OPERATIONS AND SUPPLY CHAIN MANAGEMENT
Vol. 1, No. 1, May 2008, pp. 57-71
ISSN 1979-3561|EISSN 1979-3871

Applying Design Structure Matrix (DSM) Method in Mass Customizations

AHM Shamsuzzoha
Department of Production, University of Vaasa, Vaasa, Finland
E-mail: zohaipe@yahoo.com

Petri Helo
Department of Production, University of Vaasa, Vaasa, Finland
E-mail: phelo@uwasa.fi

Tauno Kekale
Department of Production, University of Vaasa, Vaasa, Finland
E-mail: tke@uwasa.fi

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.

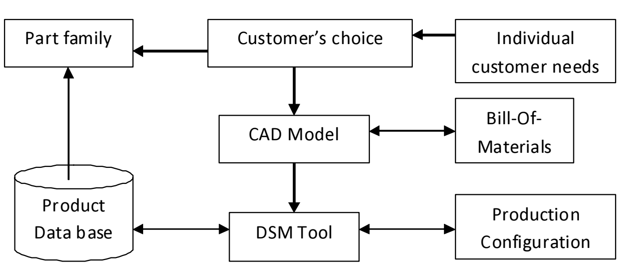
3. Integration of DSM Tool for Mass Customization

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.

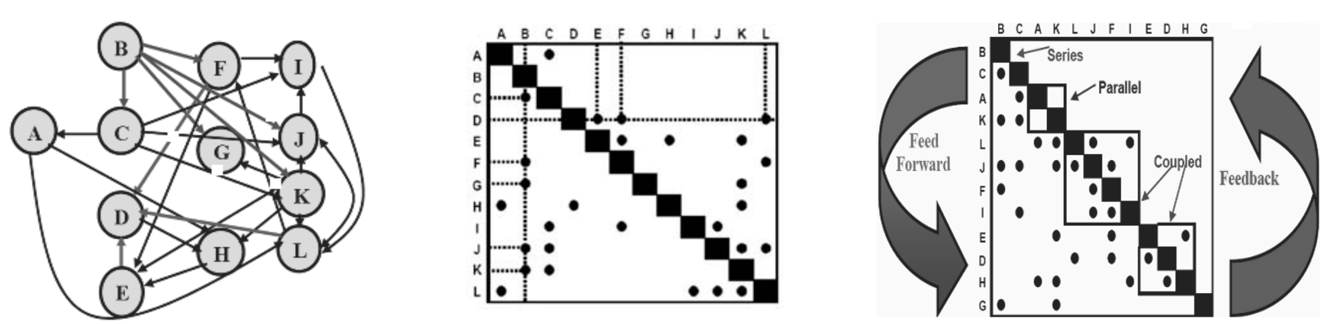
DSM Tool: The DSM is a powerful tool for representing and analyzing task dependencies of a design project (Steward, 1981). It is a compact representation of the information flow structure of any design project. This method differs from conventional project-management tools such as PERT, Gantt chart, 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

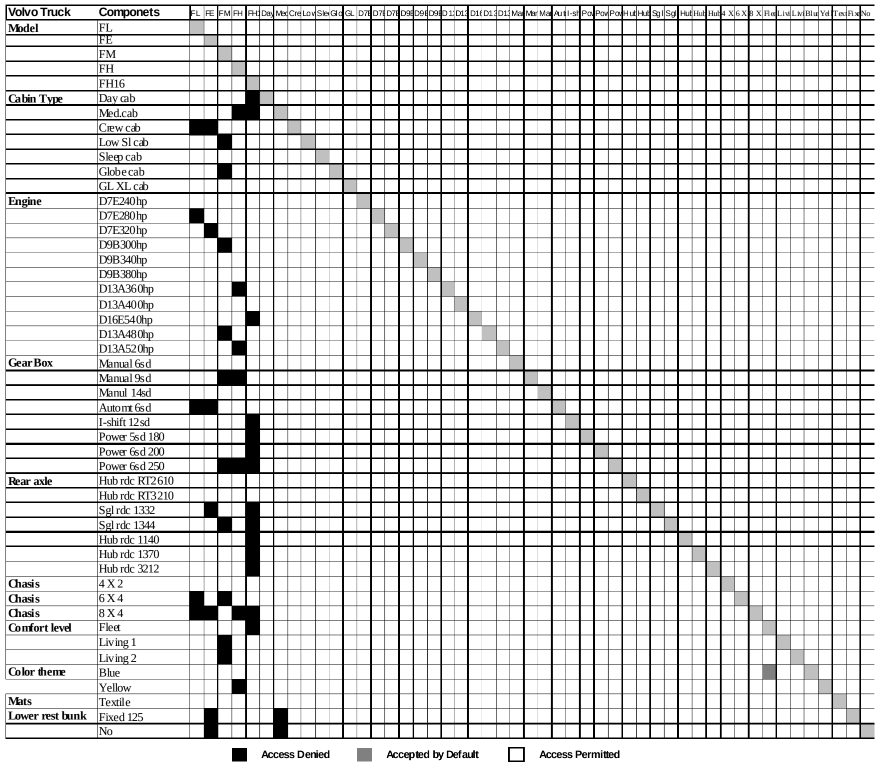
The example stated below is taken from the ongoing CATER project, an EU funded project aiming at networked business and mass customization in the automotive industry. The world leading automobile company Volvo is one of the partners of the project from which this example is taken from. AB Volvo / Volvo 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

