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MODEL AND CHARACTERISTICS OF MANUFACTURING SYSTEM FOR MASS CUSTOMIZATION

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Abstract: *The successful implementation of Mass Customization (MC) strategies to a great extend depends on information systems (IS) through which interactions between business organizations and their contragents (customers, subcontractors, outsourcers) are realized.*

Customer Order De-coupling Point (CODP) separates the manufacturing systems to two different managed subsystems – Lean Manufacturing System and Responsible Manufacturing System. These two manufacturing subsystems possess different characteristics and therefore are supported by IS in a different manner. Hence, it is necessary to exist a model of IS supported MC manufacturing system. The establishment of such model is the aim of the presented work.

Key Words: ***mass customization, lean manufacturing, responsive manufacturing systems, flexibility***

1. INTRODUCTION

In a globally competitive market for products, manufacturers are faced with an increasing need to improve their flexibility, reliability and responsiveness to meet the demands of their customers. Mass customization (MC) has become an important manufacturing strategy, because it broadly encompasses the ability to provide individually designed products and services to customers in the mass-market economy.

It is expected from manufacturers to increase flexibility through continuous innovation and shorter production runs that can accommodate changing and more specialized customer requirements together with shorter product life cycles. Mass customization will entail businesses tailoring product functionality to satisfy individual customer requirements, but making differentiated products at high speed and in high volumes in order to keep low unit costs. Mass customization involves intensive communication between suppliers and customers, in the course of which the customer's needs are clearly defined and fed into the product specification.

Changes in the business environment are leading companies to adopt a new production model termed as agile manufacturing. Agile manufacturing is different from the traditional mass production paradigm and focuses on producing customized products. Agile manufacturing is an emerging technology for a company to achieve flexibility and rapid responsiveness to the changing market and customers needs. Agile manufacturing focuses on manufacturing highly customized products as and when customers require them. Agile Manufacturing sets out to identify and apply practical tools, methodologies, and best practices that enable companies to achieve manufacturing agility within a turbulent business environment. In order to adapt to the competitive environment, a manufacturer must be able to produce multiple and diverse products, upgrade and redesign its products in short life cycles, and execute efficient production changeovers simultaneously [1].

The emergence of a new manufacturing paradigm for customized products is agile production. Flexibility is a key component in any agile manufacturing enterprise. In a competitive manufacturing environment a company must be able to simultaneously produce multiple and diverse products, upgrade and redesign its products in short life cycles, and execute efficient production changeovers [1]. To have total flexible production system, company should have three important characteristics. staying close to the customer; closer relations with suppliers, reduction of their number, improvement of quality and delivery time, participation in the design of the product, etc.; using technology for strategic advantage [2].

2. MASS CUSTOMIZATION CONCEPTS

Mass Customization is nowadays lived and practiced by many firms from various industries. The implementation of mass customization takes place by means of various methods, which combine different options for customization while maintaining the cost option.

The modularization (platform thinking) can be regarded as the central principle of mass customization. A product with a modular design provides a supply network with the flexibility that it requires to customize a product quickly and inexpensively. A relatively high level of prefabrication permits scale-oriented basic production whose results (modules) are combined or completed in the final steps of production according to a specific customer order.

Until today, mass customization is connected closely to the potential offered by new manufacturing technologies (CIM, flexible manufacturing systems) reducing the trade-off between variety and productivity. The information shall be regarded as the most important factor for the implementation of mass customization.

There are different conceptions to implement mass customization with diverse demands on production, all methods lead towards a sharp increase in the amount of information and communication necessitated among those involved. Mass customization is successful only when it can cover this need for information and communication both purposefully and efficiently.

The reason for this information richness is based – in comparison to the traditional push-system of mass production – on the need for direct interaction between the customer and seller for every single transaction, a mechanism that will be discussed more detailed at the end of this paper. Every order implies coordination about the customer specific product design as a result of the divided construction process of mass customization.

3. MASS CUSTOMIZATION SYSTEMS DESIGN

MC systems consist of and are characterized by two separate but related processes: mass production and customization. A MC manufacturing system may start with mass production stages and end with customization. The key difference between various MC systems is where the customers become involved in the manufacturing process. This difference leads to different MC strategies, five of which have been described in the literature [3]. These strategies may be defined as:

- post-distribution-there is no customization performed in the factory, and any customization is carried out by the customer;
- distribution-to-order-the customer has package options at the delivery point;
- assemble-to-order-fabrication is carried out prior to order, with inventory held as raw material and components;
- fabricate-to-order-only the raw material inventory is held;
- engineer-to-order-no inventory is held, and the customer is involved at the design stage.

