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Manufacturing Concepts of the Future – Upcoming Technologies Solving Upcoming Challenges

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Abstract

This paper presents an examination of Western European manufacturers' future challenges as can be predicted today. Some of the challenges analyzed in the paper are: globalization, individualism and customization and agility challenges. Hereafter, the paper presents a broad analysis on manufacturing concepts and technologies that are being developed today which may be used to solve manufacturing challenges in the future, such as: (self) reconfigurable manufacturing systems, (focused) flexible manufacturing systems, and AI inspired manufacturing. The paper will try to offer a critical point of view on manufacturing challenges, concepts, and technologies, and is meant to address both academia and industry.

Keywords: Reconfigurable manufacturing systems, manufacturing challenges, cognitive factory, mass-customization

1 INTRODUCTION

The amount of literature written on manufacturing concepts and challenges illustrates just how complex and interesting the subject is. In the past decade, many advances in theory, strategy and practice of manufacturing were created (e.g. LEAN, JIT (just-in-time), SCM (Supply Chain Management), TQM (Total Quality Management)). Progress was also made in the development of new manufacturing concepts such as: Flexible Manufacturing Systems (FMS), Reconfigurable Manufacturing Systems (RMS), mass-customization (MC), Decentralized/ Distributed Control, etc., many of which will be discussed in this paper. These paradigms are important in foreseeing and identifying potential manufacturing challenges in the future.

This paper forms a first stage investigation in a joint project between LEGO Systems A/S and The University of Southern Denmark (SDU). LEGO is one of Denmark's biggest manufacturing companies and is one of the world's leading toy manufacturers. The complexity of their products, challenges in their supply chain management, and difficulties in being flexible and agile towards their customers, all contributed to establishment of this research. The project is set to examine, conceptualize and possibly implement the manufacturing concepts of the future. LEGO, with SDU, is searching for an implementable yet novel concept that will challenge the existing ideas of present manufacturing.

It is this paper's aim to provide an insight to uprising technologies and concepts and to combine them with upcoming challenges manufacturers will face in the future. By providing a broad overview of future challenges and concepts, this paper aims to reach both academia and industry in order to illustrate possible advances. The paper's purpose is to present concepts and technologies that are currently being developed, which may be used in the future for manufacturing.

What challenges will manufacturing companies face in the future? What are the manufacturing concepts of the future? How will upcoming technologies help companies face these challenges?

2 WESTERN MANUFACTURING CHALLENGES

During the last decade, several European initiatives set their goal to enhance manufacturing in Europe. Among these were projects such as Futman and Manvis. The largest one of them is known as Manufuture. This initiative aims to increase the level of European manufacturing competitiveness by creating new business models, focusing on manufacturing education, developing new manufacturing technologies, and highlighting value-adding processes and services. Several public-private initiatives rose as a result, including: Factories of the Future, which aims to develop new sustainable technologies for future manufacturing [1] [2] [3] [4].

In order to truly analyze the manufacturing concepts of the future, it is important to first examine the challenges manufacturing companies may face, particularly those in Western Europe.

2.1 Globalization and fragmentation of production

The expansion of current emerging markets will continue to affect global competition and economy, and will increase its intensity. As BRIC (Brazil, Russia, India and China) continues to expand, so will their economies and their effect on global manufacturing. Literature shows that BRIC's GDP and manufacturing ability, as economies, will exceed that of most western countries by 2025 [1] [2] [3].

The effect of globalization on the manufacturing industry rises above the international economic factors. Globalization will illustrate, more than ever, the effect of human capital on the structure of the manufacturing industry. BRIC will keep providing cheap labor and affect the location of production as well as shape the environment of global competition. However, as social benefits continue to rise in BRIC and with the addition of cheap and geographically closer "new" EU members (e.g. Romania & Bulgaria (joined 2007)) the attractiveness of off-shoring to/from BRIC may decrease gradually. Nevertheless, the attractivity of Western Europe as manufacturing ground will continue to decline [2] [4].

