Implementation of Reconfigurable Manufacturing Systems, the Case of The LEGO Group

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Abstract
Turbulent market under global competition forced manufacturers to search for new manufacturing concepts to stay competitive. How to consider a new manufacturing system becomes an important issue. The objective of this paper is to examine the most suitable areas for the implementation of reconfigurable manufacturing systems (RMS). A literature review is made to describe the advantages and core characteristics of RMS. Based on the theory, a conceptual model is developed to analyze where RMS would be most suitable and have most benefits in The LEGO Group. Finally, the conclusion is drawn based on the analysis through the model.

Keywords: Reconfigurable Manufacturing Systems, Conceptual Model of RMS, Production of The LEGO Group

Introduction
Because of market turbulences caused by global competition, manufacturers will face more and more challenges in the future, such as: 1) increasingly frequent and unpredictable market changes, 2) rapid introduction of new products and constantly varying product demands, 3) quest for higher customized products, etc. (Koren, 2010). All these challenges are driven by strong competition on a global scale, more educated and demanding customers, and rapid changes in product and process technology (Koren,
To stay competitive, manufacturers have to make rapid responses to market changes and customer demands while maintaining their high-quality products at low cost. Traditional manufacturing systems, such as dedicated manufacturing lines (DML) and flexible manufacturing systems (FMS), cannot handle such situations because of their respectively lacking on flexibility and throughput (Koren et al., 1999). To be able to react to changes rapidly and cost-effectively, a new manufacturing approach is required (Koren et al. 1999, Mehrabi et al. 2000).

A reconfigurable manufacturing system (RMS) is defined as a system which is “designed at the outset for rapid change in structure, as well as in hardware and software components, in order to quickly adjust production capacity and functionality within a part family in response to sudden changes in market or in regulatory requirements” (Koren et al., 1999). The objective of RMS is to provide the exactly capacity and functionality when needed (Koren et al., 1999).

Even if much research effort is laid on exploring RMS, it is still not clear how RMS should be considered in production systems in the industry today. The objective if this paper is to develop a conceptual model to analyze the most suitable areas to implement RMS, through which the future manufacturing concepts will be concluded.

A literature review is made in order to describe the advantages of RMS and the determining characteristics, through which a conceptual model is developed. In addition, a case study has been carried out to analyze the most suitable production processes for RMS in The LEGO Group (Yin, 1984).

**Literature Review**

**RMS Advantages**

With the ability to adjust its manufacturing system and elements quickly and efficiently, and the combination of the high throughput of DML and the flexibility of FMS, RMS is able to make a rapid and cost-effective response to market changes. Responsiveness, capacity, functionality and cost, are the four features which define the difference between RMS, FMS and DML (Koren et al. 1999, Mehrabi et al. 2000, Koren 2006).

Typically DML has high capacity but limited functionality, whereas FMS has high functionality but lower capacity. Both DML and FMS are static at the capacity-functionality plane, however, RMS is dynamic and is able to change both capacity and functionality in response to market changes, which shows a great advantage in the adjustment of capacity and functionality (Koren 2006, Koren et al. 2010, Koren 2010).

In the manufacturing system cost versus capacity plan, DML is constant at its maximum planned capacity (Koren 2006, Koren et al. 2010, Koren 2010). To get greater capacity, a whole additional line must be built, which will make the total cost high. FMS is scalable at a constant capacity rate through adding more machines in parallel, which will also make the cost increase in parallel for greater capacity. RMS is also scalable, but it is at a non-constant rate that depends on the initial design of the RMS and the changing market situation. Compared with FMS and DML, RMS will not be more expensive. Unlike DML and FMS, RMS can be reconfigured and more elements can be added to increase the functionality or capacity on the same system.
instead of more machines in parallel or additional line (Mehrabi et al. 2000).

**RMS Core Characteristics**

Reconfigurable systems and their machines should be designed at the outset for reconfigurability, otherwise the reconfiguration process will be lengthy and costly, and therefore impractical (Koren et al. 1999, Koren 2006, Koren et al. 2010, Koren 2010). To achieve this goal, RMS is required to be designed to possess six core reconfigurable characteristics. RMS core characteristics include “modularity”, “convertibility”, “scalability”, “integrability”, “customization” and “diagnosability” (Mehrabi et al. 2000b, Mehrabi et al. 2002). “Modularity” means that both software and hardware system components are modularized for optimal arrangement (Koren et al. 1999, Mehrabi et al. 2000, ElMaraghy 2006, Bi 2008, Wiendahl 2007). “Convertibility” means it’s easy to switch exiting products and suit new products (Koren et al. 1999, Mehrabi et al. 2000, ElMaraghy 2006, Bi 2008, Wiendahl 2007). “Scalability” implies that it’s easy to enlarge or downsize of production capacity (ElMaraghy 2006, Bi 2008, Wiendahl 2007). “Integrability” means the interfaces are easy for rapid integration for the system, subsystems and components (Koren et al. 1999, Mehrabi et al. 2000, ElMaraghy 2006, Bi 2008, Wiendahl 2007). “Customization” means the system or machine flexibility is limited to a part family and obtains customized flexibility (Koren et al. 1999, Mehrabi et al. 2000, ElMaraghy 2006, Wiendahl 2007). “Diagnosability” means it’s easy to identify the quality and reliability problems in large systems (Koren et al. 1999, Mehrabi et al. 2000, ElMaraghy 2006, Koren 2006, Bi 2008, Wiendahl 2007). The influences of these characteristics on system requirements have been discussed by Mehrabi et al. (2000, 2000a)