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

Units / Departments		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Engine production unit	1	1	1	1	1		1											
Gear box manufacturing	2	1	2	1									1					
Repair & maintenance unit	3	1		3		1		1										
Research & development dept.	4			1	4					1							1	
Customer care unit	5	1		1		5		1										
Purchasing unit	6	1	1				6									1		
Marketing & sales department	7	1						7	1							1		
Supplier for raw materials	8	1		1					8	1					1			
Assembled chassis	9				1			1		9		1	1		1			
Assembled cabin	10	1					1			1	10	1	1			1		
Electronics & lighting department	11									1	1	11		1				
Measurement & control unit	12										1		12	1		1		
Wiring & transmission	13									1	1			13				
Painting & decoration	14							1			1	1			14			
Tires supplier	15						1		1							15	1	
Rims manufacturing unit	16															1	16	
Planning & administration dept.	17	1	1			1			1								1	17

iii

Customer needs	Ranking
The truck will be modern and luxu	8
Colorful looking	7
Include safety features	10
It looks sporty and masculine	7
Easy handling for required transpo	9
Long lasting tires	6
Comfortable in driving	8
Entertainment facilities	3
Sleeping arrangment at night	3
Spacious cabin interior	4
Needed cooking facilities	4
Low fuel consumption	9
Affordable cost	7
Adjustable cabin temperature	4
Low engine noise	5
Smooth power transmission	8
Comfortable cabin floor	3
Excellent visibility	7
Cleanliness	2
Easy maintenance & servicing	6
Comforatble seats & bed	7
Easy handling of goods	6
Goods are safe in all season	9
Aesthetically pleasing	6
Appropriate artificial lighting	3
Share natural light	2
Keep ventilated (air quality)	5
Appropriate communication facili	6
Higher salvage value	2
Durable parts	7
Attract customers for renting	4

i

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

ii

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.

Acknowledgement

The authors like to acknowledge CATER (Computerized Automotive Technology Reconfiguration), Contract No. 035030, a European Commission funded project of the 6th Framework is undertaken by a consortium comprising 11 European partners and 3 Asians for funding this research.

References

Anderson, D.M. (1997). *Agile Product Development for Mass Customization: How to Develop and Deliver Products for Mass Customization, Niche Markets, JIT, Build-to-Order and Flexible Manufacturing*, IRWIN Professional Publishing, Chicago.

Baldwin, C.Y. (1997). Managing in an age of modularity, *Harvard Business Review* 75(5), pp.84-93.

Cavusoglu, H. and Raghunathan, S. (2007). Selecting a Customization Strategy Under Competition: Mass Customization, targeted Mass Customization, and Product Proliferation, *IEEE Transactions of Engineering Management* 54(1), pp.12-28.

Eppinger, S. (2001). Innovation at the Speed of Information, *Harvard Business Review* 79(1), pp.149-158.

Eppinger, S., Whitney, D., Smith, R. and Gebala, D. (1994). Model-Based Method for Organizing Tasks in Product Development, *Research in Engineering Design*. 6, pp.1-13.

Farrell, R. and Simpson, T.W. (2003). Product platform design to improve commonality in custom products, *Journal of Intelligent Manufacturing* 14(6), pp.541-556.

Guilabert, M.B. and Donthu, N. (2006). Mass customization and consumer behaviour: the development of a scale to measure customer customization sensitivity, *International Journal of Mass Customization* 1(2/3), pp. 166-175.

Helo, P. (2006). Product configuration analysis with design structure matrix, *Industrial Management & Data Systems* 106(7), pp. 997-1011.

Helo, P. and Kyllönen, S. (2007). Design and implementation of web-based reconfiguration models for online collaborative product customization, *CATER Project, No. IST-5-034030-STREP, 3rd Plenary Meeting*, Santorini, Greece, May 14-16.

Hyam, L. (2006). Mass customisation in the electronics industry: based on modular products and product configuration, *International Journal of Mass Customization* 1(4), pp. 410-426.

Jiao, J., Zhang, L. and Pokharel, S. (2005). Coordinating product and process variety for mass customized order fulfillment, *Production Planning and Control* 16(6), pp.608-620.