Contrary to the opportunities globalization presented (new markets, cheap labor, etc.), many challenges for manufacturers rose as well. Production fragmentation can be a challenge in areas of SCM (coordination of processes), Technology transfer (coordination of knowledge), company culture (coordination of organization), etc. The physical division of production, that is the result of fragmented production, creates issues in the standardization of manufacturing processes (e.g. facilities in low-cost labor countries have different levels of automation than those in high-cost labor countries) making it difficult to implement identical processes and procedures [3].

2.2 Higher demand for individualization

The current movement from mass production to mass customization will continue to increase. As general social individualism increases, the demand for personalized unique products will increase. Manufacturing companies will be required to supply personalized demand on a mass scale as the fluctuation of the market will also increase. Additionally, batch sizes will exponentially decrease creating immense challenges in SCM and challenging manufacturing capability and flexibility [5].

Not only will the demand for customization and individualism rise, customers will expect products to maintain their mass-produced price as the availability of features and functions increase. The demand for both *"mass"* quantities and qualities, and *"customization"* of products and supply will increase gradually. Manufacturers of the future will have to adjust their manufacturing facilities, concepts and technologies to withstand the increasing demand on both aspects. [6]

2.3 Seasonality and fluctuation of demand

As the demand for specialized, customized and unique products increases, demand fluctuations will increase as well. As strategies of manufacturing shift from made-to-stock to made-to-order (as a result of practices of principles such as LEAN and MC) the complexity of forecasting will increase significantly. This effect will be magnified when introducing the element of seasonality, thus causing the uncertainties to rise even more. Manufacturers will have to progress from tackling operational uncertainties and fluctuations of demand, to tactical and even strategic levels (e.g. complex and flexible production planning) as oscillations through the supply chain amplify—a result of vast changes in demand[1] [7] [8].

2.4 Agility and optimization

It seems that some manufacturers already realize that optimization of current process is reaching its limits. Western European manufacturers' inability to compete with lower prices presented by BRIC and other low-cost labor countries will force manufacturers to seek other competitive advantages. Optimization will also reach a certain point where advances will decrease and other competitive advantages will be necessary. These competitive advantages will be found in value adding for customers and will most likely be formed as agility and flexibility of manufacturers (e.g. flexibility in capacity, short time-to-market, innovative capabilities, responsiveness to environmental regulatory changes, etc.) [9] [10].

2.5 Time based competition

The trend of time based competition is not new to the manufacturing industry. As the demand for shorter and shorter time-to-market will increase, organizations and supply chains will have to adjust their business models to withstand the fast pace. Product life cycles will be shortened as well, and the demand for new products will boost even more. As a result, manufacturers will have to evolve with fast pace of technology integration to meet the demand for new products. New concepts of automation, production and manufacturing will develop as a strategic tool of competitiveness. The ability to execute a product through all stages of development, design, production and distribution - quickly, flexibly and effectively, will boost the manufacturers' ability to fit manufacturing technologies and concepts to new products; thus constituting new competitive advantages. [11] [12]

There is something to be said about the lack of **visionary** research on the manufacturing challenges of the future. A great amount of valuable research was made in the late 1990s, predicting future manufacturing challenges and compatible technologies that would resolve them (See e.g. (13) (14)). However, in the past 10 years, there seems to have been a lack of research analyzing the future advances and challenges of manufacturing, especially in light of the latest advances which pose an opportunity for future research.

3 FUTURE MANUFACTURING CONCEPTS AND PRINCIPLES

After analyzing potential future manufacturing challenges, it is important to investigate some of the upcoming paradigms and concepts of manufacturing.

3.1 Mass-customization

Although MC is not a new theory, practice or strategy, recent years' interesting advances in technology transformed it into a highly preferable one. Essentially, MC is manufacturers' ability to meet customers' changing product or service demand - both efficiently and effectively - while maintaining a commercially competitive price[2] [15] [16].