Koren (2006) shows a quite useful relationship between these characteristics and system goals of improving responsiveness, productivity and reducing cost (Koren, 2006). Modularity, convertibility, intergrability, and diagnosability will improve the responsiveness of manufacturing system through decreasing the reconfiguration time and effort.

**Where to implement RMS**

As was mentioned before, RMS is dynamic at the capacity- functionality plane and is able to change with capacity and functionality in response to market changes and customer demands. Furthermore, RMS is scalable at a non-constant rate in the system-cost versus capacity plane, which is much more flexible on the cost capital, depending on the initial design of the RMS and the changing market situation. Moreover, RMS is able to make a rapid and cost-effective response to market changes. In sum, **capacity, functionality, cost** and **responsiveness**, these four features are the main advantages of RMS compared with the traditional manufacturing systems – DML and FMS.

Based on the theory developed by Koren (2006) regarding the relationship between RMS core characteristics and system goals (Koren, 2006), a conceptual model was developed in order to analyze the most suitable areas for RMS implementation, shown by Table 1. The analysis concentrates on the four features of RMS as specified before, namely: responsiveness, capacity, functionality, and cost. In each of the features the
relevant RMS characteristics were identified and narrowed down. The analysis will concentrate on each of the respective production areas. “1” will mark an area where a feature and principle of RMS is currently implemented in the production, “0” will mark a feature and a principle where is it not, and the scale between 0 and 1 will mark areas and features is slightly or partly implemented, where 0.25, 0.5 and 0.75 are mainly used.

<table>
<thead>
<tr>
<th></th>
<th>Process A</th>
<th>Process B</th>
<th>Process C</th>
</tr>
</thead>
</table>

Case study: The LEGO Group
The Danish toy manufacturer-The LEGO Group is facing challenges that are common to Western European Manufacturers. As one of the world’s leading toy manufacturers, the complexity of their products, difficulties in being flexible and challenges in their manufacturing and supply chain, makes The LEGO Group a very interesting case to analyze.

There are approximate 4200 different elements and 58 different LEGO colors in the LEGO range. The total number of the active combinations is approximately 9000, since each element could be sold in a large range of different colors and decorations (The LEGO Group, 2012). The abundant diversity of their products greatly increased the complexity of The LEGO Group’s production and supply chain. The LEGO Group’s production is quite precise and detailed, which makes their products of high quality and high accuracy so that only 18 out of 1 million LEGO elements produced is considered defective (The LEGO Group, 2012).

The LEGO Group’s production contains four main processes: molding, decoration, assembly and packaging. The four production processes are physically separated in The LEGO Group which requires even more transportation and warehouses, making their supply chain quite complex and increasing the lead time a lot. The unpredictable market demands and higher customized products will challenge their supply chain management and production systems more than ever. RMS shows great promise in terms of responsiveness. In which of The LEGO Group’s processes RMS is most needed? To answer this question, the existing problems and potential challenges of The LEGO
Group’s production will first be analyzed in different sections according to these four different production processes, which are as follows:

(1) Molding Process
Certain parts of the molding process are rather modular where there are currently about 7000 active standardized molds being used at The LEGO Group, which are accurate to 0.005 millimeters. Many of the machines can produce a high variety of LEGO elements providing a changeover of molds. However, the molding-machines are designed for mass production and not for quick changeover, which makes the long changeover time typically a couple of hours, including the mechanical change, material change, color change and the stability test. Changeover time is a downtime that translates to wasted capacity and productivity during changing periods. If the changeover time can be decreased, it would be a huge progress in the molding process. First, the productivity will be increased significantly. Second, The LEGO Group will be able to make more changes to switch the existing products in a certain period. Moreover, the molding machines and molds are extremely costly, which occupied quite a big part of the investments in production (Petersen, 2012).

