3rd International Conference on Mass Customization and Personalization in Central Europe (MCP – CE 2008)

Mass Customization and Open Innovation in Central Europe
June 3-6, 2008, Palić - Novi Sad, Serbia

OVERVIEW OF CURRENT RESEARCH RESULTS OF MASS CUSTOMIZATION

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Abstract: *This paper presents an overview of the current research results in the field of mass customization worldwide. In the first chapter, general information about main fields of interest concerning mass customization is presented. The following chapters deal with various approaches in the research area, showing some of the interesting results. The last chapter deals with the proposed future research possibilities in the area of mass customization in the context of presented overview.*

Key Words: ***Mass Customization, Product Configuration, Customer, Knowledge Support Systems, Product Configurators***

1. INTRODUCTION

This paper presents an overview of some of the current research results in mass customization.

Global competition is forcing producing companies to change their activities from a seller point of view towards a buyer point of view, what results in a drastic increase in the number of product variants and costs (Franke at al., 2001). To maintain there competitiveness, companies are modularizing their products and introducing platform concepts, and this transfer from no customizable products to modular products that involve individual customer variants is one of the most important industrial strategies nowadays.

The recent development of *IT* technology enabled the software based product configuration systems that support the process of customized product development. They compose customer specific solutions using the modules based on the customer's requirements.

Many companies develop their own configuration systems, so the required rules for combining product components or modules, as well as the design of the entire product are usually statically implemented in the configuration system. As a result of this approach, any change concerning the product or the system itself, requires comprehensive changes in the configuration system's source code. This direct conversion of the rules into source code also leads to more dependency on software engineers, because other users cannot edit or change the configuration rules. This can be a large psychological barrier for many companies due to the necessity to share know-how with external persons, knowledge engineers and computer scientists. The other problem is the unclear structure of the rules, which leads to hard serviceability.

These problems lead towards a development of an open framework that would allow the creation and maintenance of different individual product configuration systems by the engineers themselves without high dependency on computer scientists. The second chapter will show one possible solution of the addressed problem (Abramovici at al. 2007).

As the practice and research of mass customization develops, there is increasing understanding of how it can be implemented in terms of manufacturing capability and expertise, data transfer and management, the implementation of business systems, and the development of product architectures. The so called 'solution space' is defined, as a conceptual 'container' for the matrix of product possibilities that are made available for any given mass customized product to a customer co-designer, established through the assessment of product architecture, range, overall company strategy and manufacturing capability (Berger & Piller, 2003). Beside this, the added importance of connection with customers is likely to have an equal, if not greater impact on future working methods and technologies (Tseng & Piller, 2003). Mass customization by its very nature consists not only of the customizable product offering but of the co-design experience. This experience differs from purchasing a mass produced product as it requires engagement and participation in the creation process, it is this participation that changes the role of the customer from consumer of a product to a partner in a process of adding value (Reichwald et al., 2004). There is a need to develop a conceptual model for mass customized product offerings that encompasses not only the current understanding of 'solution space', but also the wider aspects relating to the co-design experience steaming from the customer co-designers emotional connection with the product and purchasing process. The third chapter shows the current trends concerning the role of customer in mass customization (Herd et al., 2007).

The main driving force for platform based development and manufacturing is the possibility to combine customization with economy of scale or the effect off production process in which an increase in the scale of the produced component causes a decrease in the average cost of each unit. The means to achieve this is reuse of common resources (common parts) in multiple customized product variants. By doing this it is possible to create new product variants without having to develop all of its contained parts, just the ones that are variant specific. The rest can be used from already existing products or from a common core of parts in a product family or in different involved families of different brands – the product platform. A product platform is a set of parameters, features, and/or components that remain constant from product to product within a given product family (Simpson et al., 2001). Configuration of product variants is thus achieved by combining the parts in the platform with variant specific parts.

Although much have been gained with this strategy it has its limitations, and it needs to be further developed in order to prevent the amount of part numbers to be managed in a developing and manufacturing company to grow out of hand. One approach towards the solution of the problem is showed in the fourth chapter (Johannesson & Gedell, 2007).