A key factor in designing a MC system is the location of the customer involvement or decoupling point [4], [5]. The customer involvement point is usually associated with holding inventory, from which items are selected for customization to match customer requirements. The inventory needs to be managed physically so that the location of items within inventory is known accurately and precisely, enabling rapid withdrawal of items for use in the assembly process.

To cope with the changing demands of customers, factories are becoming increasingly more complex: a development that is manifested as greater difficulty to describe where everything is and how things are organized. Efstathiou et al. [6] consider the complexity of a manufacturing system to be a function of the number of products, the number of and relationships between suppliers and customers, the production processes, the structure of the plant, the size of the batches, the dynamism of the environment and the quality of available information. This analysis showed the complexity of a manufacturing system to be dependent not only on its inherent structure and difficulty, but also on the dynamic conditions under which the schedule is generated and implemented.

The customers, in accordance with their individual preferences, penetrate in different points of the manufacturing process. Depending on location of the penetration point (Customer Order De-coupling Point – CODP) various manufacturing strategies are implemented – Engineering-to-Order (ETO); Make-to-Order (MTO); Assembly-to-Order (ATO); Pack-to-Order (PTO).

A complete MC manufacturing process normally consists of three consecutive parts: push assembly line; inventory; pull assembly line.

The push assembly line deals with mass production in the MC system. In a push assembly line, each workstation pushes its completed work to the next workstation according to a predetermined schedule. Traditionally, manufacturers employ push assembly lines to optimize production, according to objective functions that involve resource utilization, rather than customer satisfaction.

The function of the pull assembly line is to address the customization of the products. A pull assembly line is driven by customer requests, with respect to the number of products to be processed and the deadline for delivery.

Inventory acts as a buffer between the push line and pull line. Various semi-finished products move from the push line to the pull line and are stored in the inventory before they are customized. Inventory is actually the decoupling point, or 'customer involvement point'. Customers become involved at the decoupling point to specify the customization of the products. If a customer is involved at an earlier stage in the production process, which means that the decoupling point moves upstream, then the push line is shortened and the degree of customization is higher. The MC strategies shift from engineer-to-order to post distribution, as the decoupling point alters from early in the manufacturing process to nearer the end. Engineer-to-order is therefore characterized by a very short push line and a relatively long pull line, while post distribution has a long push line and no pull line.

4. MODEL OF RELATIONS IN MASS CUSTOMIZATION MANUFACTURING SYSTEM

The successful implementation of Mass Customization (MC) strategies to a great extend depends on information systems (IS) through which interactions between business organizations and their contragents (customers, subcontractors, outsourcers) are realized.

Figure 1 presents the model of IS supported MC manufacturing system, which is supported from three IS – Customer Relationship Management (CRM) system; Product Configurator (PC); Advanced Planning and Scheduling System (APS).

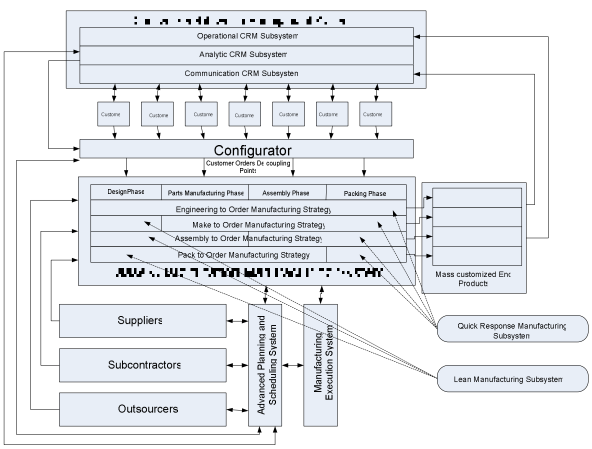

Fig. 1. Model of Relations in Mass Customization Manufacturing Systems oriented to E-business

CODP separates the manufacturing systems to two different managed subsystems – Lean Manufacturing System (before CODP) and Responsible Manufacturing System (after CODP). These two manufacturing subsystems possess different characteristics and therefore are supported by IS in a different manner. Hence, it is necessary to exist a model of IS supported MC manufacturing system. The establishment of such model is the aim of presented work.