(2) Decoration Process
The decoration systems are not completely dedicated and can be potentially changed. However, they are not flexible and can be changed only for another dedicated decoration processes. There is one setup for each product, which is very dedicated and automatic. If it is only the decoration that needs to be changed, the same machine can be used by changing the cliché, the pad and the element fixtures, which takes some changeover time for these operations. But if the geometry also needs to be changed, different kind of machines will be necessary.

(3) Assembly Process
The LEGO Group has one setup in Billund, Denmark, which is totally dedicated to assemble mini-figures. Another setup called the Sigma-line is rather modular and different modules with different functionalities can be added or subtracted to the system. It is possible to add more modules of the same functionality and by that potentially increase the capacity and output of the system. The changeover time in assembly is not quite long, which only contains the mechanical change, with no material and paint to change.

(4) Packaging Process
Packaging process contains both Pre-Pack and Final Pack. The former system is dedicated and potentially unable to make changes, while the latter one is a bit flexible to make changes for the certain families of different sized final packing.

In pre-pack process, big LEGO elements, like DUPLO products, are pre-packed by different machines than the small LEGO elements. The machines are unable to change to switch products for different sizes.

However, the ability to switch the exiting similar sized products in the same pre-pack machines easily by emptying them for other products, together with some a bit more flexible final pack system and some manual operations, makes it easy to switch certain existing products quickly in packaging process.
Analysis
The analysis will concentrate on each of the respective production areas as mentioned in the case of The LEGO Group, namely: molding, decoration, assembly and packaging. Values between 0 and 1 are given to have a better understanding. The five values of “0”, “0.25”, “0.5”, “0.75” and “1” are mainly used to mark an area where a feature and principle of RMS is currently not, partly, half, more than half and fully implemented in the production of The LEGO Group.

The values are defined based on this analysis of the case of The LEGO Group.

(1) Molding Process:
Considering the rather modular and standardized molds, as were described in the case of The LEGO Group, we can see the RMS principles are somehow implemented in molding, which are very modular and with the ability to change functionality. However, there is no diagnosability in molding, which makes the score quite low.

(2) Decoration Process:
Considering the almost dedicated decoration lines and limited changeability for other dedicated products, as were described in the case of The LEGO Group, we can see the RMS principles are somehow unimplemented in decoration system. Taking that into consideration, the scores will be quite low. However there is a quite small part family of the cliché, pad and fixtures, makes it a little bit customized and convertible.

(3) Assembly Process:
Some of The LEGO Group’s assembly systems are very dedicated to the assembly of one product alone. However, considering the Sigma-lines, as were described in the case of The LEGO Group, we can see that The LEGO Group does have several systems that are more flexible, modular, and with the ability to change capacity to some extent. Taking that into consideration, we can see that RMS principles are quite implemented in the production. That said, there is no diagnosability in the Sigma-lines, hence the score will not be perfect.

(4) Packaging Process
Considering the ability to quickly switch the exiting similar sized products, as were described in the case of The LEGO Group, we can see that the packaging is very flexible on the similar sized products, but the opposite way for the different sized products. Taking that into consideration, we can see that RMS principles are partly implemented in the packaging.

The structured values are shown in this model below, as Table 2 shows.

<table>
<thead>
<tr>
<th>Table 2: A conceptual model to evaluate the most necessary areas for RMS</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Responsiveness</strong></td>
</tr>
<tr>
<td>-------------------------</td>
</tr>
<tr>
<td>1. Modularity</td>
</tr>
<tr>
<td>2. Integrability</td>
</tr>
<tr>
<td>3. Convertibility</td>
</tr>
<tr>
<td>4. Diagnosability</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Capacity</strong></th>
<th>Molding</th>
<th>Decoration</th>
<th>Assembly</th>
<th>Packing</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Customization</td>
<td>0</td>
<td>0.25</td>
<td>0.5</td>
<td>0.75</td>
</tr>
<tr>
<td>2. Scalability</td>
<td>0.5</td>
<td>0</td>
<td>0.5</td>
<td>0.5</td>
</tr>
<tr>
<td>3. Diagnosability</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Functionality</strong></th>
<th>Molding</th>
<th>Decoration</th>
<th>Assembly</th>
<th>Packing</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Customization</td>
<td>0</td>
<td>0.25</td>
<td>0.5</td>
<td>0.75</td>
</tr>
<tr>
<td>2. Convertibility</td>
<td>0.75</td>
<td>0.25</td>
<td>0.5</td>
<td>0.5</td>
</tr>
</tbody>
</table>
It is shown from table 2 that responsiveness has four determinants, while capacity and functionality both have three and cost has five. By adding these determinants together, a new table is obtained showing the respective values of responsiveness, capacity, functionality and cost in these four production processes of The LEGO Group, which are as shown by Table 3.