In today's global business environment, that includes all the aspects of the product and its surroundings, product development is highly dependent on knowledge-intensive and collaborative systems for building on specialized knowledge across nations, organizations, and professions to develop customized products for different market segments (Szykman et al., 2001, Fürstner et al., 2005, Lefebvre et al., 2006). Knowledge-intensive and collaborative support has been increasingly important in product development to maintain future competitive advantages (Zha & Sriram, 2006). A knowledge support system can provide a solution for iterative design and manufacturing activities that are performed by sharing and reusing knowledge related to product development processes. By sharing and reusing assets such as components, modules, processes, information, and knowledge across a family of products and services, companies can efficiently develop a set of differentiated products by improving flexibility and responsiveness of product development (Simpson, 2004). Product family planning is a way to achieve cost-effective mass customization by allowing highly differentiated products to be developed from a common platform while targeting products to distinct market segments (Shooter et al., 2005). In the fifth paragraph, one approach is shown concerning the development of a knowledge support system for product family design (Moon et al., 2007).

Usually, the literature regards the degree of customization as how early or how far the customers are integrated in the product's production cycle, or more generally in it's life cycle. The point at which the customers' involvement or input starts is referred to as the "Order Decoupling Point" (Piller, 2006). The earlier the customers' involvement in the product's life cycle is, the higher is the degree of customization. On the other hand, the closer the customer involvement is to the final product and distribution stage, the lower is the degree of customization. The level of customization can be also viewed from a supply chain perspective. A higher degree of customization would entail direct customer involvement starting backwards at the first tier suppliers, while a lower degree of customization occurs when customer involvement is close to the retailers or end users. The stage at which the customers' actual input integrates into the system is referred to as the "Stockholding Decoupling Point" (Hoekstra et al., 1992; Barlow et al., 2003).

However, there is a need to determine a certain degree of customization concerning the possible increase of the market share and premium price, while lowering costs, risk level, time to market, and other.

To achieve this, determining the degree of customization from a product structural design perspective is necessary. That is, the degree of customization is determined by breaking down a product into a number of modules or components, and then examining the various options for each module or the extent to which some features within each module can be changed if required. One of the possible approaches considering the determination of the optimal level of customization proposed in literature (Spahi et al., 2007) is presented in the sixth chapter.

2. OPEN FRAMEWORK FOR PRODUCT CONFIGURATION SYSTEMS

The developed product configuration solution has the following main characteristics:

- Virtual $3D$ model of the product as a result of the configuration process, which is applicable directly in the further developing process of the product;
- Accompanying standardized services for the support of the system introduction to a company;
- Accurate assessment of costs and profit already before the start of a project with the goal of minimizing the risk;
- Unitized software system, which can be tailored to customers;
- Open communication structure between the involved systems and concentration at the relevant object and attributes of the configuration, which facilitates the maintenance by engineers and leads to less dependency on computer scientists.

The framework of the developed software consists of the generator or the administration interface, the configuration database and the configuration software or user interface.

The generator provides various editors for knowledge acquisition and representation and for designing the configuration software's interface.

The product structure and the entire configuration knowledge are filled centrally in the configuration database, which is serviced using the generator.

Users can only use the configuration software's interface, which has read access to the configuration database on the server, and therefore always the current set of rules as well as the product data.

Generally each product composed from components and modules can be represented by the developed software, however the developed generator provides three different types of parts:

- Fixed parts, which are directly associated to each other. Those are standard, catalog or outsourced parts, which are only used in one unique way. The interaction with other objects is carried out by the help of attributes;
- Rule and constraint based alterable parts, whose parameters are adjustable in predefined limits. These alterable components may be adapted to the demands of the customer by the entered parameters, in case that they do not already exist in the demanded specification.
- Free parts, which have no associated rules to comply with and have to be redesigned or engineered from scratch. In the configuration process they are considered as black boxes with predefined requirements and interfaces. These components can be integrated as placeholders in the product structure and the configuration process. After the completion of the configuration they can be engineered manually in the *CAD* system.

The created configuration rules and constraints are the core of the configuration data base, which is used for the configuration of products. The configuration data base comprises of a three level rule base structure, where the levels are set up on each other. These three levels of the rule structure are the basic rule set, the customer specific rule set and the project specific rule set.

The basic rule set that is initially provided with the software consists of two types of rules:

- Rules about the general setup of the graphical user interface of the configurator and the structure of the configuration knowledge as basic knowledge;
- Basic knowledge about the product design.

The customer specific rule set is created in close collaboration with the customer within the scope of a service component and consists of two types of rules:

- The customized basic knowledge that comprises the rules, which concern general design regulations;
- The product structure rules.