Several developments in technology in recent years made the blossoming of MC, as a concrete and applicable strategy for manufacturers, possible. First, progress in modular and flexible systems gave birth to the technical feasibility of MC (Modular Manufacturing Systems (MMS), Flexible Manufacturing Systems (FMS)). Additionally, manufacturers have also been using delayed differentiation (or form postponement, late dedication) in order to delay the specification (unique characteristics) of a product (to be discussed further). By doing that, manufacturers have been able to minimize inventory, increase product range and eventually decrease prices [5] [6] [17] [18].

The second and crucial enabler of MC's success is the internet and the development of advanced IT (Information Technology) Systems. The importance of these systems is twofold. IT systems enabled manufacturers to connect in real-time with their suppliers, making their supply chain significantly more agile. By doing that, manufacturers were able to better fit the supply of raw materials, components and other necessary elements to real-time demand from customers. Thereafter, manufacturers were also able create direct links to their customers, hence the ability to communicate and co-design on one hand, and receive real-time demand information, on the other [5] [17] [18] [19].

Mass personalization

A new concept has been emerging in the past few years in both research and industry. The development of *"a market of one"* transforms MC strategies into Mass Personalization (MP) in selected industries. As suggested, MP is manufacturers' ability to **tailor** a specific product to a specific customer on a mass scale. In a way, the term MP forms a fundamental contradiction where the ability to personalize a product opposes the ability to manufacture with commercially competitive prices, even more so than in MC. However, in practice, further progress in technology makes MP a competitive advantage to selected segments. According to Kumar (2007), the reasons manufacturers will transfer from MC to MP include: (1) **Customer/market share:** Since low prices are almost a given in today's competitive market, manufacturers must compete over customer satisfaction and gain market share by providing highly customized/personalized products. (2) **IT capabilities:** Web 2.0 enabled manufacturers to have a higher degree of user and

[1] This effect is also referred to as the bullwhip effect. See e.g. [50]

[2] For an extensive literature review on different aspects of MC, refer to [15].

customer involvement in design, marketing and sales efforts. Other powerful IT tools make business operations simpler and faster (e.g. search engines, CRMs, manufacturing control systems, etc.). (3) Powerful and **intelligent manufacturing systems** powered by contemporary manufacturing concepts and principles [5]

As mentioned before, though MP is already an applicable strategy, it is only implemented in a few industries and sectors. The question still remains: Will MP become the future of manufacturing? Evidence indicates that some companies benefit greatly both financially and in terms of increased market share by implementing aspects of MP. However, will MP be a preferred strategy to all manufacturers in the future?

Delayed Differentiation

An increasingly interesting term in the area of MC/MP is Delayed Product Differentiation (DPD)[3]. DPD is a concept that separates different stages of a product's production in such fashion that its uniqueness materializes in as late stage as possible. A product is manufactured so that its process is divided into two stages: standardized and differentiated. The standardized stage can also be seen as the "mass" stage where the product is not unique, thus allows economies of scale production. Since frequently different products (and part families) have many features in common, the standardized stage involves all mutual processes. The differentiated stage, which can also be seen as the "customization" or "personalization" stage, is the stage a product will get its uniqueness which can involve: shape, color, functionality, feature, etc. [20]. The success of DPD and that of MC/MP in general, depends greatly on the standardization of components, products and processes. DPD is the concept that truly makes MC/MP a feasible and financially justified principle by achieving economies of scale, product design, and process selection. Examples of successful implementation of DPD can be found in the automotive, shoe and clothing industries, among others[4]. [20].

3.2 Intelligent Manufacturing Systems

Intelligent manufacturing systems (IMS) contain a wide range of concepts that increase and enhance a production system's flexibility, adaptability, autonomy and general functionality. This section will discuss some of these concepts that have been in the focus of research in recent years and that may pose solutions to future manufacturing challenges, as presented in section 1. A number of distinguished authors have described different aspects of IMS (see e.g. [21] [22] [23] [24] [25]). The following section provides a review of some of the relevant ones.

Flexible manufacturing systems

Though FMS is not a new concept for either research or the industry, it constitutes the basics of our interest in IMS concepts. Mehrabi, et al. (2000), defined FMS as*: "a machining system configuration with fixed hardware and fixed, but programmable, software to handle changes in work orders, production schedules, part-programs, and tooling for several types of parts" (pg.404).* FMSs are usually constructed of several changeable modules incorporated with a material handling system [26]. Implementing FMSs enables manufacturers to achieve cost effectiveness, short change-over time and variation of tooling possibilities [27].

