INTERNATIONAL DESIGN CONFERENCE - DESIGN 2002
Dubrovnik, May 14 - 17, 2002.

FORMING A BASE FOR A MANUFACTURING SYSTEM DESIGN AND EVALUATION METHOD

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Keywords: Manufacturing System Design, Design Evaluation, AIP, Assembly-Initiated Production

1. Introduction

Customer and business owner demands often result in for example, a need for shorter lead-times as well as higher quality of products and services. In many cases these demands result in shorter product life cycles and a greater need to be able to introduce the requested product, or product variant on the market quickly. Increasing levels of demand are certainly, and constantly, decreasing the margins of error.

As a result, there are often discussions, both within the academic community as well as in the industry, on how to design new manufacturing systems and/or how to improve the performance of systems already operational.

To be able to know how to improve manufacturing performance, one has to be able to find performance reducing causes and problems, as well as to choose the appropriate improvement methods. Such methods could create improvements in processes directly involved in finalising a product. This may include reducing resetting-times, but also the improvement of support processes such as introducing modern Production Planning and Control (PPC) methods.

Performance related problems are also very important to identify when designing new manufacturing systems, since correcting errors early in the system design phase, is often more cost effective than when the system is in use. Means for comparing different design solutions are also desirable to include in the system design phase. There are numerous philosophies, strategies, methods etc available to presumptive users. Nonetheless, there is an outspoken need for a method that is simple and yet powerful enough to account for the most relevant manufacturing related issues.

This project consists of different levels. First, it presents a management strategy for designing manufacturing systems that should comply with demands for mass customisation, but at the same time be able to accomplish short and accurate lead times and to be able to keep inventory costs down. This strategy is called Assembly-Initiated Production (AIP), and is described briefly in 4.2. The AIP strategy has been developed concurrently with the Hyper Flexible Automatic Assembly (HFAA) project, which aims at designing stepwise expandable, and reconfigurable assembly systems with standardised interfaces (Gröndahl & Onori, 2001). The AIP strategy is a part of the proposed method base and the HFAA results are used within the AIP strategy.

2. Project structure and goals

The main goal within this project is to create a method that addresses the needs and desirables presented in chapter 1. The method should also be easy to use. The building blocks of the method should give reliable and accurate data and also, display the relationships between the different building blocks that form a manufacturing system. Partial goals are to find and evaluate these building blocks

and to examine how different changes in a manufacturing system influence other factors than those intended to improve.
The project is being conducted in cooperation with companies of different sizes, active in Sweden. So far 18 companies have been involved. A large industrial survey, examining company needs, known problems and applied solutions, was initially conducted (Karlsson, 2001). Therefore the work is being based on identified industrial needs as well as on theoretical scientific studies. The theoretical studies have mainly been aimed at finding and analysing modern performance enhancing manufacturing related activities and solutions.

3. Identifying the demands

There are many strategies and methods available that are directly aimed at suggesting a single solution to a problem, like choosing a cell layout instead of a department layout of a factory. The argumentation is often based on the superiority of the suggested concept. Such a method could be easily dismissed by its users, if the concept of cell manufacturing has been tested at one time and then considered a failure due to a variety of reasons. This would probably render cell manufacturing unsuitable for a foreseeable future within the company. Using the wrong method at the wrong occasion could, in this way, create an attitude against a specific kind of solution, which could be quite useful in other occasions. This was quite common when Just In Time manufacturing and Lean Production were hot topics within the manufacturing community (Womack et al, 1990). Therefore there are reasons for creating a method that at a first stage, would suggest certain properties that a manufacturing system should have to fulfil company demands, and later at a second stage, suggest specific solutions like using cell manufacturing. This gives more room for understanding why a solution is suitable and also enables the user to actively choose between different solutions.
There are also reasons for keeping the method simple, for example to encourage its use and to minimise risks for handling errors.