The highest category project specific rule set contains project relevant knowledge. In this category only those rules should be stored, which are valid for a certain configuration project, so it includes only those rules that do not apply to standard configurations of the customer. This rule set is also created in collaboration with the customer.

The necessary rule set is generated in the form of $if - then$ rules, decision tables, external reference tables and computation and simulation programs and is automatically converted in the declarative programming language Prolog. This creates the basis for configuration creation by the configurator.

At the end of a configuration process, an *xml* based script is produced, with which the configured product is finally generated and visualized as a virtual model within the *CAD* system. Also communication with other systems is enabled, which results in connecting all the aspects considering the product and its environment.

3. THE ROLE OF CUSTOMER IN MASS CUSTOMIZATION

Mass customization alters the traditional product development and moves towards a two-stage model, the first, the realm of company/designer establishing the solution space and the second, that of customer as co-designer. This second stage fundamentally changes the role of the customer from consumer of a product, to a partner in a process of adding value (Reichwald et al. 2004).

The literature describes a spectrum of research in the area of designing for co-design and has identified a number of design considerations, which include:

- Minimizing the potential complexity experienced by the customer, keeping their expenditure in the buying process as low as possible, whilst providing clearly perceptible benefits (Berger and Piller 2003, Kumiawan et al. 2003);
- Reducing cognitive overhead, which lies not only in extent of choice, but also in areas such as lack of understanding about which solution meets their needs, uncertainty about the behaviour of the supplier, and uncertainty regarding the purchasing process, ordering and paying in advance for something that's only been seen virtually (Franke and Piller 2003).

These findings often fall into one of two areas for investigation:

- Issues surrounding the contents of the solution space;
- Communication and application of the contents through an appropriate product configurator.

Based on previous analysis, two questions have to be answered:

- What is the co-design experience for the customer?
- How can one design for the co-design experience?

If the co-design experience is an intrinsic element of a mass customized product, there is a need to develop a conceptual model for mass customized product offerings that encompasses this wider context within which the solution space resides, the entire co-design and product purchasing experience.

It is easy to assume that increased product performance heightens levels of customer satisfaction, but trends indicate that users are expecting increasing levels of 'connection' with everyday products (Demirbilek and Sener 2003). As markets have segmented, product development has begun to move beyond traditional considerations of usability and functionality. Consumers now look for more from the products that they buy; they are looking for pleasure and the fulfillment of their emotional needs" (Porter et al. 2005). There is a growing acceptance of the need to design for consumer experience.

To further understand this phenomenon, it is necessary to look not only at consumer behavior, but to delve deeper and understand the meaning that consumers attach to possessions, which drives the act of purchase.

Mass customization is an approach that is fundamentally driven by an individual customers' emotional connection with the product, exemplified by their participation and engagement in the co-design experience. To design for a co-design experience an understanding of the customers, their behavior, expectations and the interface between the customers and the configurator is needed.

One of the works (Jordan, 2000) that explicitly address the creation of positive feelings in product use is particularly useful as a hypothesis generating tool since it provides not a theory of pleasure, but rather a tool to help those involved in the design process take a structured approach to understanding the entire spectrum of pleasures a product can bring. It identifies four types of pleasure associated with products:

- Physio-pleasure – relates to the body and is concerned with positive feedback from the sensory organs; touch, taste, smell, hearing and sensual pleasure;
- Socio-pleasure – refers to relationships with others – individuals, groups and society as a whole. Socio-pleasure is drawn from the aspects of products that confer social, material or cultural status, help to construct personal identity and/or stimulate desirable social interaction. These product qualities give positive feedback to the owners about their personal view of themselves in society;
- Psycho-pleasure – refers to a user's cognitive interaction with a product and their subsequent emotional reaction. Psycho-pleasure is drawn from products that give emotionally satisfying results from the cognitive demands of interaction;
- Ideo-pleasure – relates to peoples' values. In the context of products this ranges from aesthetics to ethics. It includes taste, moral values and personal aspirations. It defines how people do, and would like to, see themselves.

The previously discussed framework resulted in the development of the product envelope model (Bardill and Herd 2006, Bardill et al. 2007) that appears to be the first complete expression of a coherent, user-centric mass customized product offering. It helps constructing the outer layers of co-design experience which surround its core element, the solution space.