Kyllönen, S. and Helo, P. (2007). Web-based reconfiguration platform for online collaborative product customization, *CATER Project, No. IST-5-034030-STREP, WP.3*, April.

Tseng. M.M. and Jiao, J. (1998). Concurrent design for mass customization, *Business Process Management Journal* 4(1), pp. 10-24.

Meyer, M. and Lehnerd, A.P. (1997). *The power of product platforms: Building value and cost leadership*, New York: Free press.

Omar, A.R., Harding, J.A. and Popplewell, K. (1999). Design for customer satisfaction: an information modeling approach, *Integrated Manufacturing Systems* 10(4), pp.199-209.

Ottum, B.D. and Moore, W.L. (1997). The role of market information in new product success/failure, *Journal of Product Innovation Management* 14, pp.258-73.

Pine II, B.J. (1993). *Mass Customization: The New Frontier in Business Competition*, Harvard Business School Press, Boston, MA.

Sanderson, S.W. and Uzumeri, M. (1997). *Managing Product Families*, Chicago, IL: Irwin.

Sheu, C. and Wacker, J.G. (1997). The effects of purchased parts commonality on manufacturing lead time, *International Journal of Operations & Production Management* 17(8), pp.725-745.

Silveria, G.D., Borenstein, D. and Fogliatto, F.S. (2001). Mass customization: Literature review and research directions, *International Journal of Production Economics* 72, pp.1-13.

Simpson, T.W. (2004), 'Product platform design and customization: Status and promise', *Artificial Intelligence for Engineering Design, Analysis and Manufacturing*, (18) No. 1, pp.3-20.

Slevinsky, M.A. and Gu, P. (2005). Modular platform design using mechanical bus architectures, *International Journal of Mass Customization* 1(1), pp. 65-82.

Steward, D.V. (1981). The Design Structure System: A Method for Managing the Design of Complex Systems, *IEEE Transactions on Engineering Management* 28(3), pp.71-74.

Tseng, M.M. and Jianxin, J. (1996). Design for mass customization, *Annals of the CIRP* 45(1), pp.153-156.

Tseng, M.M. and Jianxin, J. (1998). Concurrent design for mass customization, *Business Process Management Journal* 4(1), pp.10-24.

Tseng, M.M., Jiao, J. and Su, C.J. (1997). A framework of virtual design for product customization, *Proceedings of the 6th International conference on emerging technologies and factory automation*, LA, USA.

Wallac, T.F. (1992). *Customer-Driven Strategy, Winning Through Operational Excellence*, Vermont, Oliver Wight Publications.

Yassine, A. (2004). An Introduction to Modeling and Analyzing Complex Product Development Processes Using the Design Structure Matrix (DSM) Method, *Quaderni di Management (Italian Management Review)*, **www.quaderni-di-management.it,** Original article is in Italian, but here is the English translation. **full text (Italian version). full text (English Translation)** 9.

Zha, X.F. and Sriram, R.D. (2006). Platform-based product design and development: A knowledge-intensive support approach, *Knowledge-Based Systems* 19(7), pp. 524-543.

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

AHM Shamsuzzoha is working as a Project Researcher and PhD student in the Department of Production, University of Vaasa, Finland since April 2007. He has received a Master of Science in Mechanical Engineering from University of Strathclyde, Glasgow, UK. Currently he is working on the EU project 'CATER' (No.035030) and his activities are devoted to the integration of Design Structure Matrix (DSM) in product development. His major interest lies in the area of product development and logistics. He has published papers in different journals such as *International Journal of Engineering and Technology, Journal of Manufacturing Technology, Bangladesh Journal of Environment Science, Pakistan Academy Science Journal, Journal of Institution of Engineers Bangladesh, International Journal of Logistics Systems and Management.*

Petri Helo is currently a Professor in the Department of Production, University of Vaasa, Finland. His major research interest addresses the management of logistics processes in supply demand networks, which take place in electronics, machine building and food industries. This research has developed new approaches on analytical modelling and use of computers solving industrial management problems. His research interest includes logistics systems and supply chain management, information technology tools and productivity measurement and technology progress. His works have been published in various journals, including the *International Journal of Advanced Manufacturing Technology, International Journal of Manufacturing Technology and Management, International Journal of Management and Enterprise Development, International Journal of Production Research, International Journal of Agile Management System, International Journal of Innovation and Learning etc.*

Tauno Kekäle is a Professor in New Product Development at the Department of Production, University of Vaasa, Finland since 2002. He received his PhD in Business Economics (Qualify Management) from University of Vaasa in 1998. He is currently the Head in the Department of Production. His current research interests include new product development, TQM, innovation and technology management, organizational culture. His research works have been published in various national and international journals, including the *International Journal of Business Information Systems, International Journal of Innovation and Learning, International Journal of Quality and Reliability Management, International Journal of Logistics Systems and Management, Management Decision etc*. He is also the Editor of *Journal of Workplace Learning*.