4. The model structure

4.1 The different stages in the life cycle of a manufacturing system

The life of a manufacturing system could be analysed and divided into many different parts, depending on the purpose of the analysis. This definition is made according to the manufacturing systems inherent properties when it comes to designing and supervising the system. The lifecycle has been divided into three phases: early design phase, late design phase and operational phase. The operational phase includes issues that are relevant when operating the system, including continuous improvement, service etc. The reason which enables such a coarse division, is that at this stage, the goal is to accomplish an accurate model of a manufacturing system, hence to be able to find relevant issues to work with, not to assume, even before the model has been assembled, what the relevant issues are.

4.1.1 The early design phase

The early design phase is here defined as when one does not have any earlier systems to build upon. Earlier systems could be models, actual plants etc. This phase includes such issues as when starting from basically a clean sheet, when one has to create a first model of how to accomplish the demands put on the system.
When working within the early design phase, strategies or philosophies are often used. In such cases, the information tells the users what to aim for rather than what solutions would be suitable.
One could argue that starting from nothing is not a desired way of designing manufacturing systems. Previous data and experience should be used. This may be correct, but at least once, one has to start from zero.
The proposed approach encourages the use of previous data and experiences by the systemisation of data and by the creation of structures. By enabling comparisons with earlier system models, the task becomes more structured.

4.1.2 The late design phase

The late design phase is defined as being the period when a model is already available for further improvement. There are many manufacturing related methods available for working within this phase. The present models could be used for simulation purposes etc. It is possible to compare different suggested solutions with each other and improving them until there is a solution available that meets company demands.

4.1.3 The operational system phase

In this phase, there is an operational manufacturing system available. There are however, striking similarities between the operational system phase and the late design phase when it comes to evaluating the system design. The benefits with continuous improvement have been an issue within the manufacturing community for many years (Womack et al, 1990). Using a model of the manufacturing system to find areas for improvement is very similar to the work for improving an early model in the late design phase, which shows the possibilities of the method structure. One has to note the difference in obtaining data for the model though. In the operational phase, the data would be retrieved from the real manufacturing system. In the late design phase, the data would most likely be calculated from a virtual model. Retrieving data from a manufacturing system may be somewhat tricky, but there are great possibilities to acquire a great amount of relevant data from an Enterprise System (ES) (Davenport, 2000). The quality of data that could be retrieved of production planning and control (PPC) modules within an ES could be questioned though. There are often problems associated with the use of PPC modules, in different ways, that renders the data inaccurate (Estep J A, 1996). There are solutions to this problem available, which will be evaluated in future research.

4.2 Building blocks for use within the early design phase

As stated earlier, a very common practice is to use strategies in different forms for designing a first manufacturing system solution. Strategies can be different in nature; some being more management oriented and others more focused upon the design of for example, technical sub-systems like automated assembly systems. The different nature could be related to the different goals. A management strategy may have the goal to accomplish a mass customisation situation within a company and the more technically oriented strategy may have the goal to accomplish highly flexible assembly systems (Onori et al, 2000). The usefulness of strategies has been well proven over time. There are however, situations when another approach would be more suitable. Either as a support when choosing and arguing for a specific strategy, or as a stand-alone tool to come up with a first design solution.

In this project, a management related strategy has been developed. The strategy is based upon assemble to order ideas, Just In Time and Lean Production principles, and other philosophies, strategies and methods. The aim is to provide means for reaching the goals of being able to deliver customer specific products, having short and accurate lead-times and at the same time minimise inventory costs (Karlsson, 2001). As mentioned earlier, close relations has been maintained to the Hyper Flexible Automatic Assembly (HFAA) project which aims at developing highly reconfigurable and flexible assembly system solutions (Onori et al, 2000). The HFAA project is conducted in parallel to this project and the results are merely used to show how assembly solutions should be designed in the AIP strategy.

A short description of the AIP strategy is made since the initial goal of the project was to form a strategy for creating a system for mass customisation with short lead-times and low inventory levels.

1. The customer order enters the computer system and is immediately available to the entire manufacturing chain, although the final assembly is where the order is retrieved and the manufacturing is initiated.
2. The final assembly will be able to see which orders are in the system at an earlier stage. This will lead to a more responsive production.
3. One of the central concepts about AIP is the modularisation of products. When an order is to be executed, components and modules will be taken from the storage and assembled into

products. The levels in the storage will be high until the AIP introduction phase is over. The goal is to eliminate the module storage.

