This matrix approach provides methodical support for managing complex design processes by considering all the domains involved. It is a square matrix like DSM that contains system elements in an identical order on both rows and columns and can be represented as a DSM on higher level of abstraction. Figure 4 shows the basic dependent relationships within a multi-domain matrix. The information exchange among the different domains enhances smoother product or project development processes that contribute to the minimisation of the developmental lead time (Maurer and Lindemann, 2007). All the matrix tools as discussed before can be compared and summarised as shown in Table 1.

Figure 3 Example of a DMM analysis (after partitioning)

Component versus Department/unit (DMM)	Engine manufacturing	Gear box supplier	Repair and maintenance	Purchasing unit	Customer service	Raw materials supplier	Wheel supplier	Rim manufacturing	Cabin assembly	Chassis manufacturing	Marketing and sales	Stationary supplier	Research & development	Electronics and lighting	Transmission & wiring	Painting & decoration
Truck model	X	X			X					X	X		X			X
Engine model	X	X	X				X						X			
Transmission	X	X	X				X						X	X	X	
Gear box	X	X	X										X			
Chassis	X		X	X		X	X		X	X		X	X		X	
Comfort level					X				X		X			X		
Color theme				X	X				X		X					
Kitchen unit				X		X			X		X	X		X	X	
Front wheel			X				X	X								
Front rim			X				X	X								
Rear wheel			X				X	X								
Rear rim			X				X	X								
Cabin type (model)	X		X						X	X						
Cabin body						X			X						X	X
Cabin equipment				X		X			X							
Cabin interior				X		X			X		X	X	X	X	X	X
Entertainment				X	X				X		X	X	X	X	X	
Office package				X	X	X			X		X	X		X		X
Resting package				X	X				X		X					X
Storage section				X	X	X			X			X		X		
Rear axle	X	X	X	X			X			X			X		X	

Clusters/ Modules

Figure 4 Representation of a MDM

MDM	Component	Department	Resource
Component	DSM	DMM	DMM
Department	DMM	DSM	DMM
Resource	DMM	DMM	DSM

3 Research theme and methodology

Success in any PD project is a critical managerial issue for modern manufacturing firms, especially those that are involved in technology-driven products or services. PD process is inherently complex in nature. A clear understanding of the different developmental tasks can help a firm for necessary resource requirements and for better utilisation. The coordination among these tasks is highly essential for reducing the PD lead time. Several measures could be taken to reduce the product lead time such as better sequencing, minimising task interdependency, increasing resource utilisation and better inter-unit coordination. To accommodate all these factors, an intensive information flow among the organisations is vital. The application of matrix-based tools such as DSM, DMM, MDM could successfully maintain this information flow among developmental processes effectively and efficiently. This matrix-based methodology increased the visibility among different PD processes both within the organisations and across organisations. Two research questions are outlined in this paper that are as follows.

1. What are the factors that influence the communication pattern of a PD project?
2. How can a PD project be improved by enhancing better information exchange among design elements?

The methodology that could answer these two research questions is through an extensive case study approach, based on qualitative methods. It is planned to interview the PD managers and/or project managers for the necessary tasks or components required for the end products and their interactions with the specified resources. The combination of both direct observation and systematic interviews/questionnaires approach will have to be taken to conduct this case study-based research. Formal interviews, informal conversations, participation in the daily life of designers or engineers and participation in management teams would be the primary methods in use. Before conducting interviews, it is important to keep in mind that all key personnel of the design team know about the entire system, its functional dependencies and consequences of changes in the various sections of the system. Some of these personnel may not have enough knowledge to the whole system but each of them has to be at least one piece of information or knowledge about different developmental subsystems.

The specific target of this work is to collect necessary data through interviews with product designers and managers of the manufacturing firms, which are required to complete an end-product after. This data might be different design tasks, parts or components, etc. and their interdependencies, organisational dependencies and could be project interdependencies too. After collecting all the required data, it will be analysed and its accuracy will be rechecked; then, the data will be populated on matrix-based tools for visualising the dependency patterns. The dependencies among different tasks, components, resources, etc. could be minimised through several operations within the matrix-based tools such as partitioning, tearing and clustering (Steward, 1965; Gebala and Eppinger, 1991; Yassine, 2004; Chen, Ding and Li, 2005). These tools are also beneficial for firms to respond quickly to customised PD by providing modular design architecture. The research methodology can be summed up as follows.

1. Interview with product designers, manufacturing engineers, workers and managers to get tasks, processes, resources and organisational dependencies to develop an end product.

2 Active participation of the PD process in order to obtain the realistic data of information flow among the PD participants.

3 Analyse the tasks, processes, resources and organisational dependencies for information exchange by using matrix-based tools such as DSM, DMM and MDM for required ordering/sequencing and clustering/grouping.

4 Matrix-based information flow: an example

As explained before, matrix-based tools provide useful information flow among different design-related elements that are required for organisation managers to control over the entire PD activities. An example is cited next in order to demonstrate the planned methodology and to understand the matrix-based tool to manage proper information exchange necessary to control the development lead time. In this example, it is explained how DSM, DMM and MDM can be applied successfully to exchange information among PD-related activities and resources. Figure 5 shows the picture of the pen and its different parts or components whereas Figure 6 shows their interactions with each other in a matrix format.

Figure 5 Different parts or components of a pen (see online version for colours)

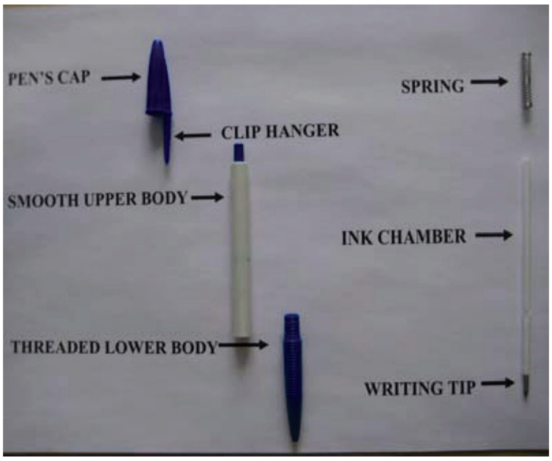

Figure 6 DSM of the pen's components

Component Vs Component	Fabricate the Cap	Fabricate the Tip	Molding Ink's Pipe	Mold & thread lower body	Manufacture of Spring	Molding upper body	Manufacture hanging clip
Fabricate the Cap						X	X
Fabricate the Tip			X	X			
Molding Ink's Pipe		X		X		X	
Mold & thread lower body		X				X	
Manufacture of Spring			X	X			
Molding upper body				X			
Manufacture hanging clip	X					X	

Figure 7 Components of DSM after partitioning

Component Vs Component	Molding upper body	Mold & thread lower body	Fabricate the Tip	Molding Ink's Pipe	Fabricate the Cap	Manufacture hanging clip	Manufacture of Spring
Molding upper body		X					
Mold & thread lower body	X		X				
Fabricate the Tip		X		X			
Molding Ink's Pipe		X	X				
Fabricate the Cap	X					X	
Manufacture hanging clip	X				X		
Manufacture of Spring		X		X			

Clusters/ Modules

Figure 8 DMM for people vs. components

People Vs. Component	Fabricate the Cap	Manufacture hanging clip	Molding upper body	Mold & thread lower body	Manufacture of Spring	Molding Ink's Pipe	Fabricate the Tip
David	X						
Steward			X				
Mark						X	
Maria		X					
Michel				X			
Kirsi							X
John					X		

From Figure 6, all the interactions can be reordered through partitioning and the output forms of the interactions are presented in Figure 7. Figure 7 shows three clusters or modules of the components that can be fabricated together in order to minimise the development time. For instance, two operations like 'moulding upper body' and 'mould and thread lower body' could be performed together in a group in order to minimise the iteration probability. This is true for other clusters too.

In order to demonstrate the information exchange among components and people, a DMM is presented in Figure 8, which shows different components and the persons responsible for fabricating them. For example, David is responsible to 'fabricate the cap', which is presented in putting an 'X' mark between the cross-sections of David and 'fabricate the cap' on the DMM and so on. In this simple way, DMM can be applied to show the inter-relationships among two different domains within a design project.

Figure 6 shows the information dependencies among components vs. components whereas Figure 8 presents the people vs. components from which a unique relationship among people vs. people could be found that is presented in Figure 9. For instance, from Figure 6 we can observe that 'fabricate the cap', for which David is responsible, requires information from 'moulding upper body', for which Steward is responsible, and 'manufacture hanging clip', for which Maria is responsible; all these are presented by the DMM in Figure 8. It is then obvious that there will be a direct relationship of David with Steward and Maria to 'fabricate the cap' of the pen and the relationship is presented on the DSM in Figure 9.

In this way, the inter-relationships among people who are required to fabricate the complete pen can be found and are presented in Figure 9. The DSM in Figure 9 could also be reordered or partitioned in order to form the necessary teams or groups required to fabricate the pen and are presented in Figure 10. From Figure 10, it is seen that Steward and Michel form a team in order to fabricate the 'moulding upper body' and 'mould and thread lower body' together, respectively and so on. In this demonstrated procedure, matrix-based tools such as DSM, DMM and MDM can be applied to reduce the PD lead time by proper sequencing and/or grouping of the developmental activities. These procedural steps also help managers in keeping track of every developmental activity and resource within the PD organisation and ensuring more visualisation of the processes involved.

Figure 9 DSM for people vs. people (before partitioning)

People Vs. People	David	Steward	Mark	Maria	Michel	Kirsi	John
David		X		X			
Steward					X		
Mark		X			X	X	
Maria	X	X					
Michel		X				X	
Kirsi			X		X		
John			X		X		

Figure 10 DSM for people vs. people (after partitioning)

People Vs Ple.	Steward	Michel	Kirsi	Mark	David	Maria	John
Steward		X					
Michel	X		X				
Kirsi		X		X			
Mark	X	X	X				
David	X					X	
Maria	X				X		
John		X		X			

Teams/ Groups

5 Limitations of matrix-based approach

Although matrix-based tools are considered to be powerful tools for representing and analysing various dependencies within a design project, there are some limitations also for their applications that can be summarised as follows.

1. In a given DSM, DMM and MDM are only sequential and parallel tasks and can be ordered by available algorithms; but, there is no methodology or algorithm for ordering the coupled or interdependent tasks.
2. Rework probabilities among tasks or domains are considered static throughout the project completion but it may also be considered to be of a dynamic or stochastic nature where the rework probabilities will change over time.
3. The task dependencies are measured by interviewing designers, engineers or managers, which might raise personal bias from the real information and always there are possibilities not to reflect the actual dependency measures. As a consequence, partitioning by matrix tools merely reflects the way by which the tasks are actually distributed among the multifunctional design teams.
4. Task overlapping is necessary in most of the design projects to reduce its lead time that cannot be displayed by using the matrix method. In the matrix representation, tasks are only presented in sequential, parallel, interdependent and coupled formats (Browning, 2001).
5. The present matrix representation accounts for only deterministic task duration and rework probabilities but cannot be displayed for dynamic behaviours where the values are changed with time.
6. The coupled blocks within a given DSM required several iterations to obtain the expected values. The probability of the iteration numbers could be added in a DSM to calculate the optimal number of iterations required for a specific design project to converge, which will also help in calculating the total time and design costs.
7. In the matrix method, the tasks are represented without showing the resources needed. It is assumed that the resources are sufficient that may not be true in a real situation. The integration possibility of the resource constraints might be investigated for further consideration.
8. The tasks within the matrix tools are expressed in a binary or cross-mark format to illustrate the dependency. Each task is described with single attribute only. It is not possible to express more than one attribute of a task in a single DSM that may often be necessary. For instance, a task 'to drill a hole' requires two attributes, radius and depth of the hole, which cannot be presented in a single DSM.
9. In matrix-based tools, only single process flow can be displayed rather than possible alternative process flows (Larson and Kusiak, 1996).
10. In order to develop accurate tasks or inter-domain relationship mapping, required data or information should have to be readily available that may not be possible all the time. Extensive knowledge and experience are also required before describing the strength of the tasks or domain dependencies between each other.
11. Substantial time and effort is needed in order to collect the required data and populate them into the matrix for necessary processing.

6 Managerial implications

In order to face fierce competition and gain market opportunities, companies need to succeed in terms of cost, quality and time to market. Efficient automated production systems and increasingly shorter product life cycle puts greater emphasis on the PD process (Clark and Fujumoto, 1991). As a consequence, the information management process has become more important for PD companies attempting to reduce their developmental time, requiring the right information at the right place at the right time throughout the entire organisation. Additionally, this information exchange needs to be distributed among the entire PD participants such as resources, departments/units, suppliers and component architecture. In order to understand and improve information processing, companies need techniques and tools to help them in modelling their operational processes (Suominen and Takala, 2006). In such cases, matrix-based tools could be a good answer to develop information exchange models among the PD participants.

The research methodology presented in this paper provides a useful approach in investigating the information flow among product architecture, development organisation and the required resources. The matrix methods are used extensively to identify the modular systems by analysing the distribution of design interfaces across system domains or boundaries. This approach captures the product architecture by documenting design interfaces, capturing the required resources by documenting team interactions and coupling the product architecture with resources by comparing design interfaces with team interactions. The presented methodology is particularly applicable to PD projects where detailed product architecture is well understood and the required resources are organised around the architecture. The type of analysis illustrated in this paper may outline organisation managers to find their specific barriers among PD projects and guide them in taking initiatives in order to mitigate them.

It is considered that PD activity is an information-processing network, which contributes to the inter-functional and -organisational terms of effective team work and problem-solving activities (Yang and Cheng, 2008). Information exchange related with communication issues encompass design and quality specifications, costing data, delivery times, material requirements, tooling and production processes. A clear overall flow of information among different design actors enables improvement of design projects through the application of appropriate coordination mechanisms for managing the existing interactions between design elements and reducing the number of interactions between design teams in order to facilitate system-level coordination. This coordination mechanism can be accomplished by a restructuring of the existing design tasks or may be through manipulation of the interactions. These simple and clear principles seem attractive ways of understanding and improving PD processes.

The aim of any PD project is to transfer valuable knowledge among resources in the early development phases (Nonaka and Takeuchi, 1995; Korany, 2007). This is performed through building the model and simulates the flow of information exchange throughout an organisation. This early flow of information provides insights into means of managing complex systems or projects, highlighting information flows, task sequences and iteration. It can help developmental teams to streamline their activities based on the optimal flow of information between different interdependent domains. These inter-domain dependencies can be managed effectively through matrix-based tools that capture the system-level knowledge of complex product architectures. Using these tools, information dependency attributes can be organised, restructured and analysed in an efficient manner to identify activity groups and sequences for concurrent execution. This analysis of information dependency can also be used to manage the effects of change.

7 Conclusions

In order to address important issues and collect the required information, it is highly useful to build and use matrix-based tools to encourage the organisation for better problem-solving. After developing a matrix-based information model, it would serve as a knowledge base or platform for continuous learning, improvement and source of innovation for a company. A matrix model can also expose a lack of appropriate and efficient information collection, interpret bottlenecks and triggers to formulate integration in an organisation. It facilitates design flexibility through increasing transparencies among design elements, simplifies design processes and information-based scheduling capability that helps in reducing the reworks both in number and length.

The matrix-based methodology supports a major need in engineering design management through information exchange among documenting, scheduling and controlling the design information. This method provides a visually powerful means for capturing, communicating and organising engineering design activities and architectural issues. Before establishing the required target specifications of products it is useful for categorising its information exchanges among its components and resources for establishing better and on-time information pattern. Successful information exchange across functional levels and the establishment of easy communication improves PD process performance and finally helps the product innovation effort by modelling, optimising and assessing its consequences.

This research work demonstrated a simple way of communication pattern among product design and development resources. It is also seen how reordering or re-sequencing improves the management of lead time for PD processes. The modular format of PD could be established easily by adopting this matrix-based methodology in any developmental activity. These matrix-based tools (DSM/DMM/MDM) enhance product or service development processes through reordering of the complex tasks and turn them into more manageable clusters or modules, which in turn help in organising tools that could concentrate on crucial business processes, which effect competitive factors, customer service, cost reduction, product quality and time-to-market.

The example cited in this paper shows the required communication pattern among the PD activities. This demonstration pattern enhances the understanding of information flow and better knowledge for controlling them. An interaction between the design elements and required resources triggers the decision-making process making it easier and offering more control over the entire system of actions. This communication system identified the weaknesses or errors within the design domain and explored them for required corrective actions. This philosophy established common goals in engineering design field which intuitively affects better and custom-designed products or services.

In future research, this cited communication pattern will be tested through an industrial establishment to justify its applicability in the organisational level. Matrix-based tools will be used to organise all the developmental activities and the required resources in an appropriate order that will contribute to the reduction or minimisation of the final PD lead time. It is hoped that this ideology will be evaluated through efficient management of information interdependencies among different tasks, components or resources that will permit organisational managers in finding optimum ways of restructuring their complex design tasks, exposing problems and creating unique solutions that could not be found simply by manually inspecting the design matrix.

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Reconfiguring product development process in auto industries for mass customisation

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Abstract: Mass customisation is today's reality in global business environment. Manufacturing firms are now in tremendous pressure to produce custom-built products/services to stay in global completion. The principle of mass customisation lies in maximising the correlations among manufacturer's technical capabilities to target market niches and in a timely manner to meet diverse customers' needs. To capture the target market niches, manufacturers need to concentrate on appropriate developmental technologies to keep production costs low, quality high and quick response. Nowadays customers' desires are to have their products quicker than before and placing an order in most convenient ways. This paper demonstrates how both product and production configuration system can be applied in global auto industries for placing an order to customised products more conveniently and efficiently. A case example from Volvo company trucks configurator is provided, which allows the integration of citarasa configurator to the basic product and production configuration system.

Keywords: mass customisation; citarasa configurator; customers need; product variety; emotional design; design structure matrix; DSM.

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1 Introduction

In today's dynamic business world, mass production strategy is no longer sufficient for gaining competitive advantages and required market share due to growing demands on customised products/services (Pine, 1997). To survive in this business environment and stay in competition, manufacturing firms have to shift from producing mass identical products to mass customised products, as much as possible, without compromising with cost and quality. Developing increasing amount of individualised products brings satisfaction to the unhappy customers, which in turn geared up firms competitive advantages for revenue earnings (Alptekinoglu and Corbett, 2004). Customer-centric industries offer unique value for their products, which bring more customer satisfaction and business growth (Piller et al, 2004). The principle of mass customisation lies in maximising the correlations among manufacturer's technical capabilities to target market niches and in a timely manner, to meet diverse customers' needs.

Mass customisation is a business planning that targets individual customer requirements with higher satisfaction, almost with the efficiency of mass production. This strategy often induces higher complexity level due to changing environment and diversified customers demands. However, customisation can contribute to reduce complexities in certain level such as; order taking process, product design and development, and inventory management (Blecker et al., 2004b). It is a relatively new theme in the business community, where individual customers' aspirations and needs might be fulfilled within the enterprise without scarifying cost and quality. The challenge of mass customisation is to build customised products as quickly and efficiently as possible. It is therefore, critical for firms to maintain a high level of coordination between customers' desires and manufacturing capabilities to produce customised products in order to minimise the developmental lead time.

The prime goal of any production enterprise is to make profits, and this can be achieved through producing the right products and services in the right time, which in turn reduce cost and reduce design and implementation times. Adoption of mass customisation principle helps companies to reduce the costly inventory and gain market segment. In customisation, the products have to be price competitive over competitors that attract new customers and higher market revenues. Besides the customised design and cost, the products also have to be higher level of productivity and quality. This interconnectivity among productivity and quality issue ensures the fundamental role of firms' operational performances (Shahin, 2008).

The objective of mass customisation is to offer customers with products that are manufactured to their aspirations and needs. To accommodate such support needs better integration of the customer into different phases of product design and manufacturing (Siddique and Boddu, 2004). In order to success in the customisation process, manufacturing firms need to leading role to integrate their customers at the very beginning of the product or service development processes (Khalid, 2006a). Customers could participate with the firm in many aspects of design, manufacturing, distribution and usage of the product or service. This ideology brings individual value creation for the products or services and helps more revenue earnings for the firms (Piller, 2005). It also ensures diversity of customers' needs and the variety of customers' demands in a more comprehensive way of considering products, which are needed to manage the complexity between customers' needs and firms' capability. However, this diversity of customers' preferences often poses a major challenge for managers to fabricate their products.

The development of communication technology enables connectivity and direct interaction possibilities among customers, manufacturers and suppliers. This collaboration and necessary information exchange among buyers (customers) and manufacturers (suppliers) have significant impacts on firms' flexibility and responsiveness for developing customised products (Squire et al., 2006). IT-based configuration process support this intrinsic information exchange among customers, manufacturers and suppliers directly. This process should iteratively generate and refine customer-focused product variants according to specific customer needs. Furthermore, it helps managers to identify as a suitable solution approach for integrating complexities faced by customers to choose among varieties, and manufacturers to organise operations and related tasks (Blecker et al., 2004a).