Though FMS provided huge opportunities to western manufacturers, particularly due to their ability to increase competitiveness, responsiveness and reduce costs, it also posed an immense strategic, tactical and operational difficulty. Several authors have described the downsides and disadvantages of implementing FMSs such as: high costs of implementation, low reliability, low upgradeability and implementation of new technology, and low volume and capacity (see e.g. [22] [28] [29] [30]).

Reconfigurable Manufacturing Systems

In order to overcome the main disadvantages of FMSs new paradigms of manufacturing appeared. One of which - RMS, extended the advantages of FMS and overcame its main disadvantages by integrating lead time reduction, lower costs, higher volumes and new technology upgradability to its features [26] [27]. In addition to that, the change in structure forms a base for changes in capacity and functionality [31]. Essentially, RMS is a system designed for frequent changes in design and functionality and is able to quickly adjust its structure to these changes to the benefit of its output (within a part family) [32]. In other words, there is an extreme focus on the system's ability to change its modules quickly and seamlessly, product-wise, in order to vary capacity and ramp-time, increase product variation, minimize lead-time, etc.

Koren, et al. (1999), have specified key characteristics for RMS to be feasible and viable for manufacturers, namely: (1) **modularity** – modules in the system are separate and independent, (2) **Integrability** – components in the system are designed with interfaces that are readily integrated, (3) **customization** – enables specific levels of flexibility and control as required by functionality, (4) **convertibility** – elements in the system support the changes of functionality dictated by a desired operation, and (5) **Diagnosability** – that of the system itself, its processes and products [22] [30][5].

Kuzgunkaya and ElMaraghy (2009) constructed a model illustrating both financial and strategic advantages of RMS. While comparing RMS and FMS strategic and financial feasibility, it was found that RMS presented higher performance in terms of return on investment, utilization, reconfiguration times, responsiveness and complexity reduction [33].

Focused Flexible Manufacturing Systems

Another concept that aims to improve the feasibility of FMS as a viable and feasible solution in the manufacturing industry is Focused Flexible Manufacturing System (FFMS). FFMS aspires to overcome the main disadvantages of fully FMS by specifying an exact degree of flexibility, i.e. flexibility is not complete but adjusted to the specific demand of the manufacturing system and dictated by market demands. The concept of FFMS proposes a combination of fully-flexible and dedicated machines altogether in order to achieve an adjustable trade-off between flexibility and productivity that will optimize the profitability of a system. Additionally, FFMS takes into consideration the integration of new technology as a main factor in the system's design [34].

According to Terkaj, Tolio and Valente (2009), the main difference between RMS and FFMS is that RMS considers the current situation and adjusts the system to fit its features to the required state. FFMS, on the other hand, takes into consideration future scenarios and demands and adjusts the trade-off between flexibility and productivity to optimize the output according to cost analysis [34].

Self-reconfigurable robotics

Some very interesting technological developments occurred in the field of Self-Reconfigurable Robotics Systems (SRRS) in recent years. Yim, et al. (2007), defined the field of (modular) SRRS as: *"…the design, fabrication, motion planning, and control of autonomous kinematic machines with variable morphology" (pg.43).* In other words, SRRS is a system constructed of independent but

[3] Also known as late dedication and form postponement in different industries

[4] See [20] for more economic justification for DPD and MP

[5] For more details about the characteristics of RMS, design, tools control and more, refer to [22], [51], [52]

interconnected machines that are able to autonomously reform their structure and functionality in order to adapt to new situations according to their current task [35].