4. The finished products are, after the assembly, packed and delivered to the customer.
5. The module storage is set just before the module (assembly) workshops. Modules are produced to keep the levels in the module storage at a preset value.
6. The demands placed upon manufacturing and ordering of components are basically the same as the ones placed upon modular workshops.

One should note that the sub-contractors could deliver to any station in the chain.

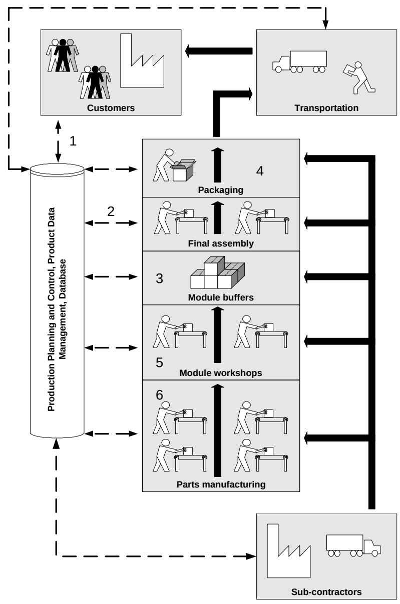

Figure 1. The Assembly-Initiated Production principle. Solid lines show materials flow, and broken lines show information (Karlsson, 2001)

What AIP introduces is the possibility to give a product its final identity as late as possible within the production chain. This is of great value in a world in which the variant flora is commonly created in parts manufacturing, with ensuing buffers and warehousing problems. It becomes obvious, then, that the application of AIP strategies require a highly reactive, order-driven control system and equally efficient assembly workshops.

One should note that using AIP is not an essential component in the proposed method structure. It is a possibility if AIP is found to be a suitable strategy to use.

Future research will be focused on finding certain properties that characterise different manufacturing solutions. The properties would then be used as a support when choosing a specific strategy, or as a stand-alone tool to come up with a first design solution. The same properties should be identifiable in the goals and demands put on the manufacturing system to be designed. By using these properties, the first stages of the design work would not be directly linked to solutions, but to the goals with the system. A similar diversification of goals and solutions is made by Suh (1990) in the Axiomatic Design Method, where for example, Functional Requirements and Design Parameters are separated and dealt with separately. By using the properties as a base for design instead of using solutions described in a strategy, it should also be easier to derive new solutions. Note, designing a quick response manufacturing system (QRM) is not equivalent to speeding up existing operations. It requires finding whole new ways of completing a job, with the emphasis on short lead-times (Suri, 1998).

4.3 Building blocks for use within the late design phase

4.3.1 Functional Process Areas

A design of a generic set structure that is to describe input, output and the influence the set has on its environment. The set structure is to describe a chosen part of a manufacturing system. The set

structure is called Functional Process Area (FPA).
The central point in this method is the process. The process is here measured and specified by;

- The input, like material and resources.
- The output, which is the product or partly manufactured product.
- The influence the process has on its environment

These factors are set by the performance of the process itself. To be able to select these three factors, one has to decide what to measure within the process and how to measure it. The total of the input, the output, the influence and the process itself is here called Functional Process Area (FPA). An FPA is depicted in figure 2.

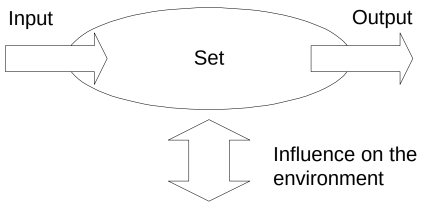

Figure 2. Functional Process Area definition (Karlsson, 2001)