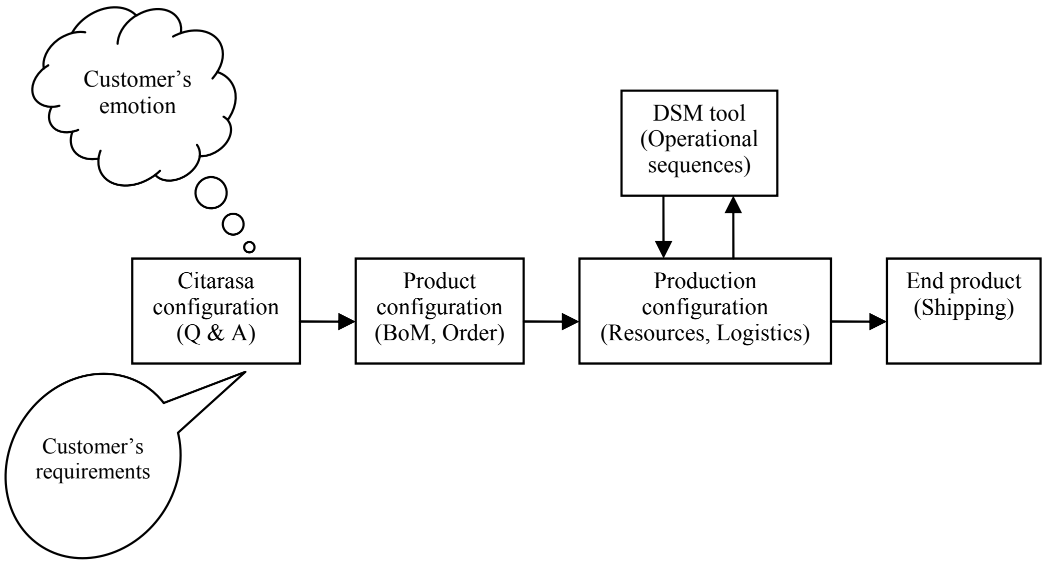
In recent days, customers' desires are changing fast and wish to have their products quicker than before and looking for convenient ways to place an order. Proper utilisation of ICT tools and methodologies might be helpful to enhance this ordering process and built a strong relationship with customers and the business processes. In this paper, we have introduced a conceptual framework in which different customers options and features are gathered using configuration systems. This framework bridges necessary information management among different segments of manufacturing company and the customer. With this network relationship, a potential customer would be able to interact with the product development phases from the early developmental process until to the shipping phase. This framework is demonstrated using a customisable truck product family.

The remainder of the paper is organised as follows. In the next section, we present the general overview of the conceptual framework and its component detailed used for mass customisation. In Section 3, we demonstrate a case example taken from Volvo Company Truck in order to present the applicability of the framework. Finally, we summarise the paper in conclusion section and discuss the future research opportunities in Section 4.

2 Conceptual framework for mass customisation

The business process is becoming more and more customer-centred networking with the collaboration of different development phases of manufacturing environment. This networked collaboration has a significant impact on developing customised product (Hsieh and Chen, 2007). This kind of business environment, configuration system for both product and production process provides a valuable insight to the firms. It accommodates customers' emotions, desires or choices directly to the production line up. A conceptual configuration framework can be outlined in Figure 1, which depicts the interrelationship between customers and product development processes. The objective of this framework is bridging the gaps among designs, manufacturing, logistics of automotive industries and sales service support into a collaborative and interactive manner. Along with different configuration systems, this framework also integrates a product development tool design structure matrix (DSM), which facilitates to organise different operational activities within a product development process.

Figure 1 Conceptual framework of configuration process



Before using any configuration software, good understanding of different customer tastes/needs are required. Until today, very few automotive manufacturers have taken up mass customised systems in their production line to gain competitive advantages. Due to lack of adequate communication mechanism, automotive industries are also impaired from meeting customer centric market demand (Tseng and Piller, 2003). The use of citarasa configurator, product configurator and production configurator will definitely help auto firms to be more customised than before. The idea behind this conceptual framework is to bring customers back to the very early value stages of product design and development according to their specific needs. This offers an enormous amount of additional flexibility among production lines to serve customers efficiently and effectively (Goodrich, 2007).

The reconfiguration concept using ICT technology to product development stages, therefore incorporate customer needs more efficiently and guide to affective/effective products that meet business opportunity (Brown, 1998). Successful implementation of the conceptual framework presented in Figure 1 can help automotive industry to uncover customer desires, tastes and preferences of vehicle models. This framework relies on customer's expertise, expressions of affective and functional needs by means of probe interviews which are then mapped to design parameters of vehicle models to generate necessary design solutions. Different elements in the framework can be described below.

2.1 Citarasa configurator

'Citarasa' is a Malay word that means 'emotional intent'. It is a combination of two words – 'cita' meaning intent, aspiration, expectation, hope and 'rasa' meaning taste, feelings and emotion (Khalid, 2006b). Citarasa configuration deals with the emotional needs of a customer. This configuration system populates data with customer demographic, general needs (behavioural, reflective, usability, feelings, etc.), functional needs (comfort level, environmental level, safety, etc.), experience and affective needs. Citarasa configurator is the software system used in configuration process where customers' general and specific needs are tabulated in a professional way. This configurator assists customers to identify their choice before they proceed to configure their own choices through product configurator. The customers have to identify their needs through answering some guided questionnaires to choose any particular products or models of their choice (Helo and Kyllönen, 2007). In this paper, we have used Volvo Company Trucks configurator as an example to demonstrate the above framework (Figure 1) where customers would be able to choose different models of trucks according their own needs after following some rules in choice. All the needs of a particular customer may not be fulfilled as there are some mapping rules.

The questionnaires within citarasa configurator were collected through interviewing with different truck drivers and truck owners to accommodate their real desires and likes for a specific model. These questionnaires were also divided for general and advanced choices according to consumers needs. General questionnaires can be described as basic elements required for any specific model such as; engine type, cabin and chassis type, etc., whereas advanced questionnaires may be included as; colour and comfort level within the cabin, smoked sun visor yes or not, coffee maker yes or not, etc. After answering these specified questionnaires, the customers are forwarded to product configurator where they may be able to find their chosen model after following some design rules.

2.2 Product configurator

Product configurator can be seen as technical enablers to support collaboration among designers and potential customers in a mass customisation environment. The main goal of this system is to share knowledge between designers and customers in order to configure customised products following the specific aspirations and needs of a specific customer (Frutos et al., 2004). Successful companies always look for eliminating unneeded time and steps from their quote to order process whilst increasing overall productivity. Product configurator allows potential customers, sales staff and design engineers to easily assemble and customise product. It is a highly interactive virtual reality interface where customers can visually configure their products and they can see the product as-is a preview of the product they may want to order. The success and effectiveness of product configuration arises from the improvement of customer satisfaction, turning him/her into a co-designer, as well as from the improvement of firms' knowledge and understanding about customer needs and preferences.

Product configurator, which is a software tool that automatically generates the customised product designs, based on the customer requirements and design restrictions (Xie et al., 2006). It enables customers to order customised products tailored to their specific desires and needs. It is also known as sales configurator increases revenues and reduces costs of production by instantaneously translating customers' unique product request into quotations, sales drawing, bills of material (BOM), routings and more. It is especially useful for manufacturing firms who produce products that are highly configurable or are routinely customised to meet the unique needs of the firms' customers (Mittal and Frayman, 1989). Customers can participate in this configuration by do-it-yourself design phenomenon through which designers can understood customers need through common semantic notation.

This configurator interfaces with customers through graphical representation of the components/product supplied with appropriate menus and choice lists containing a large number of basic BOM from which customers can enters his/her first choice of requirements. The first choice may be typically rough and incomplete but it makes the potential customers possible to get a basic idea of what the final product's features can be and to articulate his/her needs in a guided and control way. The use of configurator enhances substantial varieties without significant reductions in productivity of any firm (Helo and Kyllönen, 2007).

2.3 Production configurator

In recent days, manufacturing firms are confronting with great amount of difficulties in dealing with frequent design changes and recurrent process variations due to the growing trends of customisation. This practice interprets complexities among product development process especially on developing product families for handling diverse customer needs. To cope up with this trend of product family structure, we can apply production configuration concepts to fabricate consumers' products economically and with reduced time. Production configurator acts like product configurator where manufacturers can choose different operational scenarios to manufacture products according to customers' choices and needs.

The concept of production configuration comes from the similar ideology of product configuration system. It is a planning tool intended for manufacturing and selling complex products according to the customer's choice and need. The core of production configuration is basically the management of process platform, which is integrated with a well-defined configuration mechanism. It also contains a set of predefined configuration rules required for the selection and arrangement of proper process elements (Zhang et al., 2006). Within the existing manufacturing capabilities, this configurator arranges optimal and similar routings for producing families of product. A production configuration defines and manages all aspects of manufacturing a product. It provides the ability for complex manufactures to capture product, service and business knowledge whilst increasing overall productivity. According to the requirements of customised products, production configuration may be populated accordingly. A poorly designed production configuration system will lead to decrease customer satisfaction that ultimately results in low sales.

In production configuration system, several steps are required to manufacture any particular product within a product family or individualised product can be scheduled and managed effectively and efficiently. This configuration system run by a software known as configurator helps manufacturing engineers to plan their production systems after getting specific order from the sales person or customers via citarasa and product configurator. Within the production configurator there are different possibilities to distribute the resources/tasks required to manufacture a product along with time required for each combination and engineers have to identify the best possible ordering/sequencing of the resources/tasks after interacting with DSM tool.

Production configurator not only helps for manufacturing the products, but also aid manufacturers in todays distributed environment. Engineers take advantages in a distributed environment from this configurator to sequence their manufacturing operations following the hierarchical structure. Any conflict arises within the operational systems can be solved through negotiable attitudes with the configurator. This configurator also aids the sales personnel before placing an order to fabricate any customised products. An order from sales personnel or consumers may be denied or modified according to the availability of resources, considering time, cost and quality issues. Before accepting an order for manufacturing products, engineers have to check different operational rules and resources populated within the configurator. The order will be accepted if there are no conflict arises during receiving the order and forwarded to the necessary departments/units concern to manufacture the products otherwise, the order may be modified after consulting with the consumers.

2.4 DSM tool

In order to reduce the product development lead time, firms need to consult with available tools in the market. These tools help to organise developmental activities faster and smoother that might not be possible by doing manually. To response quickly with customers needs, product development process needs to be integrated with different available design tools among which DSM is one of them. This tool, which is designed and developed by Steward (1981) used for representing and analysing various developmental tasks or activities among a design project. It is a compact representation of the information flow to manage uncertainty in multiple product development project situations (Danilovic and Sandkull, 2005). This method differs from the conventional project-management tools, in that it focuses on representing information flows of a design project rather than on the work flows (Eppinger, 2001). This method provides a major need in engineering design management through documenting information that is exchanged. Building a DSM model of a project/system, improves the visibility and understanding of project/system complexity through information flows.

The integration of DSM tool with configuration process results in faster, flexible and cost-effective paradigm in planning product configuration process. This tool may also be used as a quick view to represent the complexity of product configurability (Helo, 2006). From the above mentioned framework, it can be seen that after getting required product specification from customers via citarasa and product configuartor, the necessary information for tasks/resources are forwarded to the production configurator. This configurator accumulates necessary tasks/resources required to manufacture that customised product but without knowing the optimal ordering or sequencing. The sequencing or optimal ordering of these tasks/resources could be accomplished through interacting with the DSM tool after partitioning and/or clustering. After doing the optimal tasks/resources ordering by DSM tool, these sequences are then feedback to the production configurator where it efficiently allocates different logistics/resources for manufacturing the product.

Not only for sequencing or ordering, DSM could also be used efficiently in the customisation process through formulating modularity in the product developmental stages. After doing optimal ordering of tasks/resources from production configuration, there may exists several coupled blocks (interdependent tasks) within the whole design project that can be considered as different modules. These modules are handled by different design teams separately and can be assembled-to-order (ATO) in quick pace of time. This interrelationship among different design teams could also be visualised and monitored through DSM tool. This compact visualisation of dependencies helps organisational management for better control of the product development strategies. In this simplistic way, DSM can be applied to optimise the production process through reduced lead time and better monitoring which in tern saves production cost and improves quality.

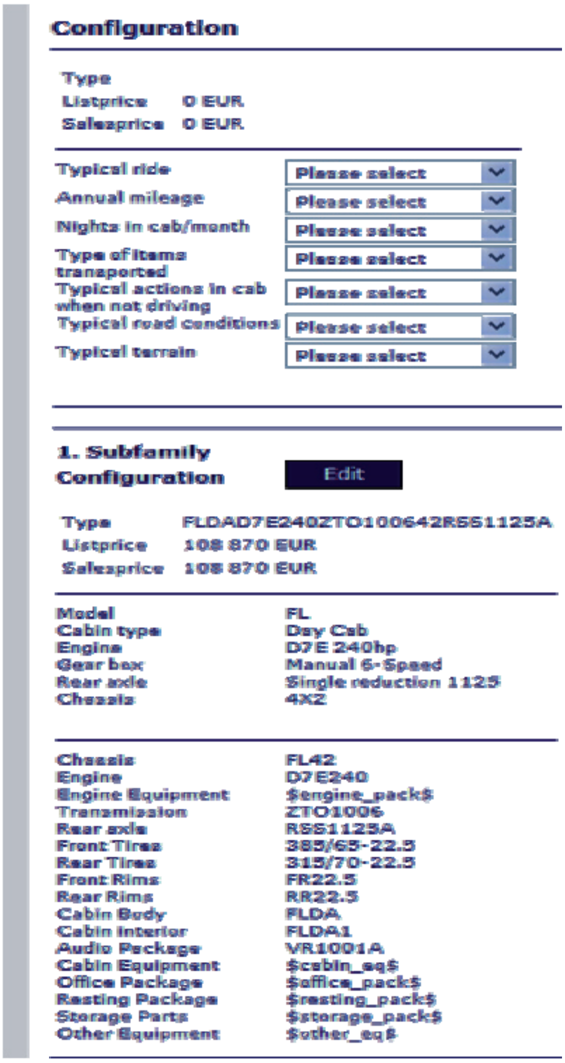
3 Application of the conceptual framework: an example

The conceptual framework presented in Figure 1 can be demonstrated in detailed by using an example, which is taken from Volvo Company Truck configuration system. This configuration system developed under the ongoing EU funded CATER project (No. 035030) aiming at networked business and mass customisation in the automotive industry (CATER, 2006). One of the world's leading automobile companies, Volvo is a partner of the project from which this case example is taken from. AB Volvo/Volvo Group is a Swedish company dealing with motor engine manufacturing founded in 1927. Volvo Company produces cars, buses, trucks, marine engines, aero engines and construction equipment. This example illustrated the basic procedural steps to customise a model of Volvo truck according to customers' own choice with some predefined restrictions.

3.1 Development of questionnaires within the Volvo citarasa

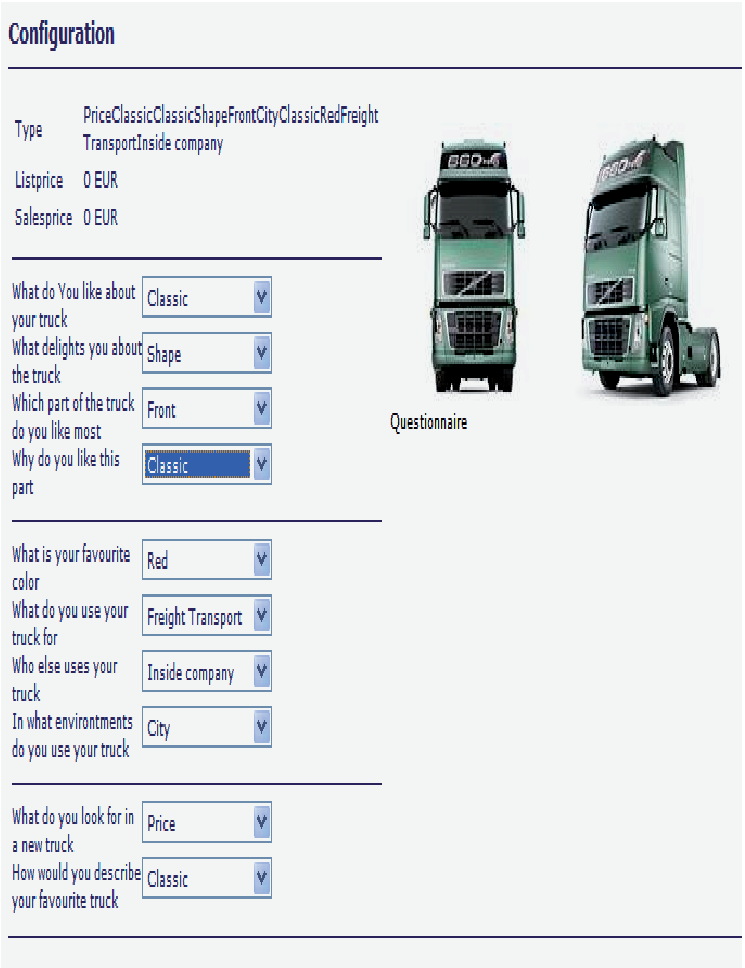
In Volvo citarasa configuration system, different questionnaires or queries and their answers or solutions are populated and stored within the configurator from which customers have to answer each question before they proceed to their specific needs and desires. The answers or solutions of these questionnaires were collected through face-to-face interviewing with different truck drivers and truck owners in Asia and Europe in order to achieve the customised model of a truck (Kyllönen and Helo, 2007). Customers have to consult with these questionnaires or queries before they proceed to their intended models.

Figure 2 Pre-selection questionnaires (see online version for colours)



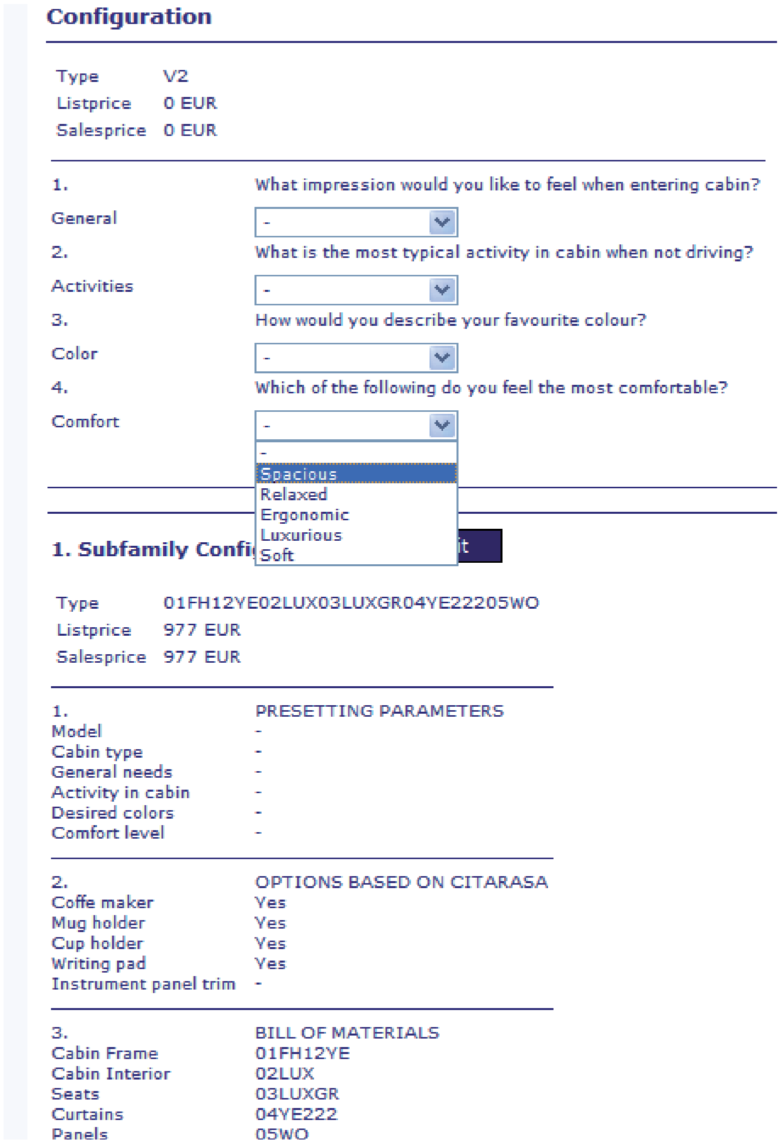
In Figure 2, some preselection queries of citarasa configurator are depicted. For instance, 'typical ride' may be distribution (local), distribution (regional), construction, long haul (national), long haul (international) or 'typical road conditions' might be highway, asphalt road, street, gravel road, which can be chosen from the pull down menu. Advanced questionnaires for specific purposes such as; 'what do you like about your truck?' can be classic, trendy, sporty, cool, modern, elegant, luxury, other or 'what do you use your truck for?' may be freight transport, wood transport, vehicle transport, courier transport, city distribution, garbage transport, sand/gravel transport, other which can also be seen in Figure 3.