Table 3: Values of Responsiveness, Capacity, Functionality and Cost in the four processes

<table>
<thead>
<tr>
<th></th>
<th>Molding</th>
<th>Decoration</th>
<th>Assembly</th>
<th>Packing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Responsiveness</td>
<td>2</td>
<td>0.25</td>
<td>1.75</td>
<td>0.5</td>
</tr>
<tr>
<td>Capacity</td>
<td>0.5</td>
<td>0.25</td>
<td>1</td>
<td>1.25</td>
</tr>
<tr>
<td>Functionality</td>
<td>0.75</td>
<td>0.5</td>
<td>1</td>
<td>1.25</td>
</tr>
<tr>
<td>Cost</td>
<td>1.75</td>
<td>0.5</td>
<td>2</td>
<td>1.75</td>
</tr>
<tr>
<td>Sum</td>
<td>5</td>
<td>1.5</td>
<td>5.75</td>
<td>3.75</td>
</tr>
</tbody>
</table>

Table 3 is processed to get table 4 with the percentages of these four features each process obtained, which shows the extent of the achievements these advantaged features of responsiveness, capacity, functionality and cost, which is as follows. It is calculated through using the values in table 3 divided by the values when the RMS features are fully implemented in the production. Taking the responsiveness in molding for example, the percentage should be calculated by “2÷ (1+1+1+1+1) ×100% =50%”.

Table 4: Extent of the achievements of the RMS features of the four processes

<table>
<thead>
<tr>
<th></th>
<th>Molding</th>
<th>Decoration</th>
<th>Assembly</th>
<th>Packing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Responsiveness</td>
<td>50%</td>
<td>6.25%</td>
<td>43.75%</td>
<td>12.5%</td>
</tr>
<tr>
<td>Capacity</td>
<td>16.67%</td>
<td>8.33%</td>
<td>33.3%</td>
<td>41.67%</td>
</tr>
<tr>
<td>Functionality</td>
<td>25%</td>
<td>16.67%</td>
<td>33.3%</td>
<td>41.67%</td>
</tr>
<tr>
<td>Cost</td>
<td>35%</td>
<td>10%</td>
<td>40%</td>
<td>35%</td>
</tr>
</tbody>
</table>

Results and Discussions
Table 2 shows a quite interesting finding, which is that the diagnosability in all the processes in The LEGO Group is 0, which indicates that The LEGO Group could design their future manufacturing systems for easy diagnostics to enable them to automatically detect the current state of a system and quickly correct operational defects or invite human interference.

From the sum values of RMS features of each process of The LEGO Group from table 3, it is shown that assembly has the maximum value, indicating that assembly has the highest extent of RMS features. On the contrary, with the minimum value, the decoration process gets the lowest extent RMS features; hence RMS should be widely implemented here to obtain better performance in the future.

The results from table 4 show that the larger percentage the process owns, the higher
level of RMS features it has achieved, and on the other hand, the smaller percentage the process owns the lower level of RMS features it has achieved.

Looking at table 4 as a whole, we can see that there are no results higher than 50%. This generally indicates that there is a large room for improvement exists in regards to RMS advantages in The LEGO Group’s production as a whole.

From the results of these quite low parameters of 6.25%, 8.33%, 16.67% and 10% from decoration, which is the most dedicated process in The LEGO Group, it can be seen a quite strong demand of the full utilization of RMS to have a radical improvement of achieving the advantaged features and better performance in decoration.

Assembly possesses relatively larger percentages of the four features, which shows RMS is not quite urgent for it. However, with the relatively simple construction, which contains only mechanical issues, it will be much easier to implement RMS here, which might be a better first trial of the RMS application.

The percentage of molding in responsiveness is as high as 50%. However, the long changeover time in molding makes it not that responsive. From this we can see that the value definition is quite important in the first stage of using this model, which would make the final results quite different. Therefore, more attention and consideration should be put on the first value defining stage.

Conclusion
This paper has discussed the main advantages of RMS based on a literature review and proposed a conceptual model to analyze the most suitable areas of RMS implementation. A case study of The LEGO Group carried out to analyze the most suitable production processes for RMS in The LEGO Group. From the analysis, it is concluded that there is a lot of room for improvement in these RMS features for the future production system in The LEGO Group, especially in decoration.

This conceptual model is to examine where would be most suitable areas of RMS implementation based on the level of performance requirements. In practice, more factors can be taken into account. As a quite important first stage of using this model, more attention and consideration can be put to the value defining to get more accurate results.

This research should be seen as a first step of the analysis of RMS implementation, focused on identifying the most suitable areas of use. In the case study, the very important value defining is made from the observation and interviews of the employees and systems of The LEGO Group, however, more accurate definition rules should be made in the future to guarantee greater accuracy.

References


Petersen, K. H. (2012 May 14), Interview with The LEGO Group. (Y. Wang, Interviewer)

