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MANUFACTURING SYSTEM DESIGN BASED ON REAL-LIFE DEMANDS – A METHOD DESCRIPTION

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1. Introduction

Manufacturing system design is a process that often results in sub-optimized systems with less than intended performance, therefore failing to meet the requirements of the people having an interest in the manufacturing system. Higher than expected costs and failure to meet customer requirements are common. It is therefore of outmost importance to base the design on factors originating from the interested party and then translate them into performance shaping factors of a manufacturing system.
Performance shaping factors are sometimes hard to predict and there is a large number of factors to consider. The manufacturing system is a product in itself where the functions and performance is affected by machinery, information systems, the people that work in the system etc. This means that the performance of a production system will partly be decided by the feelings, mental and physical state of people, which often is hard to predict. Sometimes the complexity of the factors affecting the system takes over in the design process, making the designers, system builders and even the buyers forget about the initial requirements – customer demands.
To make things even more complicated, the manufacturing system will need to evolve over time and in extreme cases even change completely very quickly. The need to evolve often comes from different sources e.g. customer, authorities, the society and the work force itself. A large amount of companies are having trouble to perform well when it comes to design of manufacturing systems. Especially small and medium sized enterprises (SME) generally do not have the same amount of resources to develop manufacturing systems as larger companies have. It is therefore a need for a method that is simple enough to use, though provides accurate enough results to be used in this task. The method presented in this paper is a method for manufacturing system design based on real-life demands, and is referred to as ManfRed. The basic structure of ManfRed was presented at the Design 2002 conference [Karlsson 2002] and since then the structure has been developed into a method.

2. Targeted user group and method goals

The target ManfRed user group would be a group of people working with manufacturing system design, primarily on SMEs. The typical target company for the method presented in this paper is therefore an SME that needs to expand or change its operations by introducing new or changing its manufacturing resources. However, there is nothing that prevents this method from being effective for use at larger companies. The focus on SMEs comes from the initial need for a manufacturing system design method from that particular group of people, and the requirements put on the method found at SMEs. Larger companies could have the same need for this method and also have the same method requirements, making ManfRed useful in such an environment as well.

The goal is to develop a method that helps its users, the designers, to design a manufacturing system that provides the interested party and partners with a manufacturing system that performs as intended. The method does not optimize on individual efficiencies. The focus is on creating flow, having a high throughput, low inventory levels and low operating expenses. This approach has been argumented for e.g. by Goldratt & Cox [1986] and proven to work at numerous occasions.

In order to increase the use of the method, current improvement methods and approaches are included in ManfRed where possible. Many companies are involved in improvement activities, often based on approaches like Lean Manufacturing or Six Sigma. Including parts of common improvement approaches means that current knowledge about improvement also could be utilized in the design phase. Using already accepted methods and approaches would at least in theory make the buy-in transition faster and increase acceptance of the design method. It would also reduce the need for training.

3. Basic structure of the method

3.1 Overview

Among others, Liker [2004], Shingo [1989] and Goldratt & Cox [1986] points out the importance to consider the operations as a whole when designing and improving manufacturing systems. Therefore the method is highly focused on helping the designer to decide the role of the design, which in turn decides what important parameters to take into account.

ManfRed has three major parts or areas that is the theoretical foundation for how to describe the sought after manufacturing system design:

- A standard building block, here called Functional Process Area or FPA
- A hierarchical structure on how to use the FPAs. FPAs are depicted in a tree structure, which is worked on using first a top-down approach, and later a bottom-up approach
- Data on how the system behaves: data on what is needed in order to make the system run as intended and data describing the system behaviour.

Using these three major areas helps the designers to draw a version of the manufacturing system design, including system properties and important parameters.

3.2 The Functional Process Area – FPA

The standard building block, the Functional Process Area, is defined as a set of activities with a required input, a resulting output and the influence the area has on the surrounding processes – its environment. A basic FPA is shown in Figure 1.

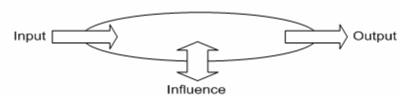

Figure 1. Functional Process Area

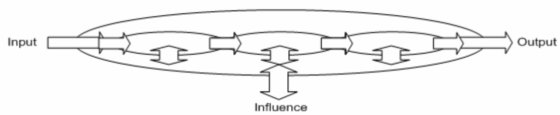

Figure 2. A combination of Functional Process Areas

E.g. a number of individual processes could each be looked at as FPAs one by one. Individual processes are also parts of a larger system. That larger system can be defined as a higher level FPA whose input, output and influence then would be the combined input, output and influence of the individual processes or individual FPAs. This is shown in figure 2.