5. MASS CUSTOMIZATION PRODUCTION SYSTEM COMPOSITE PARTS

5.1 Manufacturing flexibilities

Manufacturing flexibility can be characterized as the ability of a manufacturing system to change states across an increasing range of volume and/or variety, while adhering to stringent time and cost metrics. Manufacturing flexibility can be manifested in different forms and at different levels in an organization. Equipment, material, routing, material handling and program flexibilities are experienced in machine or shop floor operations. Mix, volume, and modification flexibilities are plant level competencies that largely develop from operational flexibilities and are exploited for tactical responses to change. The highest order flexibilities - new product and market flexibilities - are strategic capabilities that can redefine competition in an industry.

This work focuses on the three components of product flexibility - mix flexibility, modification flexibility and new product flexibility - and examines these through the dimensions of range, cost and time. Managers most frequently identify these flexibilities as important and understandable. In addition, these flexibilities are externally driven and closer to the customer, as compared to process flexibilities. Furthermore, it is more feasible that these plant level flexibilities rather than lower level flexibilities, such as equipment or routing flexibility, would be influenced by supplier actions and purchasing competence practices posited in the theoretical framework earlier.

Mix flexibility is defined as the ability of a manufacturing system to switch between different products in a product mix, without incurring major set-up costs or extended set-up times. Modification flexibility refers to the ease of making minor alterations in product design to meet customization or differentiation requests. Such design modifications are often seen in customization strategies, and in declining product life cycle situations. New product flexibility refers to the capability of the manufacturing system to introduce and make new parts and products, using existing facilities. It enables the manufacturing system to stretch its product line and adopt proactive competitive strategies.

Researchers agree that flexibility goals cannot be achieved by manufacturing technology hardware alone: concurrent investments in human and organizational factors are required.

This work organizes advanced manufacturing technology as a latent factor with four complementary dimensions - manufacturing systems, infrastructural support systems (material handling, production planning and control.

The need to respond rapidly to changes in market demands creates a need for new designs of Manufacturing Systems (MSs). In order to sustain competitiveness in dynamic markets, manufacturing organizations should provide sufficient flexibility to produce a variety of products on the same system.

5.2 Lean subsystem characteristics

The ability to build mass-customized and standard products on-demand is the payoff for lean production programs. Lean production is ‘lean’ because it uses less of everything compared with mass production – half the human effort in the factory, half the manufacturing space, half the investment in tools, half the engineering hours to develop a new product in half the time. Also, it requires keeping far less than half the inventory on site, results in many fewer defects, and produces a greater and ever growing variety of products.

There are four basic principles of lean thinking which are most relevant mass customization: Add Nothing But Value (Eliminate Waste); Center On The People Who Add Value; Flow Value From Demand (Delay Commitment); Optimize Across Organizations.

The first step in lean thinking is to understand what value is and what activities and resources are absolutely necessary to create that value. Once this is understood, everything else is waste. Since no one wants to consider what they do as waste, the job of determining what value is and what adds value is something that needs to be done at a fairly high level. To develop breakthroughs with lean thinking, the first step is learning to see waste. If something does not directly add value, it is waste. If there is a way to do without it, it is waste.

Lean production system is a key prerequisite for Build-to-order and mass customization manufacturing strategies. The key prerequisites of lean production are product line rationalization and standardization which simplify both the supply chain and manufacturing operations. This will make implementation easier and faster and ensure the success of lean production as well as build-to-order and mass customization.

The most important attribute of lean production subsystem is the ability to build products quickly and efficiently in batch-size-of-one. In order to do that, all setup must be eliminated including any delays to kit parts, find and load parts, position workpieces, adjust machine settings, change equipment programs, and find and understand instructions.

Manufacturing in batches drastically raises costs and lead times because of the following considerations:

- **Space.** Batched parts occupy much more space than a single piece flow, especially if batches are so heavy that fork lift aisles are needed.
- **Throughput times.** Batching parts slows throughput because, at each step, the batches wait in line for setup changes and the processing time of all the parts in the batch.
- **WIP inventory.** Batches create WIP inventory; inventory carrying costs are 25% of the value of the parts per year.
- **Defects.** Parts made in batches could be made with recurring defects which may not be determined until after hundreds of defective parts have been made.
- **Disruptions.** "Rush jobs" can cause major disruptions to scheduled production by adding two additional setups for every affected part. "Treasure hunts" may be needed if there are any part shortages due to errors in forecasting, bills-of-materials, or inventory counts. Womack and Jones conclude that treasure hunts "are the distribution equivalent of the expediting always necessary in batch-and-queue production operation."[2]
- **Flexibility.** Because of all of the above, batch & queue manufacture is not flexible and therefore does not support build-to-order and mass customization.