The product envelope is generated by the producer of the mass customized product. As a co-designer, customer penetrates the envelope and engages with a number of experiential layers before reaching the solution space where the mass customized product resides; those layers are interconnected and the co-design experience will not necessarily provide a linear route through the envelope.

The design of the product envelope is characterized by regular traversal of the design line to ensure all regions of the envelope are integrated; this is important in ensuring coherence in the customer's perception of the entire mass customized product offering.

Brand is important in differentiating between product envelopes, in circumscribing the envelope and in permeating through the core of the envelope. This is an essential consideration, as brands generate choice, simplify purchase decisions, offer quality assurance, and reduce risks involved in purchase (Karjalainen 2003). Brand has an ability to trigger emotional responses that will often provide it with a wining edge over less familiar products and services (Lewis & Bridger, 2004).

Every brand consists of an essence consisting not only of the product or service, but the mental constructs associated with it.

The product envelope must communicate a coherent brand to the customer co-designer throughout every element of the co-design experience.

A key aspect to designing the experience is to understand and design the product 'touch points'; the tangible aspects which make up the experience of using a product or service, "instances of direct contact either with the product or service itself, or with representations of it by the company or third party" (Meyer and Schwager 2007).

4. CONFIGURABLE PRODUCT PLATFORM MODEL

The indicated problems with the conflict between reuse and commonality versus increased demands on product variety, call for new approaches for platform descriptions and *IT* support. What is needed is an integrating tool that handles all knowledge related to the whole platform system as well as to its contained sub-systems and components, the relations between contained items and the rules governing the use of the contained knowledge for different purposes during the platform lifecycle.

A new strategy for handling the problems has been proposed by Claesson (2006). The proposed strategy is based on a more abstract and knowledge based platform definition consisting of linked system structures of configurable sub-systems. With input values on its variant defining parameters such a configurable system structure automatically generates the variant defining information (i.e. part numbers, instantiated CAD models, material specifications, valid reference documents etc.) needed for preparation of production. To function as stated, each configurable sub-system must carry three kinds of knowledge about itself:

- Knowledge about its origin, i.e. what it should do and be, how this is realized and why the chosen solution is what it is;
- Knowledge about its interactions with the external environment;
- Rules specifying the composition, functionality and external interactions of instantiated sub-system variants.

A platform definition based on this kind of knowledge carrying sub-systems provides much more configuration flexibility than a part based defined platform, and it does not generate new part numbers to be managed for each new configuration.

Based on this strategy, a platform is defined as a common knowledge based configurable system model containing system design rationales (including requirements, generic design concepts and decision history) and rule based models for variant instantiation plus common resources used by the configurable system model.

Such a configurable and knowledge based platform is much more robust as reuse of configurable sub-systems instead of reuse of parts makes it possible to have the complete product knowledge contents available for redesign in order to meet new demands.

Each configurable sub-system object is a configurable system that has relations to other configurable sub-systems, and it can be instantiated by setting values on its variant parameters through an appropriate interface.

Composition of variants is defined by the composition set, and the result of a composition is transferred to other used configurable sub-systems or external applications like *PDM* and *CAD* systems. An instance of a product or a sub-system that shall be manufactured is specified by its variant defining parameters. With this input the system of involved configurable sub-systems automatically generates the variant defining information (i.e. part numbers, instantiated *CAD* models, material specifications, valid reference documents etc.) needed for preparation of production.

The knowledge about sub-system's origin is realized by describing the configurable sub-system's design rationale, what is done by using an enhanced function-means tree (Andersson et al., 2000) which is reflecting the functional requirements, derived from the product specification, and shows the design solutions chosen to fulfill these functional criteria and relevant design constraints. Each functional requirement, constrain and design solution is described with variation ranges (bandwidth). This reflects the required variety of the design solutions implemented by the configurable component. Each design solution can be finally realized by physical hardware components or software components as:

- Single component or sub-system;
- Integrated part of a complex component or sub-system;
- Result of the interaction between two or more components and/or subsystems

The knowledge about sub-system's interactions is realized with special interface design solutions handling the external interactions.

The knowledge about sub-system's rules specifying the composition, functionality and external interactions of instantiated sub-system variants is realized with a configuration rule set containing programmed procedural and/or inferential rules linked to the configurable sub-system object and its relations.