The entire relationship between the FPAs is then depicted as a tree structure. The encircled area at the right hand part of the tree in figure 3 would resemble the FPA depicted in Figure 2.

The ManfRed method is based on a combined top-down and bottom-up approach. The design process starts with overall manufacturing system requirements, which gives the high level requirements for the manufacturing system. These requirements are then broken down, following the FPA structure, to requirements for each part of the system, level for level, resulting in an FPA tree as in figure 3 and a set of requirements for the sub-systems. However, in order to make sure that the initial requirements are met, the resulting design is analyzed, starting with the lowest level and moving upwards, which is the bottom-up approach.

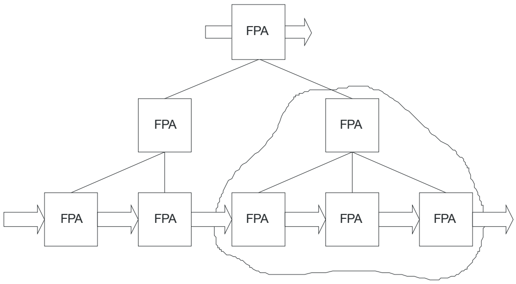

Figure 3. A tree structure resembling a number of FPAs, displaying their relationship

Hence, the top-down part of the method provides the designer with the manufacturing system requirements in whole as well as in part, based on requirements from customer and other interested parties. Then the bottom-up part of the method gives the actual performance of the manufacturing system in part and in whole, basically performing a design review of the system as a whole.

An example of the importance of reviewing the entire system is the phenomenon of process variation. Variations in throughput at one process in isolation will even out over time, converging towards an average uptime. On the other hand, in a system of processes, variations each individual process will affect the other in a different way. Lost time at one process will slow down the others as well. This will cause the system to perform even worse than the individual process and variations will not even out over time, resulting in serious losses overall [Goldratt & Cox 1986].

3.3 Data on system behaviour

In order to describe the system influence on the environment there is a need for data. The data is divided into two categories: data on factors needed in order to make the system run as intended and data describing how the system behaves.

Data on factors needed to make the system run as intended is divided into:

- Supply
  - Input: e.g. material needed, energy, coolant, tools, indirect material
  - Output: e.g. the product itself, scrap and re-work, bi-products, energy
- Information
  - Input: e.g. product and manufacturing specifications, plans, manufacturing control
  - Output: system performance figures, manufacturing control
- Human resources
  - Input: e.g. training requirements, manning, risk and accident prevention
  - Output: e.g. operator experience to be communicated to the rest of the organization, risks and accidents
- Process
  - Input: needed process performance in terms of volume, flexibility, agility and robustness
  - Output: actual process performance in terms of volume, flexibility, agility and robustness
- Product
  - Input: needed product properties, e.g. quality
  - Output: actual product properties e.g. quality

System behaviour is divided into:

- Volume: as in the number of products and product variants to be manufactured: are data on capacity requirements and data on actual capacity for the final design.

- Flexibility, as in being able to change: data on the ability to change the manufacturing from one product to some totally different product. This term usually focuses on long-term data.
- Agility, as being physically and mentally quick: is the short-term equivalent to flexibility. Agility data tells the designer how fast the manufacturing can be re-set between product variants.
- Robustness, as in unlikely to break or fail: is data on how robust the system is in term of reliability, which also product quality or lack thereof.

The system behaviour will be derived from the Process and Product data, but the data is here brought out and highlighted separately.

4. Usage and practical approach

4.1 Workflow

The workflow of the ManfRed method should be clear enough to help the practitioners to make the correct interpretations and thereby design choices.

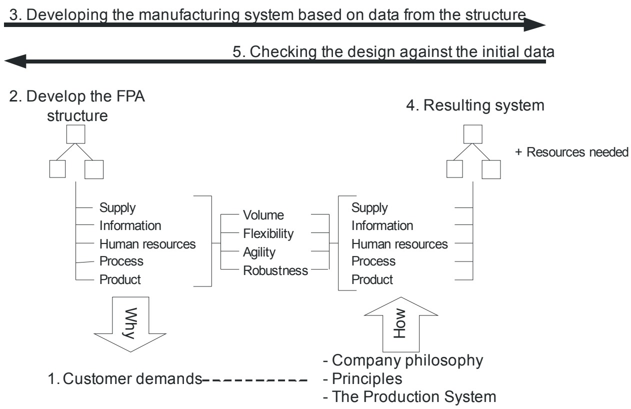

Figure 4. The ManfRed method workflow

Even if the workflow shown in figure 4, and rules and priorities used in step three of the method will be similar from time to time, there are parts that will be different. For example, important parameters describing the influence of the FPA could be added or changed, if those in the method description are found not to be enough to describe system influence. On the other hand, it is highly recommended not to remove any parameter without carefully specifying why, which includes presenting proof for the lack of relevance for that particular parameter.