Figure 3 Advanced questionnaires (see online version for colours)



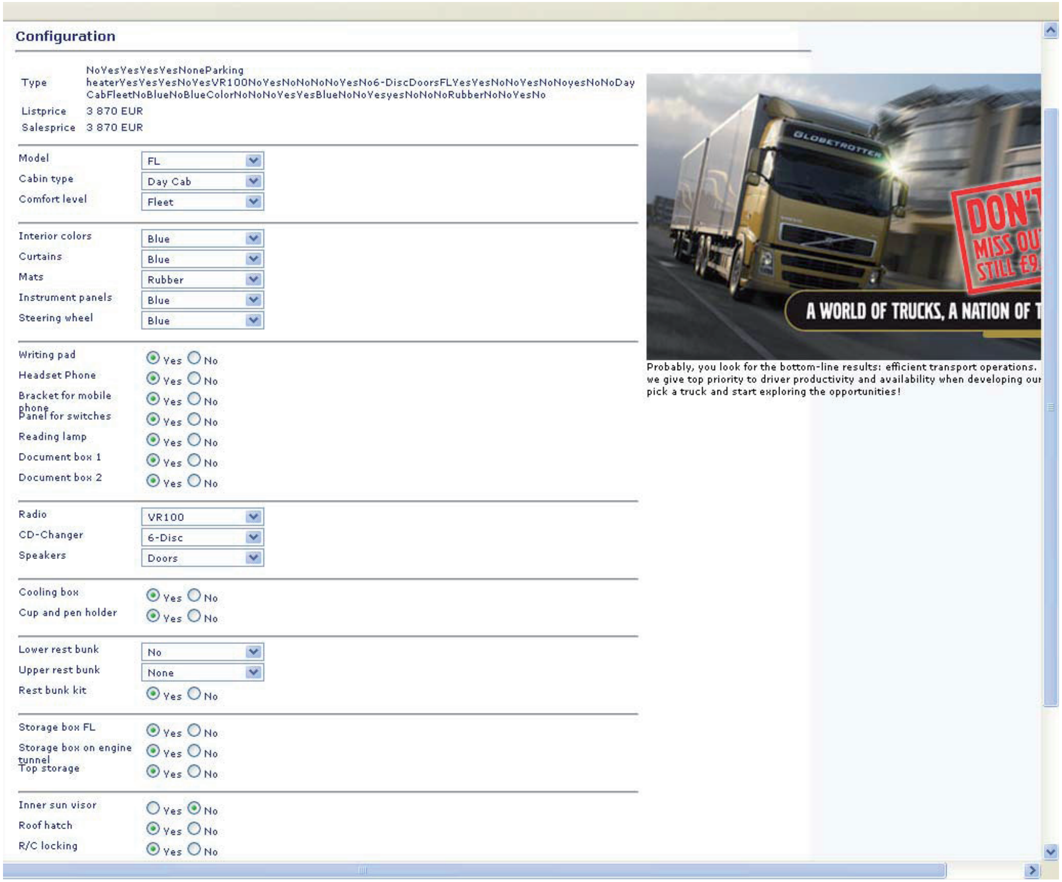
Along with the generalised questionnaires of a product, citarasa configuration system could also be designed for specific sections of an end product; like cabin of a truck as shown in Figure 4. Here, customer could choose different features within a cabin such as; 'what impression would you like to feel when entering cabin?' might be exciting, functional, durable, high tech, home like, relaxing, robust or 'which of the following do you feel the most comfortable?' could be spacious, relaxed, ergonomic, luxurious or soft and so on. Not only have these specific questionnaires, cabin configurator also contained options like coffee maker, mug holder, writing pad, etc. All these questionnaires or queries within citarasa configurator can be used as guidelines for the customers to select for specific model of a truck.

Figure 4 Example of a Volvo cabin configurator (see online version for colours)



It is very important to accumulate all the customers' desires; aspirations or needs of any product or model and forwarded those for fabricating the intended products or models. In this consequence, a product configurator could be the answer of choice. Figure 5 shows the basic steps of our Volvo Truck configurator where the specific requirements from customers are configured according to their needs. This product configurator demonstrate detailed features of the trucks required to meet customers desires such as; model type, cabin type, bracket for mobile phone, radio, cup and pen holder and so on. These features could also be chosen from the pull down menu as like as citarasa configurator. To meet up these customised features, all parts or components are populated and justified within the configurator after consulting with the basic customers' needs and aspirations.

Figure 5 Volvo Truck configurator (see online version for colours)



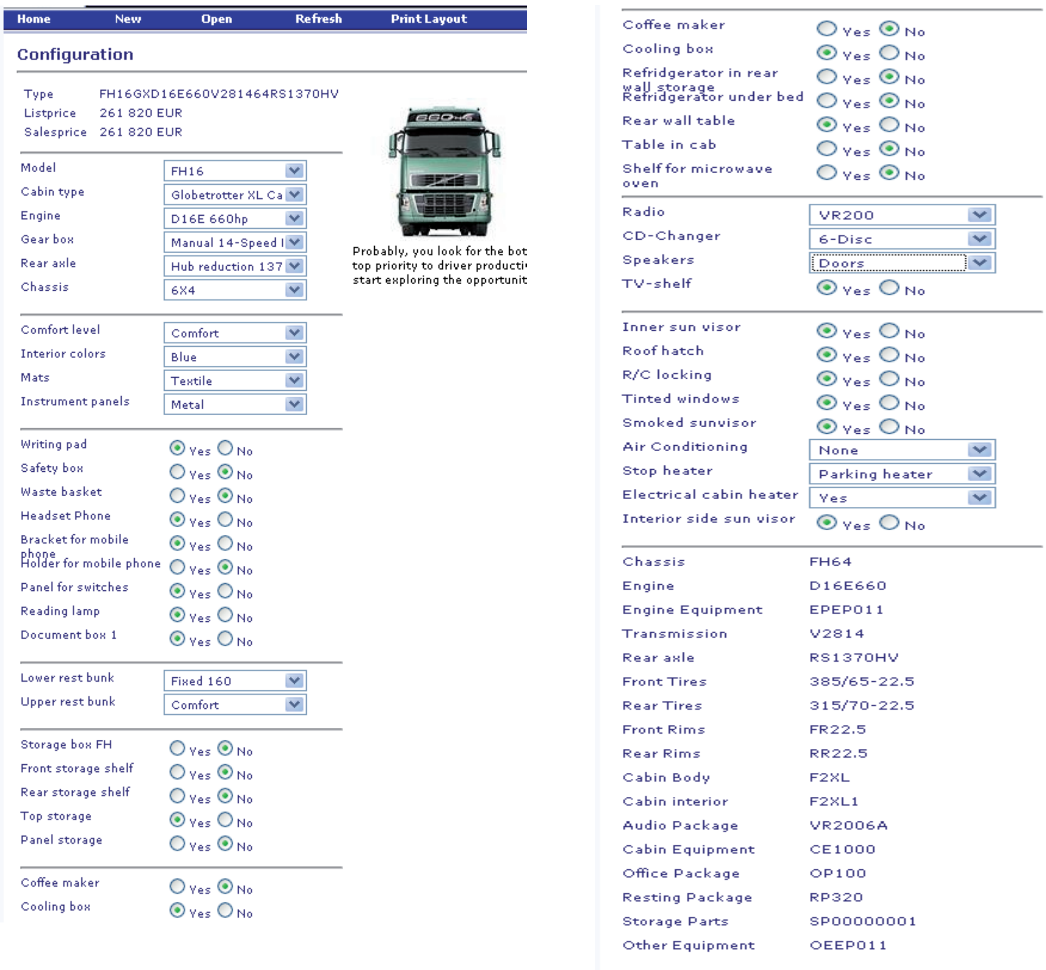
3.2 *Integration of design rules with the configurator*

Before designing the Volvo Truck configurator, designers should have to follow predefined design rules. These rules are created according to the availability of different features or components among various models of trucks. Some of the customised features or components may not be available to all other standard models. Due to these predefined design rules, customers may not be able to move freely within the configurator to choose all of their desired features or parameters among models but with some guided pathways. From this configurator, customers are also able to know the list price or sales price of their chosen models. The Volvo Truck configurator consists of 268 design rules among which first ten rules are presented in Table 1 as an example. From Table 1, it can be seen that in case of rule no. 1, if a customer chooses a Truck Model FE-FE, he/she will be denied cabin type ‘Globetrotter Cab – Globetrotter Cab’ and upper rest bunk ‘Narrow – 1’ but allows other available cabin type such as; ‘day cab’, ‘medium cab’, or ‘sleeper cab’ and allow upper rest bunk ‘None – 0’ respectively. In the case of rule 2, if someone choose a model other than ‘FL-FL’, he/she will be refused to choose cabin type ‘Crew Cab – Crew Cab’ in his/her model but allows cabin type ‘day cab’, ‘medium cab’, ‘sleeper cab’, ‘low sleeper cab’, globetrotter cab’ and ‘Globetrotter XL cab’. These rules are also applied in other sections of the trucks such as; chassis, engine, colours, comfort levels, steering wheels, entertainments and so on.

Table 1 Design rules of a configurator

Rule no.	*Design rule*
1	IF Model = FE-FE => DENY Cabin type >= Globetrotter Cab-Globetrotter Cab AND DENY Upper rest bunk = Narrow – 1
2	IF Model != FL-FL => DENY Cabin type = Crew Cab-Crew Cab
3	IF Model > FE-FE => DENY Cabin type = Crew Cab-Crew Cab
4	IF Model = FL-FL => DENY Chassis = 6 × 4-6 × 4 AND DENY Chassis = 8 ×4 -8 × 4
5	IF Model = FEFE => DENY Chassis = 8 × 4-8 × 4
6	IF Model = FM-FM => DENY Chassis = 6 × 4-6 × 4
7	IF Model = FH-FH => DENY Chassis = 8 × 4-8 × 4
8	IF Model = FH16-FH16 => DENY Chassis = 8 × 4-8 × 4
9	IF Model ! = FM-FM => DENY Side document box = Yes – 1 AND DENY Front document box = Yes – 1
10	IF Model <= FE-FE ==> DENY Air Conditioning = Automatic-Automatic

Figure 6 A simple bills of materials (BOM) (see online version for colours)



A customer creates an order for his/her chosen model after consulting with the Volvo product configurator and the order is forwarded to the concern departments. The order is checked immediately after its arrival and the required BOM is created to fabricate the intended model of choice. The formation of BOM is also attached with the configurator and updated according to customers' preferences. Figure 6 below shows a sample BOM with the chosen features of a specified model. Here, it can be observed that if a customer choose a model type 'FH16', Cabin type 'Globetrotter XL cab', Chassis type '6 × 4', engine type 'D16E 660hp' writing pad 'Yes', coffee maker 'No' and so on, a BOM is formed automatically according to predefined features or conditions and displayed at the end of the configurator screen. This created BOM is forwarded to the production configurator where manufacturing engineers consult with the configurator for necessary resources and operational sequences to fabricate the parts or components of the specific model.

3.3 Interdependency of DSM and production configurator

After having the required BOM for a truck model, necessary resources are populated within the production configurator. With the aid of this configurator, production engineers piped all the resources and logistics systematically and in order which is very important to minimise the developmental lead time. The outsourced parts or components can also be monitored through this configurator by keeping the records of different components manufacturers or suppliers. In this configurator, different fabricating tasks or assembly operations could be sequenced optimally by using DSM tool. This tool guides the tasks or resources to be completed in serial, parallel or coupled. All coupled activities are grouped together to form clusters or modules.

Figure 7 A DSM showing different design elements and their relationships of Volvo Company trucks (before sequencing or partitioning)

Name		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
Truck Model	1	1	1	1																					1							1
Cabin type	2	1	2															1					1				1					1
Engine type	3	1		3		1											1								1							
Gear box	4			1	4	1																										
Rear axle	5	1		1	1	5																										
Color theme	6						6	1						1									1									
Comfort level	7		1				1	7			1																		1			
Mats	8							1	8														1				1					
Office	9		1							9													1					1				
Resting	10		1								10												1				1		1			
Storage	11											11											1							1		
Kitchen	12												12										1				1					
Entertainment	13						1				1			13										1								
Other	14														14																1	
Chassis	15	1	1													15									1	1						1
Transmission	16	1		1	1												16															
Cabin body	17		1															17	1				1		1		1					1
Front tire	18		1													1		1	18		1				1							1
Rear tire	19															1				19		1			1	1						
Front rims	20															1			1		20				1							
Rear rims	21															1				1		21			1	1						
Cabin interior	22		1				1	1	1	1		1	1					1					22				1	1	1	1		1
Audio package	23		1											1									1	23			1					
Assembled chassis	24	1														1									24	1						1
Assembled tireset	25	1														1		1	1	1	1	1			1	25						
Cabin equipment	26		1																				1				26		1	1		1
Office package	27		1						1	1													1					27				1
Resting package	28	1		1							1												1						28			
Storage parts	29											1											1							29		
Other equipment	30														1																30	
Assembled cabin	31	1	1							1	1		1			1							1	1	1			1	1			31

Figure 7 shows different design tasks of Volvo Company trucks without sequencing or partitioning, while Figure 8 shows after sequencing or partitioning. After sequencing or partitioning, Figure 8 shows five groups of interdependent tasks or modules which can be done together to complete. This partitioning operation also reduces the iteration or rework probabilities among coupled tasks. In this brief demonstration using Volvo Truck configurator's as a case example gives inside of the presented conceptual configuration framework. This could also guide manufacturers to customise their products in an easy and nicer fashion with higher customers' satisfaction.

Figure 8 A DSM showing different design elements and their relationships of Volvo Company trucks (after sequencing or partitioning) (see online version for colours)

Name		1	2	3	28	5	7	6	24	26	10	30	29	4	11	15	17	16	18	20	19	21	14	23	8	13	9	27	25	12	31	22
Truck Model	1	1	1	1					1																						1	
Cabin type	2	1	2							1							1														1	
Engine type	3	1		3		1			1									1														
Resting package	28	1		1	28						1			1																		
Rear axle	5	1		1		5								1																		
Comfort level	7		1		1		7	1			1																					
Color theme	6						1	6																		1						
Assembled chassis	24	1							24							1													1		1	
Cabin equipment	26		1		1					26			1																		1	
Resting	10		1		1					1	10																					
Other equipment	30										1	30											1									
Storage parts	29												29		1																	
Gear box	4			1		1								4																		
Storage	11												1		11																	1
Chassis	15	1	1						1							15													1		1	
Cabin body	17		1						1	1							17		1												1	
Transmission	16	1		1										1				16														
Front tire	18		1						1							1	1		18	1											1	
Front rims	20								1							1			1	20												
Rear tire	19								1							1					19	1							1			
Rear rims	21								1							1					1	21							1			
Other	14																						14									
Audio package	23		1							1														23		1						
Mats	8						1			1															8							
Entertainment	13							1			1													1		13						
Office	9		1																								9	1				
Office package	27		1																						1		1	27			1	
Assembled tireset	25	1							1							1	1		1	1	1	1							25			
Kitchen	12									1																				12		
Assembled cabin	31	1	1		1				1		1	1				1								1			1	1		1	31	1
Cabin interior	22		1		1		1	1		1		1	1		1		1								1		1	1		1	1	22

4 Conclusions

In mass customisation strategy, product and production configuration plays the crucial role to fabricate sales and order processing of products (Hyam, 2006). Configuration software known as 'configurator' contains all the features and information such as dependencies, rules, constraints and resources necessary to develop a product. The use of configurator reduces the technical tasks required in sales phase of any product and helped to develop platform based products with rapid pace of time. The integration of different configurator's such as; citarasa, product and production configuration with the DSM tool enhances modularity in product development process which helps to bring product varieties. Modular design in industry especially in auto industry facilitates ATO with minimum lead time. Different modules can be manufactured separately while assembled in a single place for the end item.

To customise any products economically with rapid pace of time, manufacturing firms are required to have a sustainable production strategy. But it is not always possible to initiate any particular production strategy as it varies according to the product varieties and customers' tastes. It is often very time-consuming and cumbersome to adapt any standardised production scenario. For business success and gain competitive advantages, it is critical for manufacturing firms to accommodate and maintain a strategic production processes. This strategic production process guides firms to stay in competition through manufacturing higher demanding and ever growing mass customised products for the consumers.

Reconfiguring any traditional product development process to more customised format requires high tech configuration systems and tools. The problem in configuring the product development process is to formalise the customer's requirements. Generally, customers express their specific needs informally but in any configuration system, it requires a more rigorous and a more stable format. In the configuration process, customers are provided with a list of conditions that they must satisfy in order to express their needs, but such a solution approach is rather to satisfy the customers. It is therefore better to design a configuration system, which has to be customer-oriented, providing interactive guidance that will assist the customer in expressing his/her requirements accurately and in a desired format.

In that sense, our conceptual configuration framework starts from acquiring the customers' expectations through asking guided questionnaires from which customers could also express their real desires and needs comfortably. Citarasa configurator performed these operations with the help of its accompanying database. This database is populated with questionnaires feedback from customers' interviews and field surveys. This configurator followed by product and production configuration to fabricate the end product. DSM tool helps to reordering the operational activities that reduces the feedback loops and also influences to minimise developmental lead time. With the aid of this conceptual configuration framework the whole manufacturing system of any enterprise would be accomplished systematically and efficiently with reduced waste of resources.

In this presented framework, there needs a detailed knowledge and understanding of the customised products for which customers are using this configuration process. Without detailed knowledge and specification of a product or service, a customer may not be able to express his/her desires perfectly for that intended product or service. Future research could be accomplished in order to make this configuration process much easier for the corresponding customers. That could be done by adding brief comments on each configurable item of the intended products or could be through displaying the parts or components along with their explanations and so on.

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Collaborative Customized Product Development Framework

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Abstract

Purpose: The objective of this paper is to introduce a methodological approach to develop customized products which offer true customer value and achieve superior competitive advantage.
Design/methodology/approach: An integrated framework is presented where both front-end and back-end features of product development activities are illustrated. Detailed explanations of the framework participants are discussed with their specifications and view points that illustrate the value of the framework. This framework communicates between citarasa and do-it-yourself-design (DIYD) configurators at the upstream, and available-to-promise (ATP), agile supply and demand network (ASDN), advanced planning and scheduling (APS) systems in the downstream, in order to visualize the complete production scenarios and to maintain the flow of custom tailored product development.
Findings: It is hoped that the illustrated framework will bridge the gap between manufacturers and customers in order to produce customer satisfied products that fulfil the business target in terms of earning more revenues.
Research limitations/implications: This research work is based on a theoretical hypothesis. Although the proposed framework is implemented in a truck manufacturing company, it requires application in more industrial organizations in order to generalize its effectiveness, suitability and consistency in the manufacturing arena.
Originality/value: This paper outlines the configuration principle, along with different tools and methodologies, which support manufacturing firms in the customization of products in both upstream and downstream activities in a profitable way. These tools or methodologies can help product developers to improve their due-date promising, exploitation of bottlenecks and the visualization of their capability to produce the customers' specific products.
Keywords: Configuration process, available-to-promise, agile supply and demand network, advanced planning and scheduling, mass customization
Paper type: Research paper

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1. Introduction

In today's competitive and largely saturated markets, customers demand high quality products which also need to be extremely price sensitive. This growing demand for customized products is pushing firms to focus on producing products which meet customer requirements and the firms' constraints. Several IT based software tools can be applied successfully to make it possible for firms to shorten product development time and sales-to-delivery process. This sales-to-delivery process means all the necessary steps that are required to design, order, manufacture, sell and finally deliver a product to a potential customer (Tiihonen and Soininen, 1997). Different configuration tools such as citarasa configurator, product configurator, production configurator and sales configurator can be applied successfully in order to maintain such a sales-to-delivery strategy.

In the configuration process, all the related data and information required to design, manufacture and then support and maintain products during the entire product life cycle is stored. This process also supports a modeling of the product development processes for fast and correct configuration of working product variants that fulfill the customers' requirements and firms´ constraints, such as production and delivery. The various available configurators that manufacturing firms uses nowadays do not fully support the customized product development process, as in most cases they are applied individually rather than combined within an integrated framework. In order to configure any customized product, integration is required between various configurators and engineering applications such as virtual reality (VR), 2D and 3D modeling in product development processes.

Before proceeding towards configuring a product, it has to be kept in mind that products do not have to be fully configurable and it may not be always possible due to the limitations in design and the capabilities of firms. Generally, customers are allowed to select predefined packages or to combine only certain characteristics or features of any product. In such cases, customers could define a partially configurable product for which they must accept the characteristics and features of products with certain values. In the configuration process, customer requirements are gathered and mapped within a configurator to set up different product options (Helo, 2006). The information as provided by the customer through follow-on questions and options guides designers to focus only on the choices that meet the customers' requirements and desires.

The trend of product customization produces many challenges for manufacturers and there is a need for greater cooperation among the participating members, from customers to suppliers. No manufacturer can have all the necessary skills and knowledge. In order to produce cost effective and quality customized products, manufacturers need to seek out specific partners with special skills or attributes and create a virtual corporation from several firms to focus on meeting the needs of a customer (Barutcu, 2007). Especially, there is a need to respond expediently beyond the borders of their own company to their suppliers, the suppliers of their suppliers, and customers in order to improve overall customer and consumer value. It needs to be ensured that their suppliers are efficient, both in terms of cost and in the delivery of parts or components to their logistics provider. This will ensure integration between manufacturing facilities with logistics operations and enable firms to guarantee a good performance in the market place as well as their survival.

To satisfy customers' desires and expectations, it is very important to deliver the products within the promised deadline. In order to maintain the delivery commitments of customers, firms need immediate access to product availability along the supply chain network (Ballou, 2006). This availability management process can be triggered through applying available to promise (ATP) strategy, which directly influences key supply chain performance, such as in customer service and inventory value. This strategy is a network-based distribution system that determines an optimal allocation of available to promise components in a supply chain. According to customers' demands whole product development scenarios are simulated to estimate how to respond quickly, with an evaluation of the availability of existing resources and supply chain performance.

The rest of the paper is organized as follows: in Section 2 we discuss common participants in developing customized products, and in Section 3 an integration framework for product customization process is presented. Section 4 outlines an implementation example of the proposed framework taken from a truck manufacturing company. Several managerial implications in the field of PD and distribution process are discussed in Section 5. The paper concludes in Section 6 with some future research directions.