The state of the art in the SRRS field has developed from a proof of concept to the development of several advanced 3-D structured systems, e.g. I-Cube, M-TRAN, ATRAN, CONRO, Miche, etc. The absolute majority of SRRS systems are constructed of intelligent autonomous modules that are able to communicate, compute and collaborate independently and inter-connectively [36] [37]. Other than its high level of intelligence and the future opportunities it possesses, some immediate advantages appear. First, its reconfigurable structure enables SRRSs to be versatile in a fashion that allows it to modify formation and functionalities, thus making it able to handle an immense variation of tasks. Additionally, SRRSs are likely to be more robust than conventional systems since the intelligence of individual modules can result in faster and better diagnosability and potentially self-repair in the future. Furthermore, the modular concept of SRRSs permits standardization - since their design is ideally identical - enabling low costs, economies of scale, upgradability, scalability and more [35] [38].

With the many opportunities SRRS technology presents, some challenges still prevent SRRS to be feasible and implementable technology in the industry. Several issues with hardware construction (mechanical robust design of a module and system) still hinder the development of larger, more general systems. As systems grow, develop and magnify, some software and control issues appear (motion control and reconfiguration algorithms for larger systems) as well as challenges in sensor technology. The most interesting challenge SRRSs currently face is the identification of a viable, market driven application where SRRS advantages and opportunities can be benefited from [35].

Could manufacturing be a feasible application for SRRS in the future? Could the principles developed presently be implemented on larger manufacturing machines?

3.3 Artificial Intelligence inspired manufacturing

Based on advances in holonic, bionic (biological) manufacturing paradigms, and heterarchical and fuzzy control concepts, some extremely interesting paradigms have evolved in the past few years. The notion of Artificial Intelligence (AI) as a part of manufacturing started to materialize and several studies emerged, formulizing ideas, models and developments of the concept's feasibility and implementation [25] [39].

Holonic and Bionic manufacturing systems

Holonic Manufacturing Systems (HMS) is no longer a new paradigm of manufacturing. However, since its major development in the early 1990s, it has formed the base for decentralized and distributed understandings and created the foundation for some of the most exciting technologies being developed in the present [39]. HMS refers to a system that is constructed of individuals (particles/subordinates) that form a collaborative organization (a whole) while being independent and autonomous [40] [41]. Though HMS presented many opportunities due to the initial understanding of distribution of intelligence and physical appearance, it was still based on the rescheduling of predefined tasks [39] [40].

In the late 1990s the Bionic (or Biological) Manufacturing System (BMS) paradigm was developed. The concept is based on biological processes and presented the autonomy, self-development, adaptation and intelligence of elements constructing a whole system. The main difference between HMS and BMS is that BMS handles unpredictable situations and illustrates the learning and conclusion-making abilities of its elements [23] [39]. HMS and BMS are not new manufacturing concepts per se; however, both have not reached their potential and still form the base for manufacturing technologies and concepts that will be developed in the future.

Decentralized concepts

Advances in HMS and BMS demanded the creation of decentralized and distributed systems and control methods. The majority of control concepts in the industry today are centralized. However, the incentive to choose a decentralized concept over a centralized one is that decentralized systems are more flexible and scalable than centralized ones due to their holonic structure [42].

Some exciting Multi Agent Systems (MAS) have been developed in recent years which are constructed of intelligent, autonomous and goal oriented entities that cooperate and collaborate in order to achieve a common goal. These systems are common in areas of real-time manufacturing control, production planning and management, and virtual enterprises that assist coordination through the supply chain (e.g. [43] [44]). Through the decentralized concepts, MASs made possible the creation of so called *self-x* properties (self-reconfiguration, self-optimization, self-healing and self-protecting) that relates to many topics covered previously. [42]

Another interesting factor is the development of BMS based concepts such as immunity based adaptive scheduling and material handling control. These concepts utilize adaptive biological concepts from the human body and the biological world (such as the immune system) to open interesting perspectives and opportunities of future manufacturing. [45] [46]

The cognitive factory

Some of the concepts already discussed the opportunities in incorporating different levels of Artificial Intelligence (AI) into manufacturing. This created an interesting concept that describes the opportunities in establishing a cognitive factory. Present manufacturing systems - even the most intelligent of them - will never reach the flexibility, scalability, adaptability and reliability of that of human manufacturing since humans have the ability to learn, make conclusions and quickly adapt to new conditions and tasks. Using many of the topics previously discussed, a new paradigm, which was able to learn and implement conclusions under new circumstances, was created [39]. In the last two years, interesting research has been made into the area of cognitive manufacturing, resulting advances in automated planning assessment [47], control of production systems [48], and monitoring and adjustment to unforeseen situations [49]). These advances and more are making the concept of cognitive manufacturing more interesting and feasible than ever. However, will AI inspired manufacturing concepts be realistic in the near future or will their fate be similar to that of FMS in its early years?