To be able to characterise the set content of the FPA, the following division of manufacturing areas has been made:
Supply, which is the area of supplying material and components to the process. It also involves the transportation of manufactured goods from the process. A large part of the area of logistics is covered here.
Information covers all information distribution from, within and out from the FPA. It includes Production Planning and Control (PPC) as well as Product Data Management (PDM).
Human resources covers organisational issues as well as competence and other personnel related questions.
Process includes machine related issues like reliability, processing times, resettings etc.
Product is an area, which includes product related issues like product design, choice of materials and aspects that affect the output of an FPA.
Commonly, more than one area affects the performance of a manufacturing system. A complex product design could cause the need for more resettings than another design would etc. The possible interactions are numerous.
The influence the FPA has on its environment is here roughly divided into:
Flexibility. The possibility to produce entirely new products, to manufacture different product variants and to be able to change capacity to meet changes in demand. This should be considered both on a long-term basis as well as a short-term basis.
Speed and swiftness. Included here are lead-times, the possibility of adapting the production in a short time, operation times, resetting times and such. Everything that affects the speed and swiftness of the system should be included.
Robustness. The reliability of the system when it comes to breakdowns, downtimes, the amount of quality approved products manufactured etc. These are non-expected events that affect the production (including flexibility) negatively.
Resources needed. The amount of resources needed to manufacture the products in the FPA. It could be measured in money, hours or anything appropriate.
These four areas should be divided into measurable factors for the general use within a factory. To render the use more intuitive, the factors are arranged in the form of a matrix.
The strength of the FPA definition is that it could be applied at different levels of the manufacturing. For example, a manufacturing section does, in turn, consist of different parts. One could start at factory level and structure in FPAs down to individual machines if desirable. Therefore an FPA could consist of lower level FPAs, which makes it possible to form a tree structure of the manufacturing system.

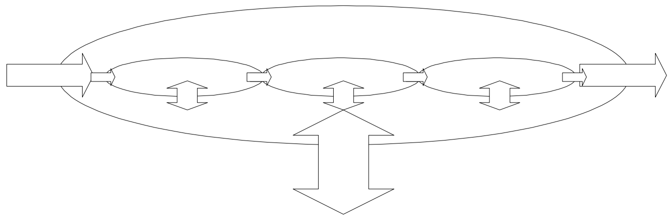

Figure 3. FPAs could consist of lower level FPAs. This picture could describe a cell that consists of three machines (Karlsson, 2001)

4.3.2 Displaying the manufacturing system in a tree structure

A tree structure is used to show the relationship between processes within a manufacturing system. The elements of the tree are FPAs.

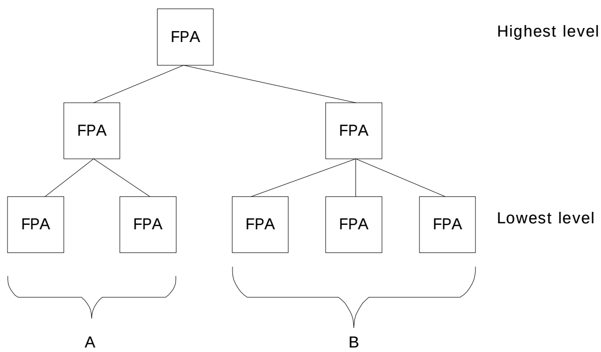

Figure 4. A tree structure formed by FPAs. The lowest and middle levels of the B part would be equivalent to figure 3 (Karlsson, 2001)

In figure 4, A and B represent chained FPAs that forms the lowest level within the factory. Each FPA in the lowest level consists of a row of individual operations. The B part resembles the structure of figure 3.

Each FPA in the lowest level consists of a row of individual operations. If looking at a data structure, the tree would contain FPAs modelled as arrays. The elements in the arrays would be the sub-FPAs with pointers down to the next lowest level. In the case of the absolute lowest level, the array elements would be individual operations and no pointers downward would exist.

Once this has been done, one starts analysing at the lowest level, which are the FPAs that consist of individual operations. The analysis is done with the help of an interaction matrix, where the areas that are included within the process are analysed upon how they affect certain factors that are important for the output and influence of the FPA. When all FPAs on the highest level have been analysed, the input, output and influence are summarised in order to obtain the total, which is the input, output and influence on the next lower level. This is done repeatedly according to a suitable data structure method. Finally, the performance at the highest level is calculated. This could, of course, only be done at a sub-level if desired.

4.3.3 A structure for displaying relevant information to the user

The information obtained by using the method has to be displayed to the users in an appropriate way. There are some rough ideas on how to do this, but are still subject to further research. Different variants of matrices have been used so far. Figure 5 shows an example of one of the versions.