2. Customized product development participants

Due to advances in modern technology, it is possible for manufacturing firms to bring products to the markets more quickly than before, with higher customer satisfaction. Customers nowadays require products to be almost individually tailored to their needs, desires and personalized statements. In this era of product customization, firms are looking forward to establishing an integrated modeling approach, where customers could directly participate and influence the whole development process in order to achieve their choice of products. The basic elements of this proposed integration model or framework to fabricate better informed design of customized products is elaborated below.

2.1 Citarasa Configurator

In today's customized world, customers are looking beyond the functionality of any products. Along with functionalities they are looking for products that can also satisfy both their aesthetic and emotional needs. This changing strategy puts extra pressure on product designers to design products that satisfy customers' aspirations with functional needs. In order to achieve successful design, there is a requirement to develop a systematic procedure that is not only explicit but can be validated in different contexts and products. In industrial design, affective design has become very important in prescribing that designed objects have a meaning that goes beyond their functional needs (Khalid, 2006). Several pieces of research have been carried out in various domains of affective design, such as Mood Board (Keyani et al., 2005) and Kansei Engineering (Nagamachi, 1989), amongst others..

Before conceptualizing a product, designers need to understand user requirements both in terms of functional and affective issues. Customer requirements can be interpreted through a concept known as 'citarasa', which is Malay word meaning emotional intent and aspirations. It is a combination of two words: 'cita', meaning intent, aspiration, desire, wish; and 'rasa', meaning taste, emotion and feelings (Khalid, 2006). In citarasa, customers are actively looking for design features that are important for their emotional intent, needs and taste. In order to integrate the customers´ aspirations and affections with the product design phase, manufacturers could develop a configuration system known as the 'citarasa configurator'. This configuration system provides support for reverse engineering and mass customization in manufacturing industry. It is populated with the general requirements and aspirations of potential customers with regard to products after formal or informal interviews with customers through market surveys. After following a basic selection process, it helps customers select the most suitable products for them.

In the citarasa configurator, customers´ desires are integrated on the basis of their experience and general needs, specific requirements for design, customer expertise and customer demographics. The data within the configurator is first collected through elicitation interviews with customers and the data is then analyzed through data mining methods in order to decide the design parameters for a specific model or product of the customers' choice. This data generally contains various features of a product or model to select from. For instance, customers are asked to investigate what they are looking for and thereby obtain an explicit identification of their affective requirements when buying a product or model of a car. The survey done by the marketing department offers information about customer needs and future markets, which determines the companies´ design goals.

The citarasa configurator interfaces directly with the DIYD (Do-It-Yourself-Design) configurator for the required design of products that satisfies customers' aspirations and needs. Customers have the facilities to add, substitute or deduct different features of their choice of products through interacting with the DIYD configurator. Citarasa offers the role of emotions in the product design phase, whereby customers intuitively look for design features which will satisfy their taste. However, it is often very hard to identify the affective requirements of customers, as these vary over time and customers often have difficulties in explaining what their requirements are (Helander and Khalid, 2006). Most often they can not even necessarily be clear about their requirements, or when they do, they have unrealistic expectations. In such circumstances, citarasa methodology aims to support the product customization process through understanding, modeling, elicitation, extraction and analysis of affective needs.

2.2 DIYD Configurator

DIYD configuration means transferring customers' aspirations, desires and needs into concrete product specifications in order to satisfy them. With this configuration system each individual customer's wishes and needs have to be transformed into a unique product specification for manufacturing (Tseng and Piller, 2003). The system which is responsible for guiding the user through the configuration process is known as the 'configurator'. This configurator enables customers to interact closely with the companies´ capabilities of producing successful customer-centric products through different variations - visualized, assessed and priced. The development and implementation of an appropriate configurator for customer interaction is an important success factor in mass customization.

The central approach of product customization is the concept of DIYD, where the aim is to providing cost-effective products and services to meet individual customers´ needs. The DIYD configurator is defined as the selection and configuration of products/parts by customers in terms of their own preferences. In order to design and develop an e-catalogue of products/parts for the configurator, customers´ preferences might be estimated through global market diversities and population choices. General customers' preferences are screened out to have cost effective product variety, and easy design procedures and rules need to be taken into account. These design procedures and rules are mapped as functional requirements within a configurator using a hierarchical approach.

Manufacturing firms are being forced to react to the growing individualization of demand (Jiao et al., 2007). Thus, turning industrial establishments to be more customers centric in an efficient way is a top management priority in most firms. A successful DIYD system powered by the citarasa configurator supports the task of customer configuration in fabricating a product of their choice. This system requires a link between the customer and manufacturer, who generally design the product concurrently in real-time (Helander, 2007). With the help of the DIYD configurator, customers choose, match and swap parts/components and different design options/offers and assembles them together to form a specific product of their choice rather than selecting a ready-made product. This design and development process follows a top-down hierarchical approach and predefined design rules when designing the final product (Khalid, 1999).

The DIYD configurator is integrated with a 3D visualization system in a virtual reality environment. This system will be suitable for suppliers and wholesalers through networking and communication tools which are supported by a front-end application (configurator) and back-end administration tool. The front-end system will be applied through a virtual reality interface and a set of interactive tools (2D, 3D, Graphics) that allow the user to visualize and perform the process of product design and assembly in an intuitive manner. The back-end system will be formulated in the form of a component repository that incorporates direct interfaces between configuration, offering/ordering, bill of materials and the logistics networks system of a project.

2.3 Supply Chain Visualization

In today's globalized economy; multiple suppliers are located in multiple locations within a country or in different countries, making supply chains increasingly complex. There are growing demands for JIT supply and manufacturing, support for lean processes and increasing pressure to reduce costs while maintaining quality products to respond to an ever-changing demand. In order to achieve effective operational decisions, organizational management demands clear visibility and direct information available on potential resources. This intuitive objective can be fulfilled by ensuring user-friendly interface to easily access, visualize and analyze different aspects of supply chain performance.

The coordination of information flows is a key element in achieving tight integration in order to optimize supply chain performance. The idea of real-time information sharing has been studied extensively in the manufacturing industry. The importance is emphasised of achieving instantaneous multilateral information sharing within a supply chain with a view to reduce the uncertainties associated with operations and demand forecast (Cooper et al., 1997; Lewis and Talalayevsky, 1997). Recently, this strategy has been moving forward due to the rapid advances in information technology (Lee and Whang, 2000). This information sharing can be used for building and integrating distributed supply chain management within and across corporate boundaries, depending on existing and emerging standards.

The supply chain visualization technique provides a way for managers to physically construct and interact with models of how products flow between their business, their suppliers and their customers. It lets managers use complex numerical simulation techniques as part of "what if?" conversations about possible changes to the way they do business. The user can change values, meanings and inventory to observe if it will change the way the system performs. This phenomenon helps companies make better decisions faster, addressing global supply chain design and sourcing strategies, transportation planning and the optimal flow and placement of inventory across the end-to-end supply chain. This comprehensive view of the supply chain allows businesses to cut down inventory, streamline logistics and optimize the efficiency of their resources in order to gain a competitive advantage (Phusavat and Kanchana, 2008).

In the proposed framework, the supply chain visualization tool ASDN has been integrated with a view to optimization-based decision support solutions designed to complement and enhance existing resource planning and scheduling solutions. User Interface Integration between the components of the back-end module is based on xml (Extesible Markup Language) messages. The functional configurator engine forms an xml file for the user interface (2D, 3D, VR), including all the parameters, such as bill of materials (BOM), BOM attributes and attributes to make the visualization possible. These attributes then launch ASDN software as http-post and it will then provide in return lead-time into the configurator interface. The ASDN integration is shown in Figure 1 below.

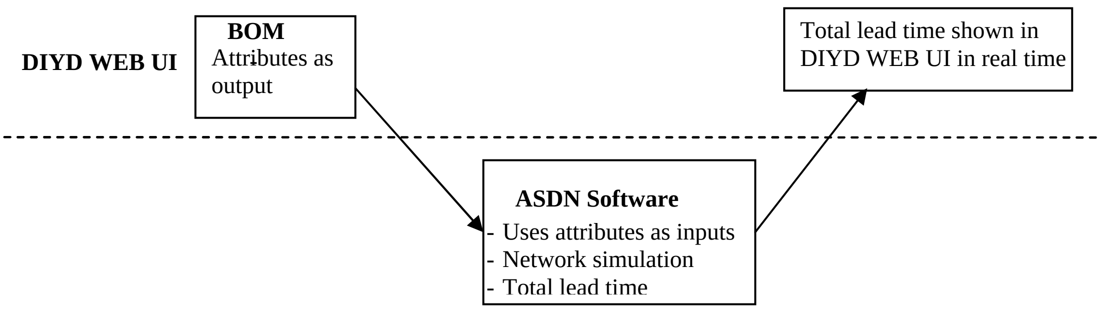


Figure 1: ASDN Integration

This tool helps decision makers to quickly build supply chain scenarios and efficiently optimize large-scale supply chains which also drive the key supply chain costs. It designs the companies´ overall supply chain in order to optimize the number, size and location of plants, warehouses, ports and cross-dock facilities that provide an optimized sourcing plan when products can be made at multiple sites across the globe. ASDN provides businesses worldwide with intuitive spatial solutions, increased opportunities for visualizing supply chain data and visual consolidation of disparate back-end data sources in an intuitive manner that promotes greater efficiency and productivity.

2.4 Available to Promise (ATP)

The Available to Promise (ATP) concept can be denoted as the set of capabilities that support responding to customer order requests. It provides a response to a customer order with a quantity and delivery date commitment (Pibernik, 2005). In general, it refers to a database look up into Master Production Schedule (MPS) which is applied for changing production strategy from make-to-stock (MTS) to make-to-order. Due to the increasing tendency of high variety product offerings, e-business and make-to-order production strategy, ATP functionality has become a critical component of many businesses. If the demand plan does not mirror future orders very well, the chance is high that ATP will not be available when a new customer order requests it. The logic or methodology of ATP can be expressed as in Figure 2 below.

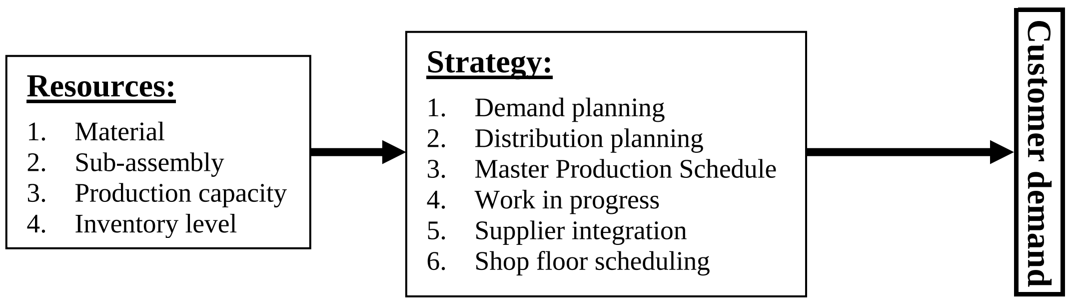


Figure 2: Available to Promise (ATP) logic

The term demand fulfillment is represented as the planning process that determines the way in which the actual demand of a customer is fulfilled. This process first of all promise a specific deadline for customers´ orders, which influences the order lead time and timely delivery. The fast generation of the order fulfillment process becomes more complex when the number of products increases, the product life cycles becomes shorter, and the number of customers increases (e.g. Gunasekaran and Ngai, 2005; Huang et al., 2006) In a traditional order fulfillment process there is an inventory search and orders are quoted against it (Lyon et al., 2006). If there is no inventory available, orders are quoted against the production lead-time.

Today's businesses are highly complex and competitive in nature, offering multiple customized quality products with shorter product life cycles to customers. In this volatile market demand and tighter due dates are forcing manufacturing firms to focus on ATP to their potential customers. This means that firms are forced to commit to their customers in advance in order to deliver the demanded amount by the specified deadline. To maintain such strategy, capacity management is the key for effective revenue management that integrates the marketing, financial and operational functions in order to maximize profit from existing capacity. The integration of ATP with the proposed framework as shown in Figure 3, could be helpful in order to accommodate the different BOM attributes and resource management for the required order fulfillment procedures.

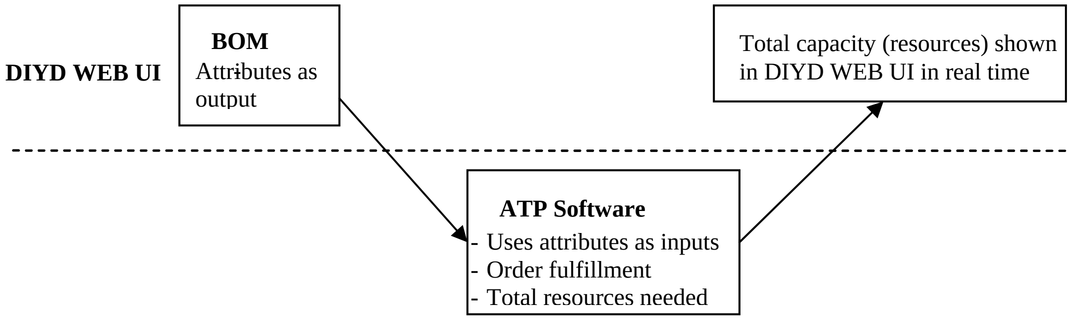


Figure 3: ATP Integration

The firms' capacity management can be performed efficiently through the ability and capability of their supply chain success. The due-date for customers' orders could be managed properly by supply chain decision makers so as to smooth the production and/or delivery schedule. It is the output of a synchronized supply and capacity planning which determines the actual and future availability of supply and capacity that can be used to receive new customers' orders. Modern demand fulfillment process is based on the planning capabilities of advanced planning and scheduling (APS) that generates more sophisticated order promising procedures. This technique ensures on time delivery, reduces the loss of business opportunities, increases revenue earning through higher sales volumes, and so on. In order to cope with today's competitive business world it is very helpful to adopt ATP strategy to satisfy customers by meeting their orders as quickly as possible.

2.5 Advanced Planning and Scheduling (APS)

APS can be defined as a system and methodology in which decision-making, such as planning and scheduling for industries, is federated and synchronized between different divisions. Unlike other available systems, APS simultaneously plans and schedules production based on available resources and capability. This usually provides a more realistic production plan, for example demand planning, master planning, distribution and transportation planning. This system could be defined as a manufacturing management process through which raw materials are optimally allocated for a production system in order to meet demand (Lee et al., 2002; Chao-Hsien et al., 2007). It is especially useful where a complex production process requires simplistic solutions in order to manage the production line. This is basically done through performing optimal scheduling of the company's resources.

The application of APS results in an improved demand-driven supply network that shifts the focus from a 'sell-what-we-make' approach to a 'respond-to-what-customers-want' approach. It promotes the delivery of the right product at the right time at the lowest cost, which results in improved customer service and profit margins. Manufacturing firms use this planning methodology to evaluate constraints and priorities and produce a detailed schedule with graphical representation on plant load, resource utilization and constraint identification. The firms' environments are modeled by simultaneously considering capacity, availability and the interdependencies of equipment, tooling, employees and materials. Materials and capacity are planned separately and many systems do not consider limited material availability. The system also brings balance between customer responsiveness and profitability.

In order to apply APS successfully within a company, managers and employers must have special training that enables them to interpret solutions and reorganize interactions with other parts of the supply chain. Not only should supply chains comply with quickly changing customers' expectations but they also have to anticipate new trends (Jonsson et al., 2007). To participate in new trends, supply chains need better integration with their key customers. APS supports the integration process effectively, whereas ATP module can show ways to use existing inventories in the most effective manner. It allows optimization of the ordering process and brings flexibility to the master planning process. If it is used successfully, it not only supports the supply chain strategy, but also improves the competitiveness of a firm significantly (Stadtler, 2002).

The APS software as integrated with the proposed framework shown in Figure 1 performs the necessary planning and scheduling of the BOM and related resources. This integration network offers the output performance as real time information flow to the configurator engine. In addition, APS software (in this case Excel based xls-file) will then read the xml-file provided by the configurator and run the calculations in real time. At the same time the xls-file is converted into an xml-file, which is then integrated to the configurator user interface as graphical display. The APS integration can be seen in Figure 4 below.

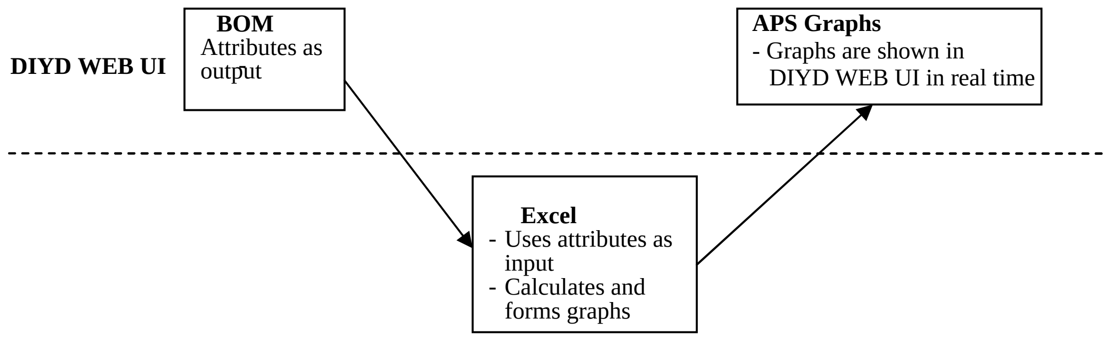


Figure 4: APS Integration

The integration of APS with other software such as ASDN and ATP gives benefit to this application by its ability to measure the inventory value on a unit and cost basis. The APS system is developed by receiving product data input from the hierarchical bill of materials (BOM), which is used as the main information to design the targeted products. This system improves the integration of materials and capacity planning by use of constraint-based planning and optimization (Van Eck, 2003). Furthermore, there are some possibilities to include suppliers and customers in the planning procedure and thereby optimize the whole supply chain on a real-time basis. Traditional planning and scheduling of systems begins with working without considering the resource constraints, whereas APS works with the available limited resources and capacity in mind. This process usually therefore results in a more realistic production plan.

3. Integration framework for customization process

The importance of different methodologies and tools required for developing customized products are explained above. In order to achieve success in fabricating the products, firms need to combine these product development items. These development items interact with each other to produce the necessary information exchange that facilitates the exploring of customers´ perceptions. Various interactions can be presented in a collaborative manner, as outlined in Figure 5 below. This collaboration expresses the real time information dependencies among manufacturer, customer and supplier. The mode of collaboration or information exchange needs specific attention when there is an increasing rate of technological complexity, risks inherent in the customized product development, and the need to gain faster access to markets (Parker, 2000).

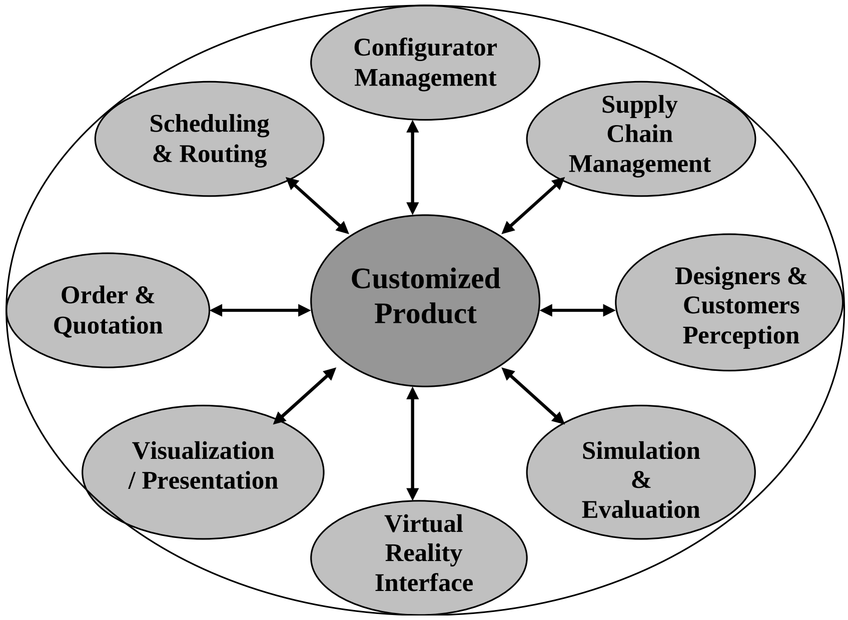


Figure 5: Information dependencies in customized product development

In networked business, there needs to be direct communication between potential customers and manufacturers in order to produce customized products. Customers can customize their products of choice based on several available options that meet their affective needs and aspirations. This customization process needs several procedural stages, which integrate different configuration processes. There are several different configurators such as the citarasa configurator, DIYD configurator, and sales configurator, amongst others. Alongside these configurators there are several tools or methodologies such as ATP, APS, ASDN, BOM, which are essential for the smooth operations of mass customization. The whole customization process can be displayed in the proposed framework presented in Figure 6 below.