So far only explicit knowledge has been modeled in the test implementation. However there are no restrictions to also handle tacit knowledge that can be formulated as design rules.

5. KNOWLEDGE SUPPORT SYSTEM

Having an appropriate knowledge support system for distributed designers or design teams in product development is important to share and reuse design knowledge effectively. The developed system for product family design uses ontology, data mining, and automated reasoning.

To define the relationships between functional hierarchies in a product, an appropriate representation scheme is adopted for the products. Ontology consists of a set of concepts or terms and their relationships that describe some area of knowledge or build a representation of it; therefore ontology is used to represent products as functional-based hierarchical structures and to describe costs related to product design.

In knowledge support and management systems, data mining approaches facilitate extraction of information in design repositories to generate new knowledge for product development. Data mining has been defined as the process of extracting valid, previously unknown, and easily interpretable information from large databases in order to improve and optimize engineering design and manufacturing process decisions. During conceptual design, data mining can facilitate decision-making when selecting design concepts by extracting design knowledge and rules, clustering design cases, and exploring conceptual designs in large product design databases interactively.

In the proposed knowledge support system, fuzzy clustering is employed to partition product functions into subsets for identifying a platform and modules in a given product family. Rules related to design knowledge among products are developed using association rule mining. In a knowledge support system, discovered design rules can provide designers with appropriate actions and decision proposals, as well as design strategies and dependency knowledge. An association rule mining technique is used to find interesting associations or correlation relationships among a large set of data items. The results of association rule mining can be design knowledge that is used to define a platform and common modules.

In the proposed knowledge support system, an automated reasoning tool that provides a formal way to achieve a goal for solving design problems is used to inference knowledge represented by ontology and to obtain design recommendation.

A product family is a group of related products based on a product platform, facilitating mass customization by providing a variety of products for different market segments cost-effectively (Simpson et al., 2005). A successful product family depends on how well the trade-offs between the economic benefits and performance losses incurred from having a platform are managed.

Design knowledge is considered as the collection of knowledge that can support the design activities and decision-making in product development. With increasing the amount of information related to design and the complexity of products, knowledge management systems face the challenge of supporting designers to find appropriate information and are difficult to control with human resources (Liu & Ke, 2007, Szykman et al., 2001). Artificial Intelligence techniques and information technology provide a natural mean to facilitate the knowledge management systems for performing knowledge acquisition, knowledge repositories, knowledge discovery, and knowledge distribution.

Design knowledge for a product depends on the experience and knowledge of designers, therefore representation of design knowledge, such as linguistic representation, may fail to describe a crisp representation completely. When clustering design knowledge, there is a need to assign the knowledge to clusters with varying degrees of membership. Fuzzy membership can be used to represent and model the fuzziness of design knowledge.

The proposed knowledge support system consists of three modules:

- Knowledge representation module;
- Knowledge discovery module;
- Recommendation module.

The knowledge representation module uses ontology to describe components, modules, products, and cost information for knowledge representation. It provides knowledge representation for given knowledge discovery module and for the recommendation module it provides rules and facts related to relationship between existing products.

The knowledge discovery module generates design knowledge to support designers and the recommendation module using data mining techniques.

Based on the design knowledge from the knowledge representation module and knowledge discovery module, the recommendation module can recommend designers to design a product platform and family according to the results of query related to product design.

1.1. Knowledge Representation Module

The knowledge representation module consists of product ontology and cost ontology.

A product can be defined by its modules that provide specific functions, and functions are achieved by the combination of the module's attributes.

Cost information for a product family can be represented by the relationships between the specifications of the product family and its activity based costs that provide cost data including resource expenses, activity costs, and their relationship with product specifications

1.2. A Knowledge Discovery Module

The proposed knowledge discovery module uses a methodology for discovering design knowledge for a product family using data mining techniques: clustering, classification, and association rule mining. The proposed methodology consists of three phases:

- Module identification;
- Module categorization;
- Design rule generation.

Module identification is done using fuzzy clustering approaches that can use fuzziness related to product design.

Module Categorization is done categorizing the results of clusters into four types of modules:

- Unique modules;
- Common modules;
- Redesign modules;
- Sub-common modules.

A unique module is based on distinctive functions within a product family and cannot be replaced by those in the different module to fulfill their tasks. A common module is based on common functions within a product family and can be shared. A redesign module can be a common module if redesigned to increase the functional similarity. A sub-common module can be a common module or a unique module based on the tradeoff between production and design cost.