4.2 Step one – Establishing the needed manufacturing system properties

Step one is a data definition step. In order to establish the scope and general performance of the design, four basic tasks are specified. It should be noted that the is neither a suggested order in which to proceed nor a rating of importance of these steps. All the data is needed an could be retrieved in any suitable order.

- Value stream analysis and mapping: in order to establish the role of the new manufacturing system in its environment. It is a tool commonly used, mainly within Lean Manufacturing but also within Six Sigma. Value stream analysis and mapping is mostly needed when the new manufacturing system plays a part in a current system and because of the need to establish its role in a long-term strategy.
- Analysis of the product structure: breaking down the product into its components and material. This is done in order to establish what processes will be needed.

- Review of company policies: in order to establish the standard way of how to manage operations in general. Documents to review could be ISO standards, local rules and regulations, a written down production system, company goals, values and philosophy.
- Customer demands: e.g. volume, quality and delivery rates.

All this information will provide the design team with data stating needed performance of the manufacturing system. The data is the set of basic performance measures that will work as design parameters at the design stage. However, these performance measures will also be used as high-level performance measures which will be recorded and analyze when the production system is in service.

4.3 Step two – Developing the FPA structure

The manufacturing system properties established in step one is the data on input, output and influence for the highest level FPA as described in chapter 3 in this paper.

Step two is where defining what processes are needed in order to manufacture the products creates the FPA structure. It is also established what the needed properties of each process are, based on the data acquired in step one.

The method does not state how many levels the structure should be broken down into, but experience says that three levels give enough detailed information about what is required from the manufacturing system. The levels would then be:

- Top level: as defined by step one of this method.
- Mid level: top level broken down into basic processes, e.g. purchasing or assembly.
- Bottom level: which is mid level broken down into more detailed processes, e.g. polishing, chroming, manual assembly step x etc.

Even though three levels often are enough, e.g. when developing new manufacturing systems in a current plant, larger projects undertaken using this method may call for more than three levels.

At this step the influence for each FPA has to be established as well, starting with the highest level depicting the entire manufacturing system design. This means that the influence is established, i.e. what influence is needed from the outside in order to make the FPA perform as intended:

- Supply
- Information
- Human resources
- Process
- Product

and the parameters describing system behaviour, divided into:

- Volume
- Flexibility
- Agility
- Robustness

The resulting set of parameters will eventually aid the designer in the development of a performance measurement system, which will be of use to monitor its performance of the completed system. It will later help the company to make improvements based on relevant facts. Hence, the result from using ManfRed is not only a manufacturing system as in hardware and manning, it also includes the development of the performance measurement system for monitoring purposes.

4.4 Step three – Developing the manufacturing system based on the data from the structure

The design process is based on a set of rules and priorities. These rules and priorities are used as guidelines when designing the flow and processes, when selecting machinery, when setting up training programs for operators etc. In the FPA structure, the rules and priorities are used when defining the set of activities going on inside the FPA itself.

The rules and priorities have been tried, tested and evaluated, e.g. in Lean Production and Six Sigma programs. A literature study including more than 80 reviewed books, research articles and papers supports these rules as when implemented correctly, resulting in high performance manufacturing systems. Some unsuccessful implementations were described. In general this was more often the result of improper implementation procedures, e.g. resulting in sub-optimization or manufacturing systems that did not comply with customer demands than having to do with the rules and priorities themselves. The overall design goal:

- Create flow: where the products are completed with the least amount of waiting. The focus on creating flow implies that individual productivity measures for each process is of secondary priority to the overall throughput of the system [e.g. Goldratt & Cox 1986]. Still, productivity is important, but focusing on individual processes may cause sub-optimizations that would hurt the overall productivity and actually reduce the performance of the manufacturing system as a whole.

The overall design goal is achieved by:

- Reducing waste in the design. The eight wastes are defined as Overproduction (producing more than needed or earlier), Waiting, Unnecessary transportation, Over processing (unneeded process steps), Excess inventory, Unnecessary movement, Defects including re-work, Unused employee creativity [Liker 2004]. It is often stated that the waste of Overproduction is the most serious waste since it generates more of all the other wastes. Liker [2004] as well as Shingo [1989] puts the emphasis on the importance of reducing Overproduction. However, it should be investigated how all the eight wastes applies to the designed manufacturing system and it should then be minimized. One has to remember that the waste in itself often is a symptom, not the root cause to the problem.
- Keeping the inventory levels down: which is actually a part of reducing waste, but there is a reason for including it as a separate rule. The inventory levels affect the throughput time as explained by Little's law, which states that throughput time increases in proportion to inventory levels. Added to the costs from increased throughput time are the costs for the inventories themselves. A key measurement is inventory turnaround.
- Preventing errors from occurring rather than deal with them later: is a part of the reduction of Defects types of waste, but it is also a strategy. In this strategy is included the idea of a 100 percent inspection rate which is accomplished by error proof design of product and process in order to prevent the error at the source [Shingo 1989]. A mechanism for preventing errors at the source is often called a Poka Yoke, which serves the functions of shutdown, control or warning, either during detection or prediction [Shimbun 1988].
- Creating high-performance information flows: successful implementation of many management best practices, e.g. Just In Time and Total Quality Management heavily depends on proper organisational communication and information management [Forza & Salvador 2001]. The needed piece of information has to be at the right place in time and it needs to be correct. Lean Manufacturing control, e.g. Kanban, lets the information follow the product meaning that it is where it should be when needed. This also implies that keeping the information at a minimum makes the information flow move easier and reduces the risk for inaccuracies.
- Evaluating the design to find all the root causes to possible problems: when solving problems in a current system this is often done by asking why five times. In the design phase this means that possible problems should be dealt with as close to the actual problem source as possible.
- Basing decisions on facts and make decisions using a scientific approach: in a completed system this would e.g. mean go and look for yourself and don't rely on data of unknown origin. It also means that the designing of a manufacturing system should be based on proven facts to as large extent as possible. In general this rule tells the user to measure, analyse and mine in order to acquire data to on which to base decisions, rather than on general belief, opinion or hearsay. This is a major principle in the Six Sigma method [Breyfogle 2003] and also in Lean Manufacturing [Spear & Bowen 1999].
- Knowing your trade-offs: meaning investigate thoroughly how a decision affects another, how a chosen design will affect other parts of the design. A similar way of reasoning is also included in the highly successful Toyota product design process [Morgan & Liker 2006]. Examples of trade-offs are agility/flexibility versus equipment cost or benefits from manual versus automated processes.

- Adapting technology to fit your people and processes: adding technology to a fundamentally flawed product development system will do little to help and may even retard performance [Morgan & Liker 2006]. Adapting technology to fit people also includes knowing how and people makes mistakes, to evaluate risks for injury and general loss of capacity. Even groups of people can fail in the error-recovery process by failing to detect the occurrence of an error, by failing to indicate which means failure to bring an error to the attention of the remainder of the team, and third by failing to correct the error [Sasou & Reason 1999]. This means that an error recovery process based on a group of people detecting an error and taking corrective action is not foolproof and should not be treated as such.

In general the method is prioritizing flow by defining the ability to manufacture the sought after volume with a system that is flexible, agile and robust enough to sustain the manufacturing of the sought after volume but at the same time doing so using the least possible amount of resources.

4.5 Step four – Draw the resulting manufacturing system structure

The finalization of the manufacturing system design is based on the data acquired in previous steps as well as the rules in the preceding step. Drawing the system structure is done by applying the acquired data on input, output and influence on the previously drawn FPA tree structure and applying the content of the FPAs from the previous method step three.

4.6 Step five – Checking the design against the initial data

The suggested manufacturing system design now has to be evaluated against the initial system performance expectations. This means that the performance of the resulting system design is compared to the expected performance and the design parameters from step two: the value stream analysis and mapping, the analysis of the product structure, the review of company policies and the customer demands. In reality this means that the practitioners would evaluate the lowest level on the system design and working upwards finally resulting in the performance figures for the highest level in the FPA tree, hence the bottom-up approach following the initial top-down approach.

5. Results and future work

The resulting method is a working method for manufacturing system design. Still it has not been evaluated enough regarding the quality of the resulting manufacturing system. The method has been used to re-design an underperforming manufacturing system and in the design of two more. The resulting designs have worked in the intended environment, performance being at levels matching customer demands. However, it cannot be proven that the resulting designs are better performing than they would if having used other methods. There are however proof that the re-designed system that was subject to the method performed more in line with customer demands than the systems did before the re-design. The output was increased by 40% without having to make any high cost investments. To conclude, the method has to be evaluated in a more systematic way in order to scientifically establish the quality of the method.

Also noted during method trials was that the use of improvement methods already known to the designers, in this case Lean Manufacturing and Six Sigma methods, in the design phase actually makes the use of the design method easier. The ease of use was however not quantified in any way.

Future work includes the development of a method training kit to be able to train designers in the use of the method. At the same time, a toolbox will be developed including forms, charts and other material that will be of good use to the designer.

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