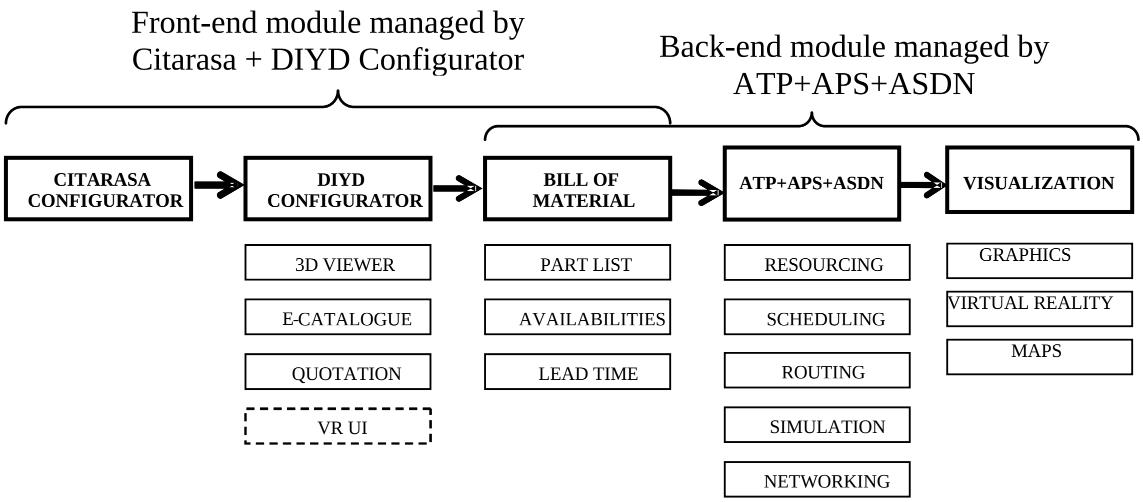


Figure 6: Specifications of the proposed customization process

In the proposed integration framework, there are two modules, namely front-end module and back-end module, as seen in Figure 1 above. The front-end module, which integrates the customers directly before the production process, consists of the citarasa configurator, DIYD configurator and BOM, whereas the back-end module that transfers customers´ expectations through the production process consists of BOM, ATP, APS, ASDN with visualisation process. BOM creates the necessary bonding between two modules to produce custom built products.

As mentioned above, the front-end module starts with the focus on both the affective and functional requirements of customers for products which are populated within the citarasa configurator. The data or information from the citarasa configurator is fed to the DIYD configurator, where customers participate in choosing, modifying or updating different product features or options according to their choices, and create their orders. In this stage, users can view different parts/components or the complete product and make the final order through a 3D viewer, e-catalogue, quotation and virtual reality user interface. When the final order is received by the configuration process, the required BOM is formed with the parts list, and their availabilities with the necessary lead times.

In the back-end module, several functionalities are integrated, such as BOM, ATP, APS and ASDN in order to facilitate scheduling, production planning, simulation, routing and networking. The integration network of this module is quite straightforward. After having the necessary information of a product or component from the DIYD configurator, the back-end module starts to formulate the required planning in order to fabricate the end product or component. Basically, this module makes the required planning according to BOM initiated from the DIYD configurator. After obtaining the necessary components or parts list with their availabilities and lead times, it is then forwarded immediately for the required planning of resources, scheduling, routing, networking and simulation with the available tools or methodologies.

In order to check the availability of the parts or components of the end product, this module also communicates with potential suppliers and calculates the promised lead time. The suppliers' involvement can be displayed with an updated information flow by the ASDN software. With this visualization capability, ASDN also ensures the balance between the supply and demand of an establishment and allocates the required resources. The ATP software within the back-end module calculates the availability of the resources required for the ordered product. This availability checking helps the production planner to formulate scheduling, planning, routing and optimal networking. The objective of this module is to support the DIYD configuration process in terms of proper functioning and visualizing the whole operational processes through virtual reality, maps or graphical interface.

There are several product development frameworks in the literature. Petersen et al. (2005) propose a research framework for a collaborative engineering in new product development which integrates early suppliers' involvement with the production process. Quiescenti et al. (2006) propose a theoretical framework, where collaborative IT tools are applied to support integration between suppliers and customers. Customer options and preferences are gathered using internet technology within a framework, as presented by Siddique and Boddu (2004), Helander et al. (1998) and Kim et al. (1999). Different frameworks presented in the literature do not fully support the customization process, as they have integrated various product development features such as the supply chain, configuration process and IT tools individually rather than in an integrative manner. The framework we have presented is a systematic approach to collaboration with available PD features, which is needed to help firms establish, appraise and improve their product development processes with higher customer satisfaction.

4. An implementation example

The presented framework has been applied to a truck manufacturing company, where the cabin was considered a customized part of the whole truck. Different features within the truck cabin could be fixed according to the customer's needs and desires. Figure 7 displays the available measures/options such as 'basic measures', 'behavioural measures' and 'reflective measures', from which customer could choose according to his/her choices and requirements. All these measures are in-house within the citarasa configurator. For instance, customers could choose by answering various questions, such as: 'what do you like about your truck', 'which parts of the truck do you like most', and so on, within the citarasa configurator. According to the choices of the customers, the sales prices of different models of trucks are calculated within the configurator.

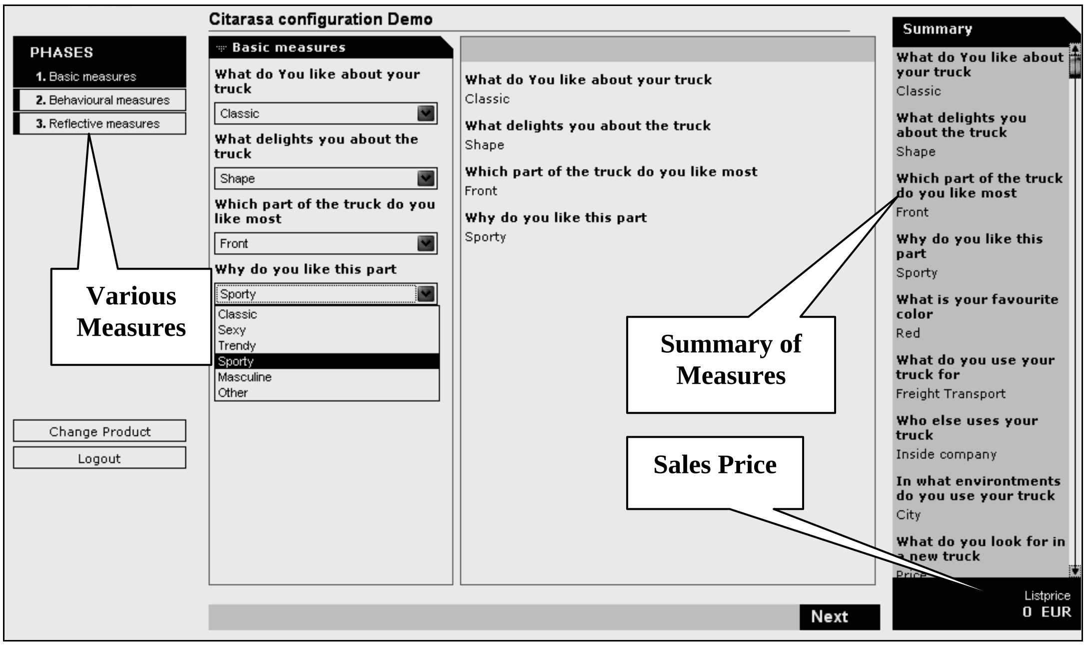
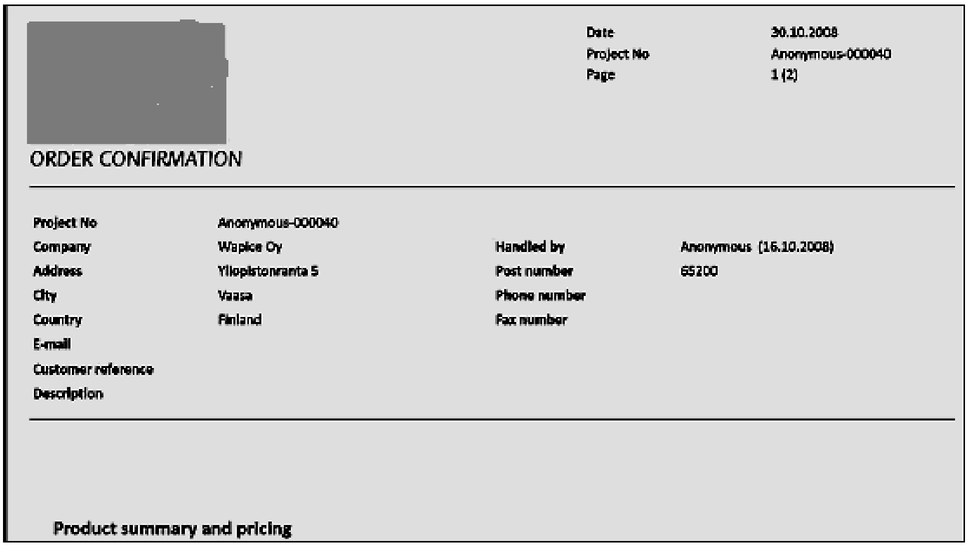


Figure 7: Different measures within the citarasa configurator

After finalizing different requirements with the help of the citarasa configurator, customers need to confirm their orders, which in turn are forwarded to the specific departments to be processed. Figure 8 presents a sample of such an order confirmation. Within this order, personal details of the specific customers are attached.



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Project No	Anonymous-000040
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ORDER CONFIRMATION

Project No	Anonymous-000040		
Company	Wapice Oy	Handled by	Anonymous (16.10.2008)
Address	Yliopistonranta 5	Post number	65200
City	Vaasa	Phone number	
Country	Finland	Fax number	
E-mail			
Customer reference			
Description			

Product summary and pricing

Figure 8: Display of customer's order confirmation

When a customer has confirmed his/her order for a specific model of truck, it is then forwarded to the target department for implementation. Designers and engineers work together in order to fabricate the specific truck. Different components/parts, together with their codes, quantities, availabilities and lead times, are accumulated within the sales configurator, as presented in Figure 9 below. This configurator also maintains a link between the production map and production scheduling in order to sequence various development tasks to complete the end product.

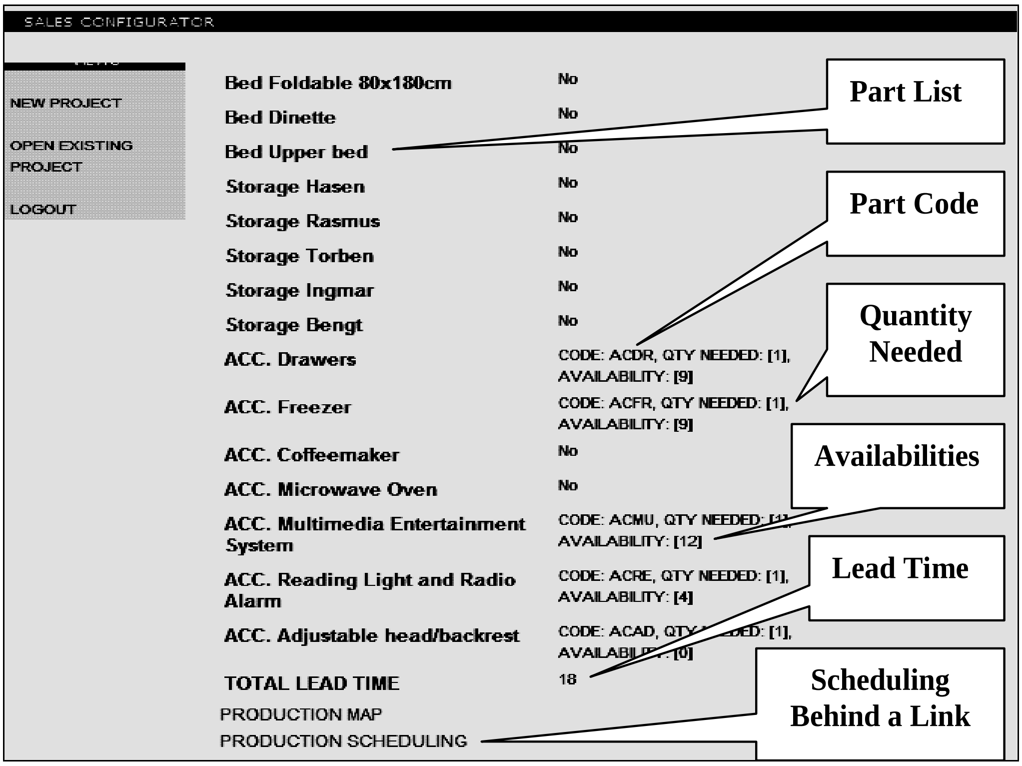

Figure 9: Different parts and their availabilities within a sales configurator

Within the sales configurator, different product development areas, such as ASDN, BOM, basic customer selections and advanced configuration items can be added, as displayed in Figure 10. With the sales configurator these development items establish direct interface between the supply chain management, various parts information, basic and advanced customer preferences, which is essential to develop a customer specific truck model.

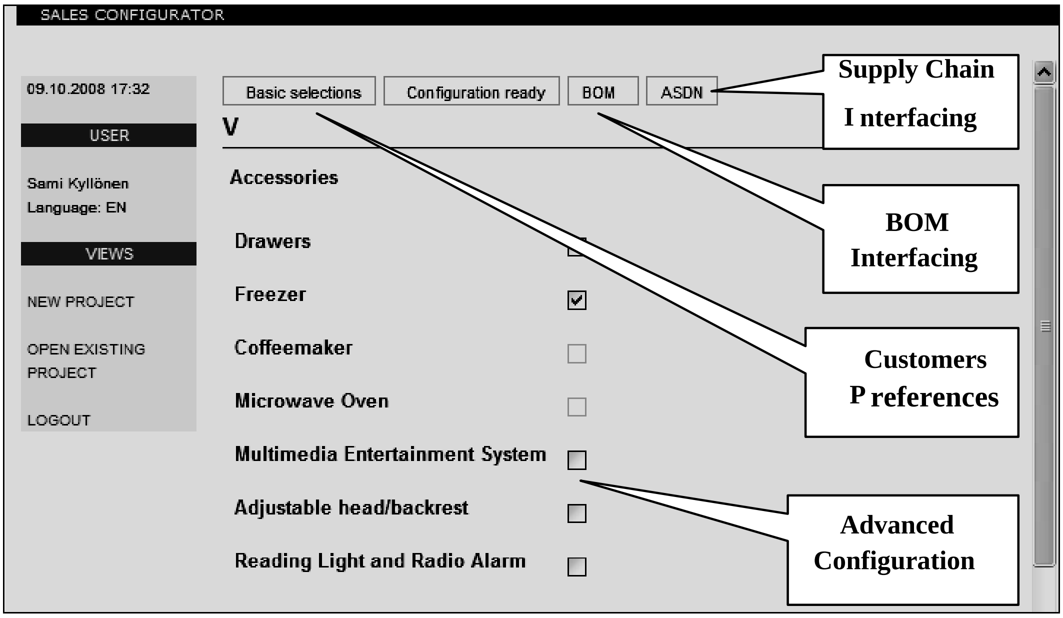

Figure 10: Interfacing of product development items with the sales configurator

In order to develop a customized truck, it is necessary to produce interaction among the configurators, supply chain, APS, ATP, etc, as explained in the integration framework displayed in Figure 6 above. For demonstration purposes, we have shown only the supply chain network using ASDN software, as displayed in Figure 11 below. With the help of ASDN, different suppliers of a car manufacturing company are networked with the necessary information, such as inbound inventory value, outbound inventory value and holding cost and this can be displayed in graphical form.

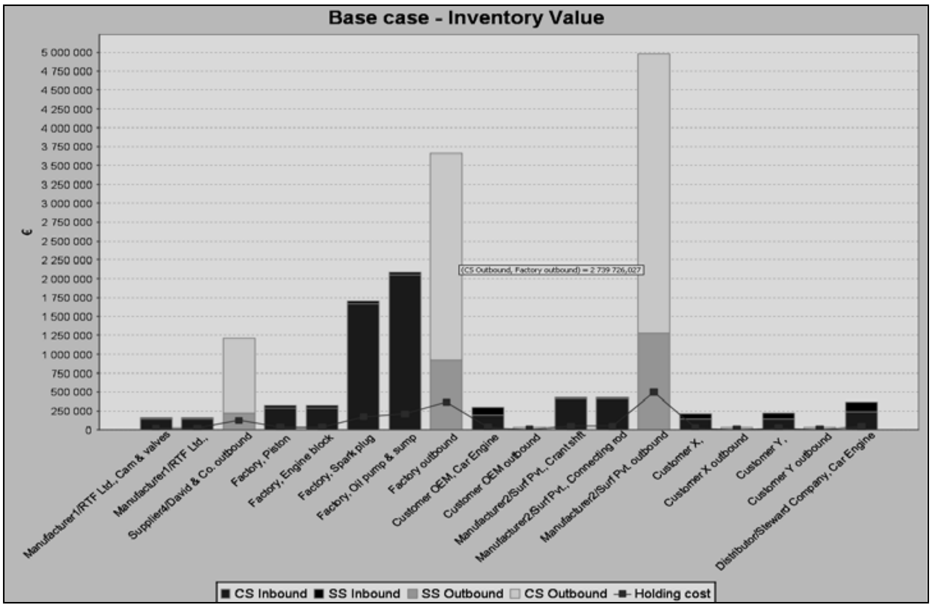

Figure 11: Display of various supply networks using ASDN

5. Managerial implications

To maintain profits and business growth, companies must be able to quickly adapt to fluctuations in customer preference and desire by creating products of their choice. This provides increasingly individualized products through configured-to-order manufacturing processes, where customers actively participate in the design and fabrication process (Jiao and Helander, 2006). There are several ways to integrate users in the product development process, such as market surveys, configuration process, workshops, etc. Along with customer integration, firms need to shorten the time to markets of their products while maintaining high levels of quality and competitive prices for smaller or larger production runs (Johnson and Luo, 2008).

In today’s hypercompetitive business environment firms also need to be innovative in supporting growth with their PD processes that will attract a major part of the market segment and ensure higher customer satisfaction (Xing et al., 2006). In order to do this, firms have to contend with increasing customer sophistication and information access, as well as customer demand for flexibility. In such a situation, innovation and flexibility in product design and development process are essential for success, as customers want their products delivered quickly, configured according to their requirements and they demand technologies which are up-to-date. The configuration process generally enhances the information flow among customer and product developers, which is crucial in meeting these expectations.

Developing customer-driven products requires taking advantage of a variety of available technologies and sophisticated production planning which can be easily configured for maximizing the potential profitability over a product’s lifecycle. Different configuration phenomena, such as sales configuration, product configuration, supply chain configuration, etc. allow firms to manage their production process smoothly, economically and effectively. These display the price and lead times of products, create BOM and routings and generate customer-friendly quotes based on product compatibility rules. The integration of the configuration process with available methodologies such as ATP, APS and supply and demand chain influence the requirements for developing customized products.

With these appropriate methodologies, the ever increasing demand from customers for individually specified products can be met. These methodologies ensure that organizational managers receive support in handling the customization efforts through reducing engineering effort and improving the sales process. During the production process, managers can control and visualize the whole operational scenarios through integrating both front-end and back-end modules in the proposed framework, which consists of configurators and dynamic tools for order fulfilment, planning, and scheduling and supply chain management.

6. Conclusion

Product customization can be defined as the ability to provide individually tailored products to every customer through high process agility, flexibility and integration, with the aim of turning market uncertainties into sources of competitive advantage (Pine et al., 1995). The main objective of this approach is to deliver products which best translate the actual choices of individual customers based on their needs, aspirations and preferences. This objective can be generally fulfilled through adopting and implementing the configuration principle in scenarios that might involve design, manufacturing, sales and distribution, installation and maintenance. The specification of the configuration process basically involves two distinct phases, namely the description of configuration rules and the specifications of the intended product or process.

The production of customized product is an important strategy for accommodating customer satisfaction with exclusive products at reasonably low costs. To implement this strategy requires an integrated support system for facilitating design and customer collaboration in the process of selecting and developing the customized products. The system integrates both the front-end and back-end features of the product development process, where customer choice is guided by a relative set of attributes, as well as a set of technical and flexible facilities to design the whole production system. Both features work as a concurrent engineering environment in order to develop a customized production system.

Various interactive configuration processes, such as; citarasa configuration, product configuration, and production configuration system help to fill the gap between manufacturers and customers. In citarasa configuration, the customers´ overall desires for a specific product or product family are collected and scrutinized to make them into as generalized a form as possible. The product configuration system establishes a bonding between upstream citarasa configuration and downstream configuration process as production and sales configuration. The production configuration system influences such manufacturing requirements as planning, scheduling and resource management in order to fabricate the end product.

Furthermore, the configuration process needs to match the opportunities and constraints of configurable products and the requirements for manufacturing and assembling them. Using this process, customers can define the rules and provide information that can be applied to share knowledge between designers and customers in order to configure customized products. In order to optimize the utility of customer expectations, it is also important to be able to include engineering operations such as commitment of order, visualizing the supply and demand level, planning and scheduling or routing in the configuration process. All these operations can be performed through available methodologies such as ATP, ASDN, APS and overall simulation of the processes.

In this paper, we have outlined various aspects of developing customers' specific products that meet their wants and needs. In order to meet this challenge, firms have to find ways to speed up customer response, reduce the lead time of products and quotations, reduce the amount of resources spent and optimize the routing and planning process. The purpose of this research is to demonstrate how effectively product development activities can be integrated between front-end and back-end features in order to achieve a smoother operational performance. Future research could be carried out on implementing this methodology in more real life industrial applications and to investigate the performance with selected criteria. Other product development instruments such as the product data model, production configurator and ERP (Enterprise Resource Planning) could be added to this framework for its universal applicability**.**

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Aligning external varieties to internal varieties for market solutions

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Abstract: Product customization is an essential requirement for manufacturing firms to achieve higher customers' satisfaction and fulfill business target. In order to achieve these objectives, firms need to handle both external varieties such as; customer preferences, government regulations, cultural considerations etc and internal varieties such as; functional requirements of product, production efficiency, quality etc. Both of the varieties are needed to accumulate and integrate for the purpose of developing customized product comfortably. Integration among these varieties for a case company are displayed and discussed with the help of domain mapping matrix (DMM) tool. Various customization strategies such as; modular design, commonality among modules and platform based product development process are elaborated and discussed critically. This paper is concluded with several managerial implications and future research direction.