If successive products are to be unique and different, there cannot be any significant setup delays to get parts, change dies and fixtures, download programs, find instructions, or any kind of manual measurement, adjusting settings, or positioning of parts or fixtures. For a plant to mass customize or spontaneously build products to-order, all product setup must be eliminated

CNC machine tools are very versatile tools to eliminate setup since programs can be changed quickly and electronically. However, physical setup must be eliminated, for example, workpiece positioning and tool changes. Products may need to be designed for CNC to completely eliminate setup. In this connection the follows should be taken in consideration:

- Maximize the amount of dimensional variation done with CNC;
- Standardize raw workpieces and fixturing to eliminate setup;
- Quick and automatic program change;
- Standard cutting tools within tool changing capability;
- Automatic material feed and eject (optional);
- For sheet metal, nesting optimization (can evolve over time);
- To make the right decisions on flexible use of CNC, total cost must be used to include machine time, material cost, and all related overhead costs.

If setup can be eliminated or reduced enough to eliminate the need to manufacture in batches, then parts, sub-assemblies, and products can flow one piece at a time. One-piece flow may be essential when building to-order a wide variety of standard or mass-customized products.

It also eliminates much of the waste of batch-and-queue manufacturing: waiting, interruptions, overproduction, extra handling, recurring defects, and other non-value-added activities.

In flow manufacturing, parts may be manually handed to the next station, which may be very close, thus eliminating the need for mechanized conveyance or fork lifts, whose aisles may occupy as much space as the production line.

Rather then laying out "lines" in a literal straight line, it may be advantageous create a U-shaped line which bends the line into the shape of a "U" for the following reasons:

- **Visual control.** Everyone in the line can see the whole operation, enhancing visual control, thus resulting in greater group ownership, continuous improvement (kaizen), and problem solving. Visual control can be further enhanced with clearly visible andon (warning or status) lights and display boards;
- **Problems heard.** When everyone in the line works close together, problems at all stations will be heard by the entire line, thus leading to faster problem identification and resolution;
- **Helping out.** If one worker gets behind, nearby workers can help out, even from end to beginning;
- **Skipping steps.** Having work stations closer together makes it easier to process orders that skip steps.

5.3 Responsible subsystem characteristics

Responsible manufacturing systems (RMS) have recently been introduced to produce different product families in the shortest time and at the lowest cost without sacrificing quality. The major characteristic of such systems, called *reconfigurability,* is the ability of rearranging and changing manufacturing elements aimed at adjusting to new environmental and technological changes. Similarly, manufacturing responsiveness, associated with reconfigurability, is the ability of using existing resources to reflect such changes. The reconfigurability of manufacturing elements is being considered as a new requirement, which plays a key role in future manufacturing systems. Similarly, manufacturing responsiveness has shortly become a new economic objective along with classical objectives such as low cost and high quality.

Traditional manufacturing systems such as Dedicated Manufacturing Systems (DMSs) are designed to produce only a certain product type with a deterministic demand while using fixed manufacturing elements, such as machines, tools, operators and material handling systems. More flexible, but conventional manufacturing systems, such as Flexible Manufacturing Systems (FMSs) and Cellular Manufacturing Systems (CMSs), have also not been shown to be full of the above RMSs characteristics. FMSs have focused on multi-purpose manufacturing facilities to make possible the manufacture of a variety of product types. Although FMSs have improved the flexibility of manufacturing systems to respond to changing production requirements, there still exist some limitations in establishing FMSs, and these can be listed as follows:

- The difficulty of design, owing to the large commitment of manpower and skill for the specification and integration of complex manufacturing elements;
- High capital costs and acquisition risks;
- Not economic for higher (or lower) product variety due to the need for investing in higher flexible multi-purpose facilities (or using more flexibility than needed).

On the other hand, CMSs are generally designed according to a fixed set of part families, whose demands are assumed to be stable with long life cycles. When a cell is formed, a single part family with identified demand is assigned to it. The structural limitations of CMSs can be listed as follows:

- CMSs are designed for predetermined and fixed parts;
- CMSs are not flexible enough to produce new parts;
- CMSs are not economic for demand fluctuations whether in type or volume;
- The cost of redesigning CMSs and layout changes is too high.