Design rule generation is done using association rule mining. This technique requires transaction data that is needed to develop rules related to product design. Based on the results of clustering and product representation transaction data is developed that consists of several properties in the hierarchical functional relationship.

An association rule describes an interesting relationship between attributes of different modules. Given a set of transactions, where each transaction is a set of attributes, an association rule is noted as $A \Rightarrow B$, where A and B are sets of attributes. The association rule $A \Rightarrow B$ indicates that transactions that contain attribute A tend to contain attribute B. Support and confidence are introduced to assess the quality of the extracted rules.The support of an attribute A in a set S of transaction data means the probability of transaction data containing attribute A. The confidence of $A \Rightarrow B$ represents the probability of attribute B occurring in S if attribute A occurs in S. An association rule with high confidence and support is called strong and is potentially useful for product design. A designer can extract important design features from association rules, which are classified and translated into knowledge and rules for product design.

1.3. A Recommendation Module

A Recommendation Module helps designers obtain the design and cost information from design knowledge, rules and facts, which are represented by ontology. In a recommendation module, two main reasoning methods, backward-chaining and forward chaining, can be used to make inference from the knowledge base. The backward chaining starts with a list of goals and works backwards to find proof for the goals. Otherwise, the forward chaining starts with the available data and uses inference rules to draw conclusions.

In the knowledge support system, the recommendation module receives the request from a user interface, forms the query sentences, and uses a reasoning tool to obtain proper answers according to designer's questions. After the query result from the reasoning tool, the recommendation module organizes the data for a user-friendly format and displays it in the user-interface.

6. OPTIMUM DEGREE OF CUSTOMIZATION

Two types of products can be defined: Component based products and feature based products. Component based products are composed of distinct components or modules that can be mixed and matched to compose a family of variants. Feature based products have different structure; they include components that have specific features that can be altered within a specific range.

On the other hand, any product that is composed from a set of components or modules is actually composed out of a set of three different types of components or modules: standard components that are standard components and unchangeable in a product, discrete option components that are components with a discrete set of options from which only one option is selected, and feature based components that are components with a set of features that can be continuously changed within a certain range.

Component based products are only composed of a set of standard and discrete option components, while feature based products consist of all the three types of components.

In a mass customization system, the products share two elements: the "common bases" and the "differentiation enablers" (Du et al., 2000). The first elements represent the standardization aspect of the product that allows for economies of scale; a production process in which an increase in the scale of product production causes a decrease in the average cost of the unit. The second elements represent a possibility of variety generation and represent the customization aspect of the product, and this promotes economies of scope; a production process in which an increase of the scope of products, in other words different types of basically the same products, causes a decrease in the average cost of the unit. The existence of different versions of the same module, the differentiation enablers, allows the generation of different variants.

The total number of combinations or total number of potential variants for a family of products for the component based products can be computed based an the possible combination of all the sets of the components as it is shown by Eq. (1), where $GMOC$ - global magnitude of customization is the number of potential variants that can be generated, MOC_i - magnitude of customization is the number of available options per module or component and C the total number of modules or components present in the product[1].

$$GMOC = \prod_{i=1}^{C} MOC_i \tag{1}$$

Some components or modules of a feature based product may contain features that can be continuously controlled within a specific range. That will in turn generate an infinite options combination which will result into a false indication for the degree of customization. In this situations an expert analysis is needed that will result in incrementing of the previously continuously controlled feature to certain degree considering the importance of the feature to the customer. After the analysis, the total number of combinations or total number of potential variants for a family of products for the feature based products can be computed the same way it is done for the component based products.

A degree of customization is set introducing a CS - customization scale as it is shown by Eq. (2) as a percentage or fraction from 0 to 1. When its value is zero it reflects a standard product with no variation or customization. If its value is one, which would be a 100% customizable product, what is only an abstract notion as there are always possibilities for further customization. τ is a constant that has a value proportionate to the order of $GMOC$ values obtained.

$$CS = 1 - e^{(-GMOC/\tau)} \tag{2}$$

The degree of customization can be increased until it reaches a stage at which further increasing the level of customization will barely contribute to any significant or noticeable value added to the customer, but will only render the producer higher production costs. That is one of the reasons for choosing an asymptotic function, where the degree of customization will tend to unity but never reach it.