4 CONCEPTS, CHALLANGES AND LEGO

In recent years, LEGO's main focus has been mainly on the optimization of its processes. Internally LEGO has been optimizing manufacturing processes and implementing contemporary manufacturing technologies. Among others, LEGO implemented modular concepts into its production allowing LEGO to be more flexible in product variation. Additionally, interesting technologies such as SLS (Selective Laser Sintering), advanced injection molding technologies and new flexible packaging solutions, were integrated to the manufacturing process. Furthermore, LEGO has recently implemented DPD in several products in order to increase product variation and process flexibility to achieve high MC.

LEGO's current challenges are challenges Western European manufacturers generally experience, making LEGO an interesting case study to analyze. Some of these challenges include: (1) Due to the increase of customization, LEGO had to decrease batch sizes and challenge its SCM more than ever. This trend is expected to dramatically rise in the current decade and challenge both manufacturing capabilities and the flexibility of LEGO's processes. (2) In order to be closer to the customer, as other western manufacturers, LEGO has distributed its production globally. At the moment, LEGO manufactures in 4 main facilities in Denmark, Mexico, Hungary and the Czech Republic, while also outsourcing production from China. The geographical separation of production makes LEGO unable to implement a cross organizational manufacturing concept due to differences in skilled employees, labor costs, automation capabilities, etc.. This results in challenges in maintaining a consistent quality and productivity level between the different locations. (3) The focus on optimization also had a negative impact on LEGO's agility. Since processes are optimized to such an extent, changes in product specifications, quantity and new product integration have been a challenge. (4) In the toy industry, as in many other industries, the effect of seasonality on demand is massive. The rapid fluctuations of demand and the challenge of following it with sufficient capacity are ever increasing. LEGO has been experiencing difficulties in forecasting specific demand, resulting in a very low fit percentage between forecasted demands, and actual demand. This results in over-production of non-demanded products, higher costs of inventory, longer lead-times for the production of actual demanded products, and challenges with customer satisfaction.

LEGO recognizes the challenges that are described earlier in the paper and is looking for new manufacturing concepts and technologies to overcome these upcoming challenges.

5 CONCLUDING REMARKS

Predicting the future is, of course, an impossible mission and forecasting is the only way to paint a picture of potential future scenarios. Identifying future challenges, technologies and concepts to overcome them is difficult as well. In that sense, this paper attempted to present a summary of both future challenges and concepts of manufacturing for both academia and the industry.

After analyzing the literature on future manufacturing challenges, we were a bit surprised by the lack of **visionary** research. It was our hope that researchers will offer "educated guesses" about the future of manufacturing which go beyond the more extreme current challenges. Will the trend of globalization continue its course or will markets become more regional/local as decentralization of production becomes more possible due to advances in technology? Will it be possible that not only distribution centers will be localized but also worldwide small intelligent production? Will MP be the manufacturing strategy of the future to all industries, specific industries or be proven to be less economical than, for example, MC?

Can it be that the initial focus of production be changed towards looking at a product as a target in order to handle fluctuations better? Is the current focus of manufacturing around processes the most financially beneficial or will another focus around the product, combined with new manufacturing concepts, bear greater opportunities? Is there a possible combination of technologies that may create the opportunity to develop even newer manufacturing paradigms? Is AI a sustainable, feasible and economical solution for manufacturing in the near future? How would it then manifest? Among the many researched paradigms, which ones will be more likely to be implemented by the industry? Many questions remain open and pose opportunities for LEGO and future research.

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