The matrix exploits the manufacturing system structuring described in 4.3.1. By using a structure such as this, one may see how each manufacturing area is affecting certain important parameters in the manufacturing system. These parameters should be directly useful when evaluating the system performance due to the tight coupling between performance and economical aspects like costs for making decisions about investments, cost calculations etc. Choosing parameters is therefore an

important part of the method design work since the most effective motivational force is based on financial incentives, with a small likelihood of that to change (Warnecke H J, 1993).
This matrix structure should give an idea of the resulting information display structure that will be included in the method.

Manufacturing areas

Influences on manufacturing systems

	Supply	Information	Human resources	Process	Product
Startup time (New system)					
Rebuilding time (Old system rebuilt)					
Resetting time (Product variants)					
Number of resettings					
Que time					
Processing time					
Throughput time					
Ammount of operations					
Stand-still					
Error frequency					
Materials transfer					
Materials handling					

Figure 5. Evaluation matrix for displaying relevant data to a method user (Karlsson, 2001)

5. Discussion and critical review

5.1 Future research

Further research will be conducted to analyse manufacturing process activities, to be able to find key issues for a method to monitor and measure. Strategic process parameters are to be identified and evaluated. Some common improvement methods will be analysed in terms of the impact they have on the manufacturing system as a whole. Finally the method will be completed and field-tested at companies that participate in the project.

5.2 Discussion on results and future research

Finding parameters that are appropriate for using in this method will not be an easy task. The data used in the different phases of manufacturing system design has to be categorised. The levels of performance needed, has to be decided. Then one has to decide how to accomplish this performance. Finally, the costs have to be calculated. The costs are in many cases, the central part of design methods, but the order in which they are taken into account is always the last.
The results presented in this paper are not, as mentioned earlier, enough to form a method. Components needed to finalise the method have been indicated and the results presented here merely forms a base for the entire method.

Acknowledgements

Woxéncentrum and The Royal Institute of Technology (KTH), Stockholm, Sweden financially supports this project.
Great contributions to the results presented here has been made by people from these companies, here in alphabetical order: ABB Corporate Research, ABB Future Center, ABB Motors, ABB Power Systems, ABB Robotics, ABB Switchgear, ABB Ventilation Product Division Stratos, Alfa Laval AB, Atlas Copco Tools AB, BT Products AB, Ericsson Radio Systems AB, ESAB Welding Equipment AB, ITT Flygt AB. Gustavsberg Vårgårda Armatur AB, Rexroth Mecman Svenska AB, Segerström & Svensson AB, TUBE Control AB and Volvo Truck Corporation AB.

References

Davenport, T H., "Mission Critical – Realizing the Promise of Enterprise Systems", Harvard Business School Press, Boston, Massachusetts, USA, 2000.

Estep J A, "Tailoring your MRP System to Meet Your Needs", IIE Solutions, September, Vol 28, Issue 9, p36, 1996.

Gröndahl P, Onori M., "Standardised flexible automatic assembly - evaluating the Mark IV approach". Assembly Automation Journal. Vol 20. Number 3. Page 217-224. 2000.

Karlsson A, "Assembly-Initiated Production, A strategy for mass customisation with short lead-times", Licentiate thesis, Royal Institute of Technology, Dept. of Production Engineering, Stockholm, Sweden, 2001.

Onori M, Alsterman H, Bergdahl A, Johansson R.,"Mark IV, A Hyper Flexible Automatic Assembly System Solution", Proceedings of the 30th Int. Symposium on Robotics, Tokyo, Japan, October, 2000.

Suh N P., "The Principles of Design"´´, Oxford Series on Advanced Manufacturing, New York. Oxford University Press, 1990.

Suri R, "Quick Response Manufacturing – A Companywide Approach to Reducing Lead Times", Productivity Press, Portland, Oregon, USA, 1998.

Warnecke H J. "The Fractal Company – A Revolution in Corporate Culture". Springer Verlag. Berlin. 1993.

Womack J P, Jones D T, Roos D., "The Machine that Changed the World", Rawson Associates, Macmillan Publishing Company, New York, USA, 1990.

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