Keywords: external variety, internal variety, product customization, variant management, product innovation, modular design, product platform.

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1 Introduction

Present competitive market and growing customer demands pushing firms to provide products and services that meet individual customer's desires and wishes. To meet up these requirements, firms need to be more flexible and responsive in their product development area. This flexibility offers them to cope with the complexity and uncertainty of customers demand (De Weerd-Nederhof et al, 2008; Larso et al., 2009). Different flexibility issues such as, technology flexibility, development flexibility, design flexibility etc are need to be considered by firms in order to meet up with growing customized products. There is a need to integrate both firms' capability and resources with the present market trend to meet up individual customers demand (Wu, 2006; Ceci and Prencipe, 2008). Along with internal capacities firms also need to consider various product development environments such as, government regulations, environmental impacts, technology obsolesces and so on.

Dynamic nature of customers' preferences influences manufacturing companies to critically concern about their technical specifications with desirable qualities (Liang, 2008). This dynamism could be controlled effectively through understanding potential customers' aspirations and needs with technical specifications (Santala and Parvinen, 2007). Anecdotal evidence suggests that failing to understand with customers dynamic needs hinders firms' effort to strengthen customer loyalty, lower customer acquisition costs and increase long term customer profitability, all of which are key factors that influence financial performance (Grieve and Ortiz, 2003). In response to this challenge, firms need to understand how customers' perceptions are changing and what the consequences of those changes on market demands are (Fuld, 2003). There is however, little indication that firms have formal processes to tackle this activity or allocate proper resources into anticipating shifts in value perceptions (Blocker and Flint, 2007).

Along with customers' perceptions and needs, firms are also facing challenges from technological innovation such as newer technology, different design changes and adaptability of changes within exiting product development environment. There may be different available techniques or strategies to adopt these changes but it is commonly difficult to choose for the best option. Rigorous research is needed before implementing any suitable strategy for a firm in order to integrate the new technologies with the existing ones. Technology needs to be adjusted and refined by understanding how customers value perceptions change according to market demands and how suppliers can directly observe the needs of change and project their impact into future corporate strategies. However, there are little observations that firms have formal processes for allocating significant activities or resources into anticipating major changes in the global marketplace.

To cope up with changing customers' perceptions, customizing product and developing product variants, firms need to reduce complexities of their product development philosophy. The effects of complexity generally arise from production program complexity, high configuration complexity for customers and increasing planning and scheduling complexity (Blecker et al., 2005). In order to reduce such complexities, designers and engineers need to coordinate efficiently among three specific design strategies such as, modular design approach, developing commonality among modules, and platform oriented product development. Along with such strategic options, there is also need to establish a mapping between external varieties which are evolved from customers' preferences, government's regulations, market demands etc and internal varieties such as, components list, products performance, quality etc. From such consequences, two objectives of this research can be summarized as:

(i) to demonstrate innovative approaches of modular design, commonality among modules, and platform-based design with a view to develop product variants.

(ii) to establish and demonstrate the appropriateness of a relationship mapping between external varieties and internal varieties of product development participants.

In order to fulfill such objectives, an innovative idea of modular design approach, justification of commonality among modules and platform-based product development process are explained in this research paper. A case example taken from a ship engine manufacturing company is also provided with this paper in order to demonstrate the suitability and appropriateness of mappings between external varieties and internal varieties of product development participants. The rest of the paper is organized as follows: Section 2 outlines literature review, where present and past researches on product development are focused on. Different product development strategies are presented in Section 3, whereas in Section 4 external and internal design varieties for customization are discussed. A case example is provided in Section 5 in order to demonstrate the mapping between external and internal varieties. Several managerial implications are stated in Section 6 whereas; the paper is concluded with future research directions in Section 7.

2 Literature review

Customization which is growing continuously aims at providing customers with individualized goods and services. Manufacturing enterprises strive for customizing their products by taking into account a high level of product variety, which increase the internal complexity in operations and manufacturing related tasks (Hu,et al., 2008). To achieve better customers' satisfactions and gaining business target, firms are taking initiation to produce as many product varieties as possible (Bramham et al., 2005; Blecker and Abdelkafi, 2006). Although there are several constraints and limitations in developing product varieties and diversifying market segment but it can not be avoided in order to gain business success. Most of the industrial companies are nowadays looking forward to customizing their products which is the most critical means to deliver true customer value and achieve superior competitive advantage.

To be successful in product customization, different development strategies such as modularity, design product family, commonality in components and/or modularity etc are the powerful ways of achieving business success (Fixson, 2007). These strategies influence reduction of lead time for products, fewer specification mistakes, reduction of the resources and the possibility of optimizing the products according to customer demands (Thevenot and Simpson, 2006; Lee, 2007; Shamsuzzoha and Helo, 2009). Customers are looking for product variety with higher quality and lower prices. There is a constant need to investigate the possibility how product variation and demand distributions affect various product development strategies. Each of the stated strategies has its own advantages and disadvantages which need to be carefully evaluated before moving for generating successful products variants.

Along with such product development strategies, manufacturing firms are also very much concern to integrate both internal capacities to meeting up with external demands (Größler et al., 2006). For successful firms there is a need to maximize the utilization of internal resources to cope up with external values or market demands. Internal resources especially technical elements such as, various parts, modules, machineries etc are carefully needed to alignment with external elements such as, specific customers requirements, emission regulations, government rules etc in order to fulfill target market solutions or offerings. To meet up today's economic environment, customers demand value optimally and to support production benchmark, firms need to map between internal elements and external elements successfully (Iamratanakul et al., 2008).

Various methodologies and models are presented in literature to map this interaction between internal capacities to external outputs. Afuah (2002) suggested hedonic model to determine the implicit prices of each product characteristic and the implicit value of the different underpinning capabilities. Firms based on resource-based views can have profound strategic opportunities in mass customization abilities (Collis and Montgomery, 1995; Hayes and Pisano; 1996; Brown and Bessant, 2003). There are often considerable debates on the possible conflict between internal resource-based strategies and external market-driven approach or solutions (Gosselin and Bauwen, 2006; De Sarbo et al., 2007). It is therefore, required to analyze what types of capabilities are likely to give a firm competitive advantage in different market solutions.

Product customization induces a high level of product variety, which creates internal complexities in product architectures, operations and production processes. Complexities also arise from configuration process for customers, planning and scheduling of various resources and matching the market demand with available capacity. There are direct relationships among the complexities, costs and efficiencies. These complexities need to be managed adequately in order to be successful in customization process. We need to consider minimum utilization of resources in order to meet certain expectations or offerings for customers (Du et al., 2006). Customization is a way of optimal understanding of customers' desires or preferences that should be considered as partners in value creation process (Shamsuzzoha et al., 2009). Customers' preferences often trigger to evolve new idea generation and/or improvements in the existing design architecture, which definitely help for firms' innovation process (Hanninen and Kauranen, 2007).

3 Product development strategies

In literature, there are several product development strategies in order to develop customized products namely, modularity, product family, postponement, component commonality, product platform, product configuration, etc. Among these strategic options, we have considered most important strategies as modularity, commonality among modules and product platform in this research with a view to develop organized product variants to meet customers' solutions. These three strategies are presented and discussed in detailed as below.

3.1 Modular design aspect: the perspectives

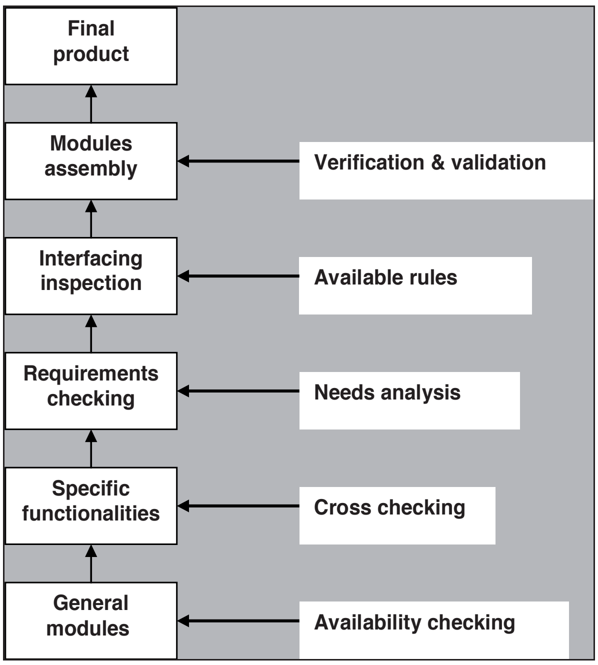
Product modularity can be defined as a special form of product design where the couplings are loosely interfaces with standard components (Sanchez and Mahoney, 1996; Gershenson et al., 2003; Ro et al., 2007). This is generally treated as a system of independent parts or modules integrated with logical units (Newcomb et al., 1996). Therefore decomposition is the main concerns of modularity as the interaction between-modules are low whereas it is high among intra-modules (Ulrich, 1995; Jiao et al., 2007). This decomposition enables the development of large number of sub systems or modules which is one of the prerequisite for product customization. These sub systems can be assembled and tested before to integrate into a final product (Worren et al., 2002; Brun and Zorzini, 2008). Modularity therefore, brings various flexibilities among product design and development such as production mix, volume, modification, and changeover (Schmenner and Tatikonda, 2005; Jacobs et al., 2007).

Modularity is generally considered as a strategy with the greatest potential to develop product variants which is an essential feature for customization. For instance, Dell received a key advantage over many personal computer companies like IBM, Apple due to the many varieties and modular design approach (Ro et al., 2007). Supply chain management nowadays becomes easier due to modular design phenomenon (Hoetker et al., 2007). In such consequences, close partnership is required between the company and module supplier. In modular design, company does not need to cope up with a large number of suppliers but only with a few number of module suppliers. It ensures closer innovativeness towards both sides. Companies could concentrate their own innovation with in-house components whereas, module suppliers innovate different functionalities among supplied modules. This ensures cooperative innovation and improvement among industrial partners.

There are several methodologies to support the development of modular product structure. Steward (1981) presented Design Structure Matrix (DSM) method to develop clusters or modules whereas, Pimmler and Eppinger (1994) proposed three steps approach namely decomposition, interactions and clustering among design elements. Modular Function Deployment (MFD) method was developed by Erixon (1998). In any ongoing design process functional elements are generally considered at the conceptual stage and developed further as the project moves on (Pahl and Beitz, 2007). Before considering modular design, various procedural steps need to be followed up in order to fulfill specific requirements from products (Lehtonen, 2007). There are two kinds of approaches namely; bottom up approach and top down approach that firms can consider developing their modular product architecture. Both the approaches are presented in detail below.

(i) *Bottom-up approach*: In bottom-up modular approach, modules are formed beforehand from initial concepts or requirements of the final products. Figure 1 illustrates the procedural steps of this approach. From figure it is seen that after forming general modules, each of them are cross checked for specific functionalities of the end product. When functionalities of the modules are screened out it is then needed to analyze for requirements checking to meet up customers demands. Up to this point designers choose suitable modules that meet both the functionalities and requirements of the targeted products and proceed for standard rules for interfacing the modules. Before the final product, all the required modules are assembled, verified and validated as displayed in Figure 1.

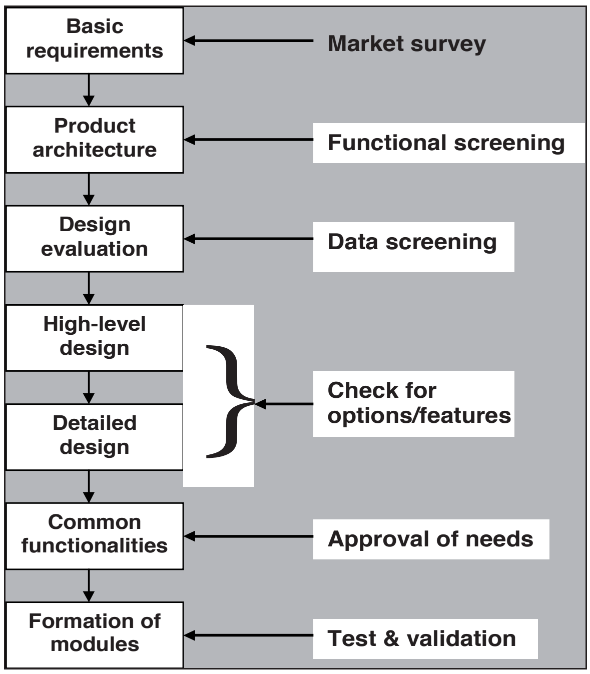
Figure 1 Bottom-up modular approach



In bottom up design approach the basic design elements are specified in great detail at early design process, which offers avoidance of complexities at the later stages. With this approach designers design products as pieces not part which are finally added together to form assemblies of modules or products. As the modules or subassemblies are carefully developed at the early design stage, this approach offers minimization of inventory cost and lead-time. The bottom-up approach has some limitations too. For instance, to apply this approach user needs a lot of intuition and or iteration to decide the functionality that a module can provide. There are also risks in this approach as the modules are formed without having a clear idea of how they link to each other modules or parts and that linking may not be easy enough as thought initially.

(ii) Top-down approach: As opposed with bottom-up modular approach, top-down approach begins from basic requirements of a product or product families which are come from rigorous market survey as seen in Figure 2 below. All the requirements are collected, screened out and formulated within the product architecture. This available architecture is studied and critically analyzed for its suitability of high level design and forwarded to detail design phase. After this stage, common functionalities among design elements are sorted out according to customers' needs which are approved finally. When all needs are finalized, designers move toward the formation of expected modules which are then tested and evaluated for the end products.

Figure 2 Top-down modular approach



This design approach basically evolves by the use of so called skeletons which are generic structures and contain information on the overall planning of the targeted products. There are fewer operational errors and higher confidence in this approach as each developed modules are processed separately and get higher time and concentration individually. Designers could apply their own knowledge and experience during modules development and in this way it is easier to identify the errors, which might generated from individual module. Top-down approach is less flexible as the modules are generally formed according to specific functionalities and requirements which can not be modified easily.

3.2 Commonality among modules: prospects

In order to faster response to the diverse customer requirements and to cope up with changing business environment, designers need to bring extendibility and flexibility among product design processes. Module-based product design and development strategy offers such objectives of extendibility and flexibility which is a burning issue in today's modern firms. It is a strategy of developing independent and interchangeable building blocks which mix and match with standardized interfaces. The objective of modular design is to minimize production complexity by developing individual modules clustered with highly dependent components or functionalities. All the developed modules are assembled together in order to have the end products after following specific design rules.

To implement this modular approach successfully there is a need to improving commonality among sub-modules and modules. A common module can be defined as having multiple usability which means commonality at system level design (Kinder, 1989). These common modules or sub-modules provide newly added value to functionalities of product when needed. Before conducting commonality among modules, each module is registered and standardized with individual specifications, which becomes the basis of commonality. There needs a clear and concise direction from top management in pursuing commonality among modules as during the design process changes for commonality may be in evitable. Common modules can be based on the reasons of manufacturing, maintenance and logistics (Lehtonen, 2007). Complexity in manufacturing process is reduced substantially through applying commonality among modular architecture.

It is pretty easy to develop product variant through common modules. Common and non-common (special function) modules can easily be interchanged in order to develop product variants to meet diverse customers' needs. Common modules reduce resource requirements, component inventory and cost of transportation by reducing volume. This philosophy also extends product life cycle through easier changeability and up gradation possibilities. Standardized specification among common modules can reduces assembly and installation time and increased the possibilities of platform-based product development process. Too much commonality among modules bring suffering for firms through reducing the credibility of customers' preference, which may negatively affects on reduced sales.

3.3 Product platform

Platform-based product development is another important strategic feature to develop customized products with many variants. Many firms are not concern about precise and operational definitions of their product platforms from which satisfied progress is difficult to achieve. In order to develop product variants, platform strategy may be an effective and efficient solution for manufacturing firms. With this strategy, the basic platform is designed and developed to match most of the parts or modules within a product or product family. Platform-based product development is especially beneficial for higher demand level and may not be suitable or cost efficient in lower demand volume. This strategy enables firms to cope with the conflict between customization and efficiency (Efstathiou and Zhang, 2004).

Before implementing this strategy, existing product architecture, business targets, potential market segment, as well as the timing of product introductions are needed to consider carefully. Organizational managers also need to reconsider the financial situation of their firms and to map the balance between the investment in the development of platforms versus products and the changes that are possible in the margins and contribution of platform-oriented products to profits. It is therefore clear that platform-based strategy embraces both the management and technology paradigm in order to be successful. There needs a sensitivity analysis to select the platform which is appropriate for individual firm with easy configuration option and to guidance for periodic design review (Dai and Scott, 2007).

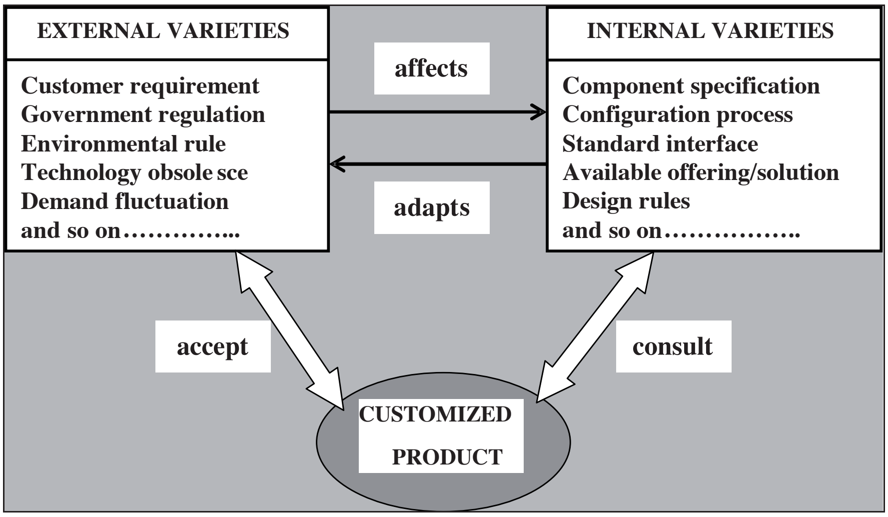
As the development of platform is highly cost-intensive and time consuming, it is therefore needed to serve it for a longer period of time to justify its usefulness and to achieve competitive advantages. This strategy offers reduction in overall pricing due to its applicability for a longer period of time. However, platform-based product development has also several limitations too. This strategy resist immediate product innovation as it is not easy and economical to modify/change a platform in shorter notice due to its rigidity and compactness. This limitation reduces product development flexibility and adjustment with current demand. There is also a risk of products look alike if developed from the same platform, which damages customers' satisfactions and reduction of sales.

4 Design varieties for customization: external versus internal

The influence of wider customization makes the product development process much complex than ever. To cope up with such complexity, organizational managers, designers, engineers need to understand and interpret the various issues of complexity that surrounds product development process. The complexity arises both from the degree of internal structuring and external factors which are needed to be examined and mapping to adaptation with each other. This mapping helps to implement architectural updating of existing product or developing new product within a firm. Internal factors or structuring is able to respond quickly with higher variety and dynamism if a manager knows in advance the external complexities with explicit adaptation and mapping.

Both the internal and external factors of product development process can be interpreted as varieties which affects each other within an organization. Internal varieties can be considered as components specifications, design rules, standard interfaces, configuration process etc, whereas external varieties are notified as customers' requirements, government regulations, environmental rules, etc. Both the varieties are needed to be scaled out carefully before proceed towards any kinds of control over them. For instance, if internal varieties are sufficiently prepared to deal with external varieties then it is easier to manage both of them successfully and economically. The affecting factors for both internal and external varieties are captured in a conceptual framework as displayed in Figure 3 below.

Figure 3 A conceptual framework for varieties (internal & external) in customized product development process



From Figure 3, it is observed that to develop any product external varieties always intrinsically affects internal varieties. In order to develop successful product or product variant, internal varieties also need to adopt external features for possible improvement or upgrading. From the figure we can also interpret that customized product must accept external features to be competitive in the market while consulting with internal features or resources. This customized product development framework integrates all the basic requirements to uphold management decisions and improving various design elements in general. It is therefore, crucial to manage these variety elements properly with a view to mitigate developmental errors.

In order to control both external and internal varieties, firms need to adopt certain strategic decisions. For instance, external varieties can be controlled and minimized through applying certain development phenomenon such as; product configuration process, implementation of web-based technology and tool, customers involvement in the early design process etc whereas, internal varieties may be controlled through adopting modular product architecture, commonality among parts or modules, platform-based product architecture, standardization etc. Through controlling both the variety effectively, firms' managers could facilitates customers' preferences and gaining market share by offering many varieties of products.