As a result, classical CMSs may be known as unconfigurable manufacturing systems in mass customization conditions. An extension to CMSs by the virtual cellular concept has been reported, based on physically reconfigurable systems using the Group Technology (GT) principles [7]. Although the virtual cell concept has been proposed in support of classical CMSs. in order to keep pace with the above limitations via reconfiguring cells, the core structural circumstances that come from the nature of cellular configurations are still unavoidable. Some CMSs' shortcomings from the reconfigurability point of view can be listed as follows:

- Uneven and low machine utilisation because of duplication of the same machines in different cells;
- Low flexibility for product variety;
- High changeover cost for cell reconfiguration, e.g. machine relocations;
- Limitation on a new product introduction because of its potential operational dissimilarities with existing products.

The Agile Manufacturing Systems (AMSs) paradigm is another modern system concept in the manufacturing environment and has the idea of responding quickly in an adaptive manner. An AMS has been defined as a system that is capable of surviving and prospering in the competitive environment of continuous and unpredictable changes by reacting quickly and effectively to a changing market. A literature review [8], [9] shows that a range of agile architectures has been discussed for the development of business environments. However, the design at plant level is still in the earliest stages, which are limited to the identification of the key attributes such as responsiveness, productivity, flexibility and reusability.

A Reconfigurable Manufacturing System (RMS) is a new paradigm for production systems that addresses the need for introducing greater flexibility into the high production environment in which changes in product volumes and types occur regularly. This can be achieved by reconfiguring the production elements according to changing demands.

The concept of RMSs has its origin in designing computing systems in which configurable computing systems try to cope with the problem of inefficiency of conventional systems due to their general orientations. The initial idea of reconfigurable computing systems dates from the 1960s [10]. This innovative paradigm dissolved the hard borders between hardware and software and joined the potentials of both. In comparison, the RMSs paradigm is intended to link the potentials of market demands and manufacturing systems that traditionally have been considered as two separate environments.

Koren *et al.* [11] defined a RMS as a manufacturing system designed at the outset for rapid changes in structure as well as in hardware and software components in order quickly to adjust production capacity and functionality within g pari family in response to sudden changes in market or in regulatory requirements. As can be remarked in the definition, RMSs were assumed to be reconfigurable only within a particular part family. In contrast, Xiaobo *et al.* [12] considered a RMS as a manufacturing system in which a variety of products required by customers are classified into families, each of which is a set of similar products, and which correspond to one configuration of the RMS.

In this work, a RMS is expected to be able to adjust rapidly to new circumstances by rearranging and changing its hardware and software components in order to accommodate not only the production of a variety of products, which are grouped into families, but also a new product introduction within each family. The manufacturing system is then required to be reconfigurable in capacity for volume changes and functionality for family changes. In this way, a reconfiguration link between the market and the manufacturing system is required to reorganize the production system according to varying requirements. The reconfiguration link incorporates the tasks of determining the products in the production range, grouping them into families, and selecting the appropriate family at each configuration stage.

RMSs must be designed with certain characteristics to achieve exact flexibility in response to demand fluctuations. RMSs are described by five key characteristics: modularity, integrability, convertibility, diagnosability. and customization [13]. Modularity in the product design stage as well as in the process design stage enables a RMS to produce different product families with common resources by means of different configurations. As a result, a RMS design must be:

- modular in both product and process design stages;
- rapidly integrated from product to process design;
- rapidly upgradeable in process technology with new operational requirements;
- able to covert to the production of new products within each product family;
- able to adjust capacity quickly whilst changing product volumes (with predictable and/or unpredictable quantities).

RMSs comprise various replaceable modules, with the intention that, once a reconfiguration takes places, a new module replaces an old module [14]. The modular structure accommodates new and unpredictable changes m i IK- product design and processing needs through easily upgrading hardware and software rather than the replacements of MS elements such as machines.

In the same way, holonic manufacturing systems have been built up from a modular mix of components in order to cope with a rapidly changing environment. To date, the holonic concept has focused on developing an architecture for planning and control functions, which is required for managing existing production systems at the machine level. For example, Chrin and McFarlane [15] presented a conceptual migration strategy for transferring a traditional manufacture control architecture into a holonic infrastructure. The holonic architecture can be used for reconfiguring the control system of an established RMS into different post-design levels, such as planning, scheduling and execution.

6. CONCLUSION

The reorganization of manufacturing systems during transition from mass production to mass customization can be assisted through the application of the proposed model in which lean and responsive manufacturing systems are taken into account. The presented model can be linked to the available information systems of the business organization, such as ERP, CRM, SCM, MES etc.

The author intends to extend and elaborate the model and after that to validate the model in 2 – 3 case studies in leading Bulgarian manufacturing enterprises (forklift trucks, bikes, electric drilling tools, refrigerators etc.).

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