The main question raised is to determine how far to customize to be most successful given a set of strategic goals subject to predefined constraints. The optimization methodology should consider criteria such as market share, customer satisfaction, risk, reputation, safety, ergonomic compliance, medical concerns, environmental issues, and outsourcing. Goal programming has been found to be a suitable optimization technique for this case, where it is a branch of multi-objective optimization, which in turn is a branch of multi-criteria decision analysis, also known as multiple-criteria decision making. It can be thought of as an extension or generalization of linear programming to handle multiple, normally conflicting objective measures.

The optimization methodology deals with two main challenges associated with such criteria: First the units per criterion are not always easily converted to money values. Second, not all the requirements can be dealt with simultaneously.

Organizational goals can be formulated in the form of constraints for an objective function that is intended to minimize the deviations from these goals. By using the preemptive style of goal programming, where criteria are ranked based on importance, a sub-optimal solution is initially achieved. After several iterations, the solution converges in such a way to best serve the predefined targets. This would make it easier for the management to set their aims, expectations and resource limitations in advance. Based on that, the management can determine the most appropriate degree of customization at which to venture. This methodology also offers the flexibility of including additional criteria if necessary.

The methodology can be applied to different products in various industries. The results provided by the goal programming methodology should give the magnitude of customization values corresponding to each module or component, based on the given criteria and their assigned priorities. If the magnitude of customization for a particular module, component or feature receives a value of zero, it means that customizing it is highly discouraged. This component or feature should be either eliminated or made as a single standard component if it

[1] This equation assumes that all combinations are feasible, but in reality some are not. Also it assumes that no component or module can be left out.

is a basic part of the product. After obtaining the whole set of values for every corresponding module or component, the global magnitude of customization and the degree of customization by the customization scale can be computed. The computed figures are only representative figures for the management to visualize or monitor the degree of customization. However, they have no further use in the analytical formulation.

7. CONCLUSIONS

The implementation of modular, standard product configuration systems by using standardized and customizable services is much easier and more acceptable than the existing ones. The advantages of the approach are the high quality of the configured products due to careful acquisition and definition of the knowledge base, the improved serviceability of the knowledge base without the need of involving external engineers and computer scientists. Additionally the flexibility of the software system makes it possible to adopt changes to the knowledge base very fast and easily.

The product envelope model that defines the role and the position of the customer in the mass customization system in its current form is useful in helping to frame the reflection of an experience, but further work is currently being undertaken to both develop the model and structured methods for its use.

The main driving force for platform based development and manufacturing is the possibility to combine customization with economy of scale. This is in practice achieved by reuse of common parts, i.e. the platform, in different customized variants. Configuration of product variants is achieved by combining the parts in the platform with variant specific parts. This strategy has its limitations as it drives an increase of part numbers to be managed in a developing and manufacturing company to grow out of hand. In order to address these problems a new more system oriented and abstract knowledge based approach is needed. The platform model and modeling approach have the potential to enable more efficient product customization without driving growth of part numbers to be managed and to provide more efficient means for reuse of product knowledge for platform development.

The proposed knowledge support system can help a designer use the design knowledge for identifying a platform that consists of common modules and determining design attributes related to the platform during initial and conceptual design phase. In addition, the design knowledge presented by ontology can provide information and specific combinations of related modules and components based on specific constraints. It is possible that a designer can also search all of the related components in a module in product family design. Future research will be focused on improving the efficiency and effectiveness of knowledge support systems, developing design knowledge for reusability and configurability in platform and module design, and expanding its application to agent-based design knowledge system to reflect dynamic design environments.

In a mass customization system, personalized products can have different choices and customizable features with varying extents. It is important to be able to determine what scope of choices would work best for the organization. Not only that, but it is important to know which set of modules, components and/or feature choices, specifically, need to be expanded or narrowed down based on a set of given criteria and restrictions.

The use of the customization scale has been introduced as an overall indicator for the degree of customization for a particular product. The methodology is not expected to provide an exact solution for the optimum level of customization. However, it should put investors or management on the right track as far as the extent of customization, regarding each component/feature of the product, is concerned.

The proposed methodology is a seed to a model that can be further expanded to provide more accurate and practical results. The formulations associated with each goal still needs to be further developed.

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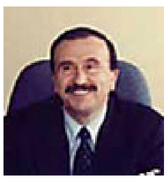

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