5 Mapping between design varieties: a case example

With a view to fulfill two research objectives, we have presented a case study conducted at Wärtsilä Finland OY, Vaasa Delivery Centre. Wärtsilä Finland OY is one of the world's leaders in ship power generation and a major solutions provider for decentralized power generation and supporting services. This company provides complete lifecycle solutions for power generation and marine propulsion. Its business units are divided in three divisions' – marine and licensing, power plants, and services. Wärtsilä Finland OY has operations in 70 countries with 160 locations worldwide. In 2008, company's net sales were totaled EUR 4.6 billion with 19000 employees.

The case company is looking forward to have a suitable tool or methodology to mapping among its external varieties with internal capabilities. To fulfill Wärtsilä's business requirements, we have collected various design data (component/module list) as internal varieties along with customers' requirements (solutions/offerings) as external varieties. In order to map both the varieties in a visual order, we used a tool named domain mapping matrix (DMM) developed by Danilovic and Börjesson (2001). This tool helps to display two different domains in a matrix format from where various clusters or modules are formed depending on the interdependency strength. Figure 4 displays two separate domains (external and internal varieties); one along the rows (customers' requirements as engine speed, direction of rotation, emission regulation, fuel type etc) and other along the columns (components/modules such as engine block, oil module, turbocharger, cylinder head etc).

Figure 4 Display of customer requirement versus component/module (before partitioning)

Customer requirement versus Component/module (DMM)	Engine block	Power train	Cylinder head	Pump cover	Valve train	Multicover	Injection equipments	Low pressure fuel system	Leak fuel system	Pumps	Filters	Sump	Oil module (cooler)	Piping	Starting air	Pipes	Starter motor	Water pumps	LT system	HT system	Air cooler	Charge air system	Cleaning device for turbo	Control system	Exhaust gas system	Insulation	Turbocharger	Turbocharger bracket	Control air system	Booster	Governor	Electronics for control air system	Connectingbox	Sensors	Cables/rail	PTO-shaft	Common base + equipments	Tools	Software
KW/Cylinder	X	X	X		X	X	X	X					X								X	X			X		X	X			X								X
Engine speed		X			X		X			X								X						X							X								X
Prelubrication pump on/off engine				X										X																									
Environment conditions													X					X			X						X												X
TC 1/2 stage																			X	X	X	X			X	X	X	X						X	X				X
TC cleaning option																									X		X	X											X
Classification	X	X					X			X	X							X								X								X	X				
Engine mounting (CBF + Resilient)	X											X		X					X	X																	X		
CAC type 1/2 stage	X																	X	X	X	X	X						X											
TC location	X			X									X	X					X	X	X	X			X	X		X						X	X				
Sea water pump (cooler for small bore)	X			X																																			
Direction of rotation				X	X	X				X			X				X	X													X			X	X				
Stand by connections				X				X						X					X	X																			
Engine driven fuel pump & filter				X				X																															
Single or multiple installation (gearbox type)													X								X	X					X	X									X	X	X
Deep sump												X		X																				X	X		X		
Thermostatic valve on/off engine																		X																					
Extra cooling water pump capacity																		X	X																				
Charge air shutoff valve																						X												X	X				X
Suction air connection																						X					X												
Exhaust pipe system (spex/pulse)																									X	X	X							X	X				
Exhaust connection degree (angle)																										X	X												
Maintenance space	X		X	X	X					X	X			X		X		X			X					X	X	X						X	X	X	X	X	
PTO for crankshaft bolts		X		X																																X			
Emmission regulation		X	X		X		X														X				X		X												X
Fuel type		X	X		X		X	X	X										X	X							X				X			X	X				X
FI system type (conventional /CR)					X		X	X	X																														X
Governor type																															X			X					X
Automation type																																X	X	X	X				X

The interactions or dependencies between each participant of both the domains are presented through the mark 'X'. The blank space represents no interactions or dependency. For instance, customer requirement (external variety) 'Engine speed' is dependent or interrelated with the components/modules (external varieties) of 'Power train', 'Valve train', 'Injection equipment', 'Pumps', 'Water pumps', 'Control system', 'Governor' and 'Software' and the dependencies are presented by marks 'X' respectively. All other dependencies between two varieties are marked with 'X' within the complete matrix as displayed in Figure 4. It has to be noticed that for the simplicity of display, we have considered sample number of components/modules and customers requirements from Wärtsilä company.

In order to manage the design process by fulfilling customers' requirements, we need to accommodate them in closer vicinity. This specific objective can be fulfilled through 'partitioning' operation, where the elements in rows and columns of the two domains are rearranged according to the tightness of dependencies (Steward, 1965). This partitioning process triggers the clustering operation where different clusters or modules are formed according to the closeness of interdependencies as displayed in

Figure 5 below. For instance, from Figure 5 it is observed that four clusters or modules are formed namely; ‘Engine module’, ‘Fuel system module’, ‘Exhaust system module’ and ‘Bus module’. All the modules are formed according to the closeness of dependencies of each element within a module.

Figure 5 Display of customer requirement versus component/module (after partitioning)

Customer requirement versus Component/module (DMM)	Cylinder head	Engine block	Power train	Valve train	Governor	Starting air	Multicover	Cleaning device for turbo	Leak fuel system	Pipes	Booster	Starter motor	Oil module (cooler)	Injection equipment	Pumps	Pump cover	Low pressure fuel system	Water pumps	Filters	Sump	Control system	Pipings	PTO-shaft	Air cooler	Charge air system	Sensors	Cables/rail	Exhaust gas system	Turbocharger	Turbocharger bracket	Tools	Connectingbox	Control air system	Electronics for control air system	Insulation	LT system	HT system	Common base + equipments	Software
KW/Cylinder	X	X	X	X	X		X						X	X			X							X	X			X	X	X									X
Engine speed			X	X	X									X	X			X			X																		X
Maintenance space	X	X		X						X					X	X		X	X			X	X	X		X	X		X	X	X				X			X	
Emmission regulation	X		X	X										X										X				X	X										X
Fuel type	X		X	X	X				X					X			X									X	X		X							X	X		X
Direction of rotation			X	X	X		X					X	X		X	X		X								X	X												
Classification		X	X											X	X			X	X							X	X								X				
TC 1/2 stage																								X	X	X	X	X	X	X					X	X	X		X
Suction air connection																									X				X										
Exhaust pipe system (spex/pulse)																										X	X	X	X						X				
TC cleaning option																												X	X	X									X
Charge air shutoff valve																									X	X	X												X
Environment conditions													X					X						X					X										X
Governor type					X																					X													X
Exhaust connection degree (angle)																													X						X				
Sea water pump (cooler for small bore)		X														X																							
Extra cooling water pump capacity													X					X																		X			
Thermostatic valve on/off engine																		X																					
Engine driven fuel pump & filter																X	X																						
Prelubrication pump on/off engine																X						X																	
PTO for crankshaft bolts			X													X							X																
Deep sump																				X		X				X	X											X	
CAC type 1/2 stage		X																X						X	X					X						X	X		
Single or multiple installation (gearbox type)													X											X	X				X	X	X							X	X
TC location		X											X			X						X		X	X	X	X	X		X					X	X	X		
Stand by connections																X	X					X														X	X		
FI system type (conventional /CR)				X					X					X			X																						X
Engine mounting (CBF + Resilient)		X																		X		X														X	X	X	
Automation type																										X	X					X		X					X

Engine module

Fuel system module

Exhaust system module

Bus module

Bus module

The developed clusters or modules can be focused and processed separately in order to achieve better product design which might fulfills most of the customers needs. For instance, to consider the customer requirements KW/Cylinder, engine speed, maintenance space, emission regulation, fuel type, direction of rotation and classification, we have to concentrate more on ‘Engine module, ‘Fuel system module, ‘Exhaust system module’ and ‘Bus module’. Designers have to consult with each module before changing any elements within a module in order to fulfill certain customer requirements. This clustering process also enhances assembly operations as it fairly easy to assemble a module than many components for certain functionalities.

Among four developed modules in Figure 5, we could also observe the large module termed as ‘Bus module’, which can be considered as basic platform of other three modules and components. This platform has the interactions with almost all the components/modules and customer requirements to fulfill the business target. This way of platform and modules development could reduce the time, cost and resources which satisfies all the customers’ requirements. The presented bottom-up innovative approach could be very much applicable and learning process for most of the industrial organizations in order to fulfill both of their external and internal varieties successfully.

6 Managerial implications

To be competitive with cost effective products, firms need to ensure right type of product that satisfies customer's expectations and at the right time with right prices. Each of the business entity should have major focus to develop product and services that satisfy the market demands. Specific guidelines are needed to be developed for organizational managers and designers in order to develop customized product. These guidelines could be formulated through considering specific product development strategies and conducting overall mapping between external and internal factors responsible for product development processes. Both the objectives are considered within the scope of this research.

Various product strategies such as; modularization, commonality, platform-based design and development, product family etc are the available ways of managing customized product efficiently and cost effectively. All these strategies are accountable for creating product variants which are essential to meet diverse customers' needs and preferences. Especially, modular product architecture, commonality among modules and platform-based product development are considered the basic design philosophy to develop variants product quickly and economically. All other strategies are also need to consider carefully.

Before considering any product development strategy or to improve an existing product or product family, managers, designers and engineers need to consider both internal and external varieties, which directly or indirectly affects on different production phases. In order to develop customer specific product, firms have to identify various customers' desires and requirements, which finally transformed into functional elements within the end product. Designers corporate these functional entities into the product design phases, which are needed critical screening before implementation. All the market or customer requirements are needed to be accommodated as much as possible within the design features of end product. Successful organizations always try to map between their market demands and internal resources to be competitive.

In product development stage, all the external and internal varieties are accumulated and could be displayed with the help of DMM tool, which visualizes the basic interdependencies among them. These interdependencies can be minimized through internal operations such as clustering or partitioning and grouped the coupled relationships together in order to develop certain clusters or modules. The formation of modules triggers to facilitate assembly operation, minimizes inventory level and help to control firms supply chain management. The highly interactive module could also be considered as platform, which offers benefits as cost reduction and minimizing assembly time with many product variants.

7 Conclusions

An effective production management process will allow firms to increase their credibility of choice by freeing up valuable engineering time, minimize product inventory and improve time-to-market by minimizing downtime. Specific production strategy such as; modular design, standardized component, product platform etc can be implemented, evaluated and documented for the purpose of effective product variety management which is crucial for any business success. Targeted principle needs to be continued if it is profitable and redundant if it is economically not viable. In firm, specific production strategy requires to be implemented at the very early stage of the new product development process, which is especially intuitive, dynamic and very flexible in nature.

In today's global business environment, product development strategy needs to be reassigned with a view to achieve synchronizing between design engineering and market demands. External elements in product development activities such as; government regulations, changeable customers attitudes and desires, environmental impacts, technology obsolesce etc need to be carefully adjusted with firms internal constraints or resources such as; components or modules list, production rate, quality specifications etc. Although it is very much essential to ensure adjustments or mapping between these internal and external elements but most of the firms do not have sufficient tools or methodologies to handle it.

In this research we have accommodated a tool named DMM through which it could quite manageable to interpret both the varieties comfortably and economically. For the demonstration purpose, we have also presented a case example to validate one of our research objectives. It was fairly easy to implement this idea with the case company. Other research objective was also presented and discussed in this research article. It is hoped and believed that both the innovative approaches will be a learning process for organizational managers, from which they would be beneficent for their corresponding firms. Future research could be carried on to investigate the economical feasibility of various product development strategies and the mapping between external and internal varieties.

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Platform-oriented product development: prospects and limitations

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Abstract: Globalised demands for products variants with reduced developmental time lead firms to consider effective and organised product development approach. In order to fulfil these requirements, manufacturing firms are increasingly moving towards platform-oriented product development or are planning to do so to reduce complexity and better leverage investments in product design, manufacturing and marketing. In this paper, an overview of key topics related to platform design and product variety management is provided. A review of recent works on product platform design and its application to industries is discussed. A generic design structure matrix (DSM) tool is presented that outlines an effective methodology for platform design. This methodology is explained through presenting an example of a diesel fueled ship engine. Different limitations and risks associated with the management of platform-based product design and development are discussed along with some future research directions too.

Keywords: product platform; customisation; product variety; design structure matrix; DSM; commonality.

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1 Introduction

Today’s global competitive environment, business firms are under intensive pressure to develop product varieties in order to meet ever-increasing customers’ desires and needs. Rapid changing of technology, shorten product life cycle and overall customers demands on high variety options are driving firms for developing new product variants (Pine, 1993; Ulrich, 1995). To manage higher product variety and complexity in development processes, companies are looking for platform-oriented product design and development. In platform-based approach, components, modules and resources are shared across the family of product lines. This strategy attempts to save costs by sharing core elements among several products in the product family. In order to design cost effective platform for product families, firms need to develop an activity based costing system, where activity costs are mapped to individual parts in the product family (Park and Simpson, 2008).

The concept of product platform first coined by Meyer and Lehnerd (1997), which focuses basically on sharing components, subassemblies, interfaces and processes among different product variants. The objective of this approach is to reduce development cost while maximising diversification of product variants. Growing trends of customised products with relatively higher varieties puts extra pressure on manufacturing firms. This paradigm could be successfully overcome through improved engineering efficiency, higher solution reliability and reduced direct cost by implementing standardisation. It encompasses more standardised sales, engineering and procurement process which create opportunity through additional customer values (Karandikar and Nidamarthi, 2007). Firms are trying hard to obtain more efficient and flexible product design and development systems with a view to satisfy global customers with minimum costs, reduced manufacturing resources and better implementation of newer technologies.

The design of a product platform is the key to a successful product family creation, shorten lead time and reduce cost. Managing product variety brings higher competitive advantages for firms through higher gain in market segment and with more satisfied customers (Yang et al., 2005). It is quite challenging for firms to create product variety economically. To reduce the cost of variety, manufacturing firms are considering product development approaches that reduce complexity and better investments in product design, manufacturing and marketing. Platform approach, which is a process of identifying and exploiting commonalities among a firm’s offerings, could be a successful strategy to create variety at low costs (Meyer and Lehnerd, 1997; Ulrich, 1995; Thevenot and Simpson, 2007).

The platform-based product development offers several benefits to business firms. Firstly, this approach can potentially reduce the fixed cost for producing individual product variants. Secondly, because of greater degree of reuse this approach often encourages firms to invest more money and time in product development, which results tighter components integration, better product architecture and lower unit cost. Due to the commonality of a platform for several identical products, its set up cost, maintenance cost and other variable costs are low in general. Platform also encourages team works and team learning within organisation, which offer insights for cross-functionality, embeddings in organisational structure and effective management of project complexity. It expedites overall project management skills, expanded social network and boundary-spanning skills (Edmondson and Nembhard, 2009).

Product family, which originates from specific platform, may have an aggregation process of distinct products. This development process of product family is tightly linked to issues of importance to the entire firm's product change, product variety, component standardisation, manufacturability and product development management (Zha and Sriram, 2006). A common platform for a product family can permit a variety of derivative products to be developed more rapidly with each product offering the characteristics and functions desired by a specific market segment. Zacharias and Yassine (2008) explained that platform-based product family contributes a percentage to overall market coverage inside a target market segment. It is also mentioned that the specific product variant contributes to the market segment is linked to the degree of distinctiveness.

This paper is organised as follows: Section 2 outlines various strategy of platform design, while Section 3 discusses the applicability of platform strategy for mass customisation. In Section 4, strategic mapping among globalisation and platform strategy is discussed, whereas, the relationship between DSM tool and product platform is outlined in Section 5. The applicability of DSM tool for the creation of platform is illustrated in Section 6. Several challenges and limitations of platform-oriented product development approach are presented in Section 7 whereas; some of the managerial implications are elaborated in Section 8. Brief discussion and future research directions are summed up in conclusion of Section 9.

2 Strategy of platform design

The design of product platform is generally related with architecture, manufacturing process, supply chain integration etc. Its applicability is highly dependent on the strategy of any organisation. Substantial effort from management concern is needed in order to implement a broad and effective platform strategy. As several products or families of products are created from the same platform, care should be taken before design this and constant monitoring is needed with fellow engineers for its evolution and updating. There must be design flexibility within a platform so that it can adapt easily any kind of addition, subtraction or redesign as needed just as a single component.

Platform design promotes better learning across products variants and it reduces the number of testing and certification of complex products such as, aircraft (Sabbagh, 1996), aircraft engines (Rothwell and Gardiner, 1990), car engines (Naughton et al., 1997) etc. In car industry, 50% reduction of capital investment is possible through platform-based production strategy, where sharing underbodies among different models and using common resources for various operations such as welding, sheet bending, forming etc. (Muffatto, 1999). Sony has built different models of Walkman using modules and platforms (Sanderson and Uzumeri, 1997). Similarly, Hewlett Packard used platform-based product development, where several kinds of inkjet and laser jet printers are developed though differentiation in manufacturing and assembly processes (Feitzinger and Lee, 1997).

There are four basic types of platform strategies available in industrial sectors such as, commonality, modularity, scalability and postponement (Huang et al., 2005). In commonality, the basic targets are to make the components as common as possible and use them with optimum numbers of end products in order to create variety. The components are made as standard as possible in commonality platform. Modularity approach concerns with developing optimal numbers of modules to share within different end products. In scalability refers to the serialisation and the ranging of product parameters that have to be changeable. Finally, postponement platform strategy involves avoiding the early product proliferation and enabled manufacturing process as late as possible until customer orders are received.

In product platform design, cohesive and flexible product architecture is very much essential for the overall corporate vision. It is considered as a base for creating variety among products or family of products. Product architecture is required to be analysed and evaluated efficiently for implementing such strategy in industrial firms. Before developing a platform, various factors such as market segments, product roadmaps, product architecture, performance targets etc., have to be considered. General product strategy should be able to use platform as supporting elements from which it allows easily to modify different subsystems and components for different market segments (Simpson et al., 2006).

It is also to be concerned for industrial establishment that abundance of product variants is undesirable, both from the product life cycle points of views and from the end users. Therefore, it is suggested to consider minimum numbers of platforms and to maximise commonality benefits. A technology-driven platform enhances firm's existing platform design elements through identifying underlying characteristics such as, performance level, principle of operation and technology architecture (Khadke and Gershenson, 2008). The platforms are to be developed in such a principle that maximum extent of utilisations are possible, since their development need significant amount of efforts and resources. Due to the investment of time and money there is always a pressure to use a platform repeatedly and options should be opened to innovation and renewal of the platform for continual usage.

3 Product platform for mass customisation

3.1 Platforms enhance customers' satisfaction

Due to globalisation of business environment and increasing trends for customer specific products pushing firms to develop products that satisfies most of their customers. This need inspires them to move towards mass customisation approach rather than traditional mass production approach. This approach could be enhanced through platform-based product development, which can support customised product and service offerings. In this approach, customers' requirements are mostly satisfied through offering modular components to formulate multiple product variants according to market segments (Li et al. 2008). Platform-based product development enables firms to offer global portfolios of products and mitigates differences in design, styling and regulations. Cross functional platform teams could have been designed to integrate and improve investment decisions among marketing, sales, engineering, manufacturing and logistics.

Faster time-to-market can be ensured through implementing a successful platform development strategy, which is essential for mass customisation approach. In mass customisation, development of product variants is highly demanding for customers' satisfaction which could be fulfilled quite comfortably by applying platform-based product design and development. In this approach, various subsystems and interfaces are coordinated and planned from which a common structure is formed in order to efficiently design and developed stream of products derivative. A platform initiates this products derivative from which a product family is evolved (Huang et al., 2005). The reduction of complexity, inventory cost and time-to-market are possible by successful implementation of platform strategy.

3.2 Influence of logistics on customisation

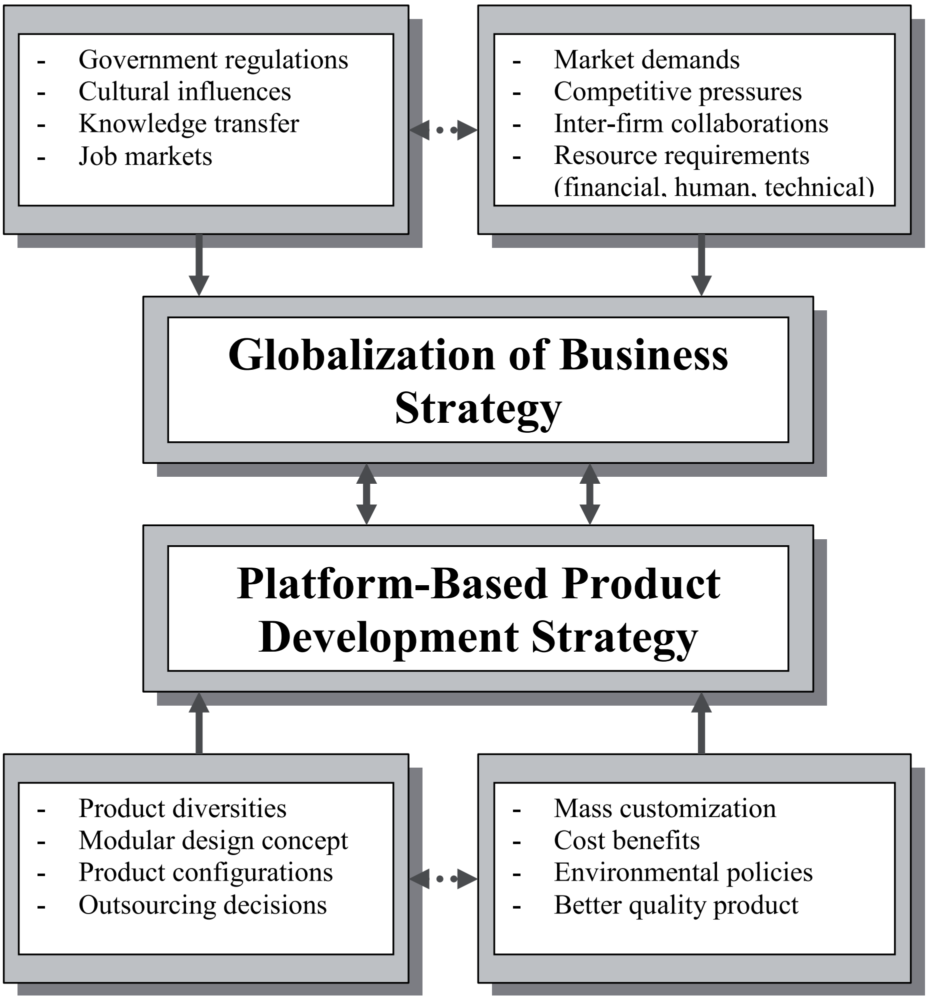
Nowadays firms are moving forward to outsource their product development process in order to gain competitive advantages from regional, cultural and availability of cheaper resources. In order to achieve outsourcing benefit, firms need to incorporate distributed and dynamic supply chain flexibility, which upholds management stability (Frayret et al., 2007; More and Babu, 2009). The integration of logistics domain with product development participants' enhances the coordination among resource allocation, supplier management and supply contracting. Therefore, an effective collaborative supply chain planning and practices are required with a view to develop better relationships with each strategic partner (Bayazit, 2007). A supply chain platform could play an important role in supporting supply chain design and mapping between process domain and logistics domain (Jiao et al., 2007). This approach implements domain specific knowledge transfer between production configuration and supply chain management decisions.

The product platform has effectively been guided for product specifications and features based on the 'voice of the customer' (VOC). In order to design and develop successful products variants for customers, firms must need to listen their customers' requirements and desires from market survey. From this market survey, several issues need to be accumulated such as, key products, volumes, market segment, revenue and profits etc., for establishing accurate platform strategy to create customised product variants that satisfies customers' expectations. Global enterprises also need to integrate direct customers' participation with the product development process through web-based configure-to-order platform (Jiao and Helander, 2006; Dai and Scott, 2007). Overall product platform development is a contemporary approach for flexible product development for mass customisation.

4 Relationship between globalisation and platform strategy

In globalised business and faster customisation approach, encouraging firms for necessary initiatives towards products differentiations. With the view to minimise cost structure, firms are adopting the possibilities of both outsourcing and off-shoring in order to achieve lower labour rates, reduced tooling and component costs, cheaper resources and so on. Nowadays, customers are almost using same brand of items or products worldwide, which facilitate product development in a distributed environment worldwide. Various factors influence the globalisation and platform-based product development process, which can be presented in a generic framework as displayed in Figure 1 below.

Figure 1 A framework of implementation for globalisation and platform-based product development strategy



4.1 Collaborative business strategy

This distributed business strategy enhances the possibilities to develop products using the common platforms globally. To fulfil such objective, firms need to be enriched with technology-based strategy in order to successfully develop new products or variants of products and processes. In the competitive market, formulating a systematic approach to the integration of inter-firm collaboration synthesises the business strategy from a practical point of view (Olson, 2008; Salmi and Torkkeli, 2009).

This inspires the designer to develop product platforms that meets global market segments with the ability to quickly and effectively commercialise newer version of products or product family. Globalisation in that respect not only offer opportunities for creating product variants or families but actually implies them successfully. Due to different regulations and cultural differences among countries, developments of flexible platforms are needed in order to adjust them accordingly with a view to satisfy the customers regionally (Simpson, 2004).

It is nowadays an increasingly significant business strategy to inter-firm collaborative product development in order to enhance product competitiveness (Hung et al., 2008). In such environment, effective partnership relationship could be developed among firms in different countries or regions to share the basic platform design or technology from where diversity of products can be fabricated easily according to market demands (Chiang and Trappey, 2007). Collaboration within firms has become an imperative to strengthen their niche values and remain competitive in global market. This ensures to maintain unique production standard globally.

4.2 Distributed platform approach

Globally distributed firms also adopt platform-oriented production process where various operational activities and knowledge are shared within their partner organisations (Jiao et al., 2005). In process platform, different operations for end products are configured according to local market needs. These platforms are needed to be so flexible that the expected or unexpected changes can be implemented during the original design of the platforms. This ensures the key challenges that firms have to face in order to predict the future changes with their product generation process. The life time of a platform is considered long from which multiple product generations are evolved (de Weck and Suh, 2006).

It is quite hard to predict the timing to change or update the existing platform for distributed firms as it depends on the customers' behavior and desires regionally. From local to global product platforms design, firms basically need to adopt modular type platforms, where various segments of platforms can be added, subtracted or replaced in order to meet market demands (Gabrielsson et al., 2006). Different modules are developed separately, transported to the regions of need and performed necessary adjustment according to customers' preferences. The advantage of modular platform is that similar product platforms can be used for derivative products all over the world.

Modular approach places greater demands on collaboration, especially geographically distributed collaborators and organisational groups for sharing and reuse the knowledge and information of developing product platforms (Alizon et al., 2006). If firms practice greater collaboration utilising a common platform can have several advantages when developing and manufacturing products. The design and development of mature products become a bottleneck for firms, which need to be developed concurrently and multidisciplinary design approach (Yu et al., 2008). The architecture based on distributed and concurrent design approach accomplishes the design analysis easier and less time consuming. Such approach proves the feasibility of platform architecture for developing complex and mature products.

5 Design structure matrix and product platform

The design structure matrix (DSM) methodology, which is developed by Steward (1981), can be used extensively for the creation of product platform. This platform could be a big contributor for firm's capability to maintain tradeoff between requirements for customised product development and driven down the production costs through economics of scale, reduction of inventory and lead time (Ulrich, 1995; Suh, 2005). DSM tool initiates optimal arrangement of components, their interactions and their mappings between function and form, which is the baseline for any platform architecture. It provides a structured methodology and shares some common architecture in the arrangement of physical components and their interdependencies.

DSM is a square matrix, where each row and corresponding column represents a single element such as component, task, people etc. The interactions or dependencies among the elements are presented within the off-diagonal spaces of the matrix through symbol as 'X' or '1'. The dependencies among elements can be considered as sequential, parallel and coupled (Browning, 2001). Generally, the interactions between sequential and parallel elements are straight forward and do not need any specific attention whereas, coupled elements are complex in nature and responsible for design iteration. Various modules are formed from these coupled elements and the module which has the highest number of interactions or interdependencies is considered as the bus module and termed as platform, upon which all other developed modules and components are assembled for the end products.

Various customers' desires or preferences are generally gathered, screen out for their viabilities and transfers those desires or needs into functional elements of the end products. These functional elements are converted to required components or parts which are finally forwarded for necessary fabrication process. Before proceed towards fabrication, it is highly demanding to investigate the possibilities of optimal sequencing process of the tasks and looking for the commonality of the operations and clustered them together. When the essential components or parts are fabricated, the next step is to find out their dependencies on each other and restructured them for possible modules formation according to the tightness of components.

Different components and modules as organised through DSM methodology are assembled over the base platform in order to form the end product. It is crucial to design and develop the platform in the early stage for specific product family or variants due to reduce lead time and developmental risks. The DSM is especially used for quick rearranging of the architecture based on proper information exchange and interface interactions. This method generally concentrates on the interfaces of the modules and components with the developed platform. It combines design elements based on their interdependency and reduces the apparent complexity of the product architecture. The DSM is also used to formulate the knowledge transfer along the complete product development system.

6 Application of DSM for platform creation

6.1 Development of platform for product varieties

The development of common platform is essential in order to share related products for creating varieties. It is a common goal for every company to maximising platform commonality with a view to meet today's customised business environment. It is therefore, necessary to ensure the reuse of components, manufacturing processes, organisational personnel and design information across the whole product development portfolios. Engineers are facing shortages of better and effective approaches to handle platform design scenarios. A platform design needs a methodology to incorporate higher level representations of design repository, which could be integrated with reusing archived design data. This design data overrides the goal to facilitate platform design through a matrix implementation approach as described in the following example.

To incorporate better platform design, firms are using successfully a matrix tool known as DSM developed by Steward (1981). This tool is recognised as an effective means to support platform creation in an intuitive and productive way. However, such tool has not been examined vigorously for designing product varieties. The application of DSM methodology improves the iterative and information-intensive nature of the design process and makes it comfortable to plan and schedule design tasks. In order to reduce platform development time, it is necessary to track exact product development information. This information is vital to know the interdependencies among product development participants and creating optimised platform for product variants (Baldwin and Clark, 2000).

Figure 2 Components relationships of a ship diesel engine

Components of a ship diesel engine		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36
Noise Mitigations Systems	1			X		X	X				X					X		X			X	X	X														X
Cooling Systems	2					X						X																X							X		
Flexible Couplings	3	X			X										X			X					X								X			X			X
Engine Management & Automation	4					X	X		X	X					X			X			X					X											
Pistons & Cylinder Liners	5	X	X		X		X																					X	X								X
Valves & Bearings	6				X	X			X	X						X								X		X			X								
Gearwheels	7																	X					X														
Fuel Injection Equipment	8				X	X				X						X								X		X											
Pumps & Filters	9				X		X		X							X	X							X		X											
Generators	10	X										X	X				X		X								X						X				
Electrical Motors	11		X								X		X						X								X						X				
Electrical & Automation	12										X	X							X		X						X						X				
Forgings Operations	13			X											X								X					X	X	X	X			X			X
Steel Constructions	14			X										X																	X			X			X
Turbochargers	15	X			X	X	X		X	X							X									X											
Emission Control Systems	16				X	X				X						X										X											
Propeller Shafts	17	X		X				X						X							X		X	X						X							X
Transformers	18		X								X	X	X								X				X		X				X			X			
Navigation and Communication	19												X					X			X				X		X					X	X				
Alarm & Monitoring Systems	20	X											X												X		X						X				
Silencers	21	X			X																		X														X
Gearboxes	22	X						X										X				X								X							X
Lub Oil System	23		X		X	X	X		X	X			X				X	X								X		X		X							X
Data Cables	24				X							X								X	X						X						X				
Fuel Supply System	25				X	X	X		X	X						X	X							X				X	X								
Electrical Modules	26										X	X	X						X		X				X								X				
Engine Blocks	27		X		X	X								X								X		X		X			X	X	X			X			X
Cylinder Heads	28		X		X	X								X												X		X							X		X
Connecting Rods	29				X									X								X	X	X													X
Common Base Plates	30			X										X														X		X				X		X	X
Certification and Documentation	31																X		X	X	X												X				
Power Cabling	32										X	X	X						X	X	X				X		X					X					
Bedplate and Mounting	33			X										X	X													X			X						X
Insulation System	34																X																			X	
Heat Exchangers	35																					X															
Vibration Dampers	36	X		X		X					X	X		X	X				X				X	X				X			X			X			

6.2 *Creation of product platform: a case example*

In order to explain the applicability of DSM tool for platform creation, an example is cited in Figure 2, where different interrelationships among components of a ship diesel engine are displayed. Different dependencies among all of the 36 components are expressed in terms of 'X' marks in Figure 2. Marks along each row of a component indicate the information dependencies on other components, whereas marks along each column of a component represent the information feeding to other components. For instance, component 'fuel injection equipment' taking information from components 'engine management and automation', 'pistons and cylinder liners', 'pumps and filters' etc., and it also feeding information to component 'fuel injection equipment', 'engine management and automation', 'turbochargers' and so on.

The DSM tool organised all the development tasks or components for an end product and groups highly interdependent tasks together known as modules or clusters. All the tasks in Figure 2 are reorganised or partitioned by changing the position of corresponding rows and columns in order achieve the groups or modules. Four independent modules are formed namely, 'fuel system', 'electrical system', 'engine module' and 'basic platform' which are displayed in Figure 3 below. 'basic platform' module indicates the highest level of interdependencies among all other modules and could be considered as main bus or platform upon which all other modules and components are integrated in order to fabricate the end product. In this way, formation of product platform reduces the design time and designers could investigate the bottlenecks if there any within the developed platform.

Figure 3 Identification of basic platform with other modules

Components of ship a diesel engine		35	34	17	14	9	15	8	23	25	24	20	32	10	11	26	12	18	19	22	7	2	29	28	6	27	5	16	21	13	1	4	31	3	30	33	36
Heat Exchangers	35																												X								
Insulation System	34	X																										X									
Propeller Shafts	17								X			X								X	X		X							X	X			X			X
Steel Constructions	14																													X				X	X	X	X
Pumps & Filters	9						X	X	X	X															X			X				X					
Turbochargers	15				X	X		X		X															X		X	X			X	X					
Fuel Injection Equipment	8					X	X		X	X																	X					X					
Lub Oil System	23			X		X		X		X							X					X	X		X	X	X	X				X					X
Fuel Supply System	25					X	X	X	X															X	X	X	X	X				X					
Data Cables	24											X	X		X	X			X													X					
Alarm & Monitoring Systems	20										X		X			X	X														X						
Power Cabling	32										X	X		X	X	X	X	X	X														X				
Generators	10												X		X	X	X	X										X			X						
Electrical Motors	11												X	X		X	X	X				X															
Electrical Modules	26										X	X	X	X	X		X	X																			
Electrical & Automation	12											X	X	X	X	X		X																			
Transformers	18										X	X		X	X	X	X					X													X	X	
Navigation and Communication	19			X							X	X	X			X	X																X				
Gearboxes	22			X																	X		X						X		X						X
Gearwheels	7			X																X																	
Cooling Systems	2		X												X											X	X										
Connecting Rods	29								X											X									X	X		X					X
Cylinder Heads	28		X							X												X				X	X			X		X					X
Valves and Bearings	6					X	X	X	X	X														X			X					X					
Engine Blocks	27								X	X												X	X	X			X		X	X		X			X	X	
Pistons & Cylinder Liners	5																					X		X	X	X					X	X					X
Emmission Control Systems	16					X	X			X																	X					X					
Silencers	21																			X											X	X					X
Forgings Operations	13				X															X			X	X		X								X	X	X	X
Noise Mitigations Systems	1			X			X					X		X						X					X		X		X					X			X
Engine Management & Automation	4			X	X	X		X		X		X													X		X										
Certification and Documentation	31											X	X					X	X									X									
Flexible Couplings	3			X	X															X											X	X			X	X	X
Common Base Plates	30																						X			X				X				X		X	X
Bedplate and Mounting	33				X																					X				X				X	X		X
Vibration Dampers	36				X				X					X	X			X		X						X	X			X	X			X	X	X	

Fuel System
Electrical System
Engine Module
Basic Platform
Basic Platform

DSM tool provides a methodology for the qualitative identification of collections of tasks and components that comprise feasible platforms. This methodology illustrates how to model exogenous effects propagate through the interdependent tasks or components of a product development system (Yassine and Kalkenburg, 1999). Increasingly, these tasks or components dependencies contribute to the development of standardised product platforms, which provide competitive advantages of firms to balance between requirements for highly customised products and necessary changes in product portfolios. Obviously, platform-based product development process reduces production cost by using economics of scale, lead times are shortened and inventory also minimised. Besides these advantages, platform formations also minimise product variants risks and increase the flexibility (Suh, 2005).

7 Challenges and limitations in platform strategy

7.1 Strategic limitations of the strategy

Although platform strategy has several advantages to create product varieties but there are some limitations too. The most common challenge for its application is to manage the multiple tradeoffs. It is often very costly to implement this strategy and there is always to be balanced between input value and output rewards. If there is unbalanced between the goal and performance of outcomes, this strategy might be abandoned. It is also challenging to choose the right platform for products with appropriate target market. Trying to choose the best platform for any firm is not an easy task to do rather complex and time consuming. The development of a platform normally takes substantial time and effort to complete and any misalignment with the goals and performances could deteriorate firm's success.

It is hard to bring commonality among platform design and development with maximum performance output. If there are several platforms within a company for diversity of products generation, it would be a successful production strategy to find commonality among them in terms of components or parts. However, it is quite hard to make this commonality phenomenon with profitable business target as it often requires huge investments and the outcomes may not be fulfilled company's objectives. Not only that any benefits from developed platform might take years to realise and its success could come at the end of product's lifecycle. It is therefore, remains a question of doubt about the evaluation of 'goodness of fit' for the developed platform and needs intrinsic evaluation for firms before applying platform-based product development.

7.2 Challenges from the customers point of view

Different product variants developed from single platform suffers the lack of uniqueness among them as the variants are fabricated using much common components. This creates the products look alike which exert risks on customers' satisfaction and potential loss of market share. Because of using many common components there are always the possibilities of performance losses and variants losses (Suh, 2005). There is also the possibility of lacking customisation as customers have to choose from several common components and less availability of customised components. As the development of product platform itself very costly and time consuming, it is not possible to change it frequently which resists the implementation of new technologies evolves by that time. It indicates that generally platforms support innovation in shorter time rather longer time, due to huge investments in standardised design processes, tools and machineries and supply chain contracts.

The culture of an organisation also affects the strategy for adopting platform-based product development. It is quite natural to offer required support from organisation for implementing any kinds of change strategy within it. However, it is not easy to change organisation culture for implementing any new strategy, whether it is beneficial or not and the development of platform is often ignored. It is therefore, a challenge to get support and involvement from organisations, operations and human factors to facilitate user adoption of platform techniques and tools. As platform is developed from scratch, there are often clashes of ideas and enthusiasm among team members, which creates lack of understanding and performance of platform usage.

8 Managerial implications

To survive in today's highly competitive global business market, many companies are adopting product families and platform-based product development to increase variety, reduce lead times and cost. The creation of product family through common platform helps manufacturing companies to reach customers in different markets, shorten the time needed to develop new products and reduce costs by sharing common components among many products. Product platform can be considered as a set of components and technologies that is used for developing more than one product. The basic criterion of platform design is that it must effectively support multiple product variants over a prolonged period. This makes platform thinking unique characteristics than a single product development concept.

There are growing demands on individualised products, which exert tremendous pressure on any manufacturing unit. Manufacturing units need to play with product varieties along with maintaining high level of productivity. These goals can be achieved through initiating commonality among manufacturing processes, various tasks or components and maintaining production flexibility. It is advantageous of any firm to keep as small number of components as possible for proper management of inventory and to maintain product variety. Commonality brings the flexibility in overall product development line. The more common parts in a production line mean the more product varieties and flexibility in that organisation. To be competitive in market place companies need to be more flexible in their production line.

Managing flexibility in product development environment enhances the commonality issue. Today's uncertain business environment, firms need to be more flexible in their product design and development strategy to meet challenging customers' requirements and market gain. Flexibility in manufacturing process can be expressed as the ability to modify a product with minimum cost. Flexibility in product development process is a powerful method that also reduces the production risk. Product platform increases the flexibility in the production process. In platform design certain functions combine together and make the production process more flexible. It coordinates organisational managers for better planning and managing the creation of product variants or product families efficiently.

Successful product platform creates many varieties of product by adding, removing or substituting modules to the base platform. This phenomenon of product family creation has matured rapidly in the last decade, which also enhanced today's increasing demand of product individualisation. The adoption of platform oriented product development provides organisational managers the required agility in their product development processes. Distinctive product varieties are derived or customised from a platform that is defined as components and subsystems commonly shared across a product family. A well organised platform is essential to satisfy customer needs and to achieve the economy scale through sharing tools, knowledge and other resources. A firm can launch new product variant quickly and with a greater chance of success if it has a good product platform.

9 Conclusions

In mass customisation era, customers are very much concern about their products of choice, which influence manufacturers to fabricate products according to the customers' requirements. To improve product customisation for global competitive marketplace, many firms are adopting platform-based product development to increase their product variety and minimise lead time. The key success from a product platform is that varieties among products can be achieved by adding, removing or substituting one or more modules to the platform or by scaling the platform in one or more dimensions to target specific market niches (Simpson, 2004). It is therefore, designed to produce for a specific target group of related products.

Product platform has received a great deal of attention in industry in recent years, with many industrial firms implementing product platforms to enable greater component sharing. It is initiated an attractive design strategy because of its potentiality to reduce inventory management, after-sales support and design structure. The term platform design is closely related with product architecture. This methodology provides valuable insights to the designer about how the design elements or tasks should be combined or partitioned in order to have better management of product complexity. If the design components or tasks are managed efficiently, product development system improvement and identification of platform elements would be achieved easily.

In this paper, a design tool named DSM is used with a view to formulate the specified platform for a product group or family of product. Different assembly operations are sequenced by using this tool, which helps to minimise the assembly lead time through maintaining better-sequenced operations. Generally, DSM methodology deploys and evaluates specifications and engineering requirements of product platform. The effectiveness of the platform is evaluated according to the information interdependencies of various tasks or components to fabricate an end product. Initial tasks or components of end products are partitioned for designing product platforms, which also needs to be cost-effective and reliable for developing products variants in order to achieve the customisation approach.

Although platform-based product development approach offers a number of benefits, but it also employs certain additional costs such as, structural setup cost, materials cost, maintenance and handling cost and so on. These costs also have to be considered along with its several benefits and possibilities. Not only can the costs, platforms also very often not be changed easily, which restricts the innovation in product fabrication process. This restriction results in compromise with the design fit and may not be suitable for most of the family member of a product. This imbalance could deteriorate the performance and reliability of a product or product family. Future research could be carried out to find out the possibility of replacing the platform easily and economically. Another idea might be investigated how to organise collaborative platform development among different regions or countries.

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