Modelling and design of flow manufacturing system for SMEs

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Abstract
This paper describes a simple and deterministic method for modelling and designing a flow manufacturing system, especially well suited for SMEs. The paper covers five themes: A brief review the history of flow manufacturing, a comparison of the flow manufacturing approach with other existing improvement approaches, a proposal of crucial design principles for flow manufacturing, a method for simple and coarse modelling and analysis, and finally an outline of a case study that demonstrates the applicability of flow manufacturing.

Keywords:
Flow manufacturing, layout, manufacturing planning and control, aluminium car parts

1 INTRODUCTION

Manufacturing SMEs are often functionally oriented, where layout and organization is based on different manufacturing processes divided into different departments. There are typically batch-oriented material flow with no distinction between the flow of high volume products and low volume products, although the long set-up times usually favour high volumes. When analysing the manufacturing one might find unnecessary handling and storing with a large number of Work In Process (WIP), leading to long throughput times and losses. Manufacturing SMEs that fits to this description would probably sooner or later be faced with the need to reengineer the enterprise in order to stay competitive.

An enterprise reengineering project can use a range of best practice manufacturing approaches (such as a lean manufacturing or quick response manufacturing) to improve performance. One such approach, flow manufacturing, is introduced to improve how operations are organised and controlled. Flow manufacturing is a form of manufacturing where the material flow is balanced and runs rapidly through a set of operations areas in an enterprise. Flow manufacturing is an extension of the group technology (GT) layout approach that also encompasses team design and modification of the MPC system. This approach was initiated at NTNU/SINTEF in the 1980s, [1] and has been implemented in many Norwegian companies.

This paper addresses a method for modelling and designing a flow manufacturing system. The emphasis is on a simple and deterministic approach with the use of spreadsheet and sketches/ drawings as main tools. This paper covers five themes; First a briefly review the history of flow manufacturing and to introduce the major concepts. Secondly a comparison of the flow manufacturing approach with other existing improvement approaches. Thirdly a proposal of crucial design principles for flow manufacturing. Then a method for modelling a manufacturing system is proposed. Finally, an outline of a case study that demonstrates the applicability of flow manufacturing at Hydro Automotive Structures, an enterprise that produces car parts in aluminium.

2 HISTORICAL ROOTS AND CONCEPTS

Flow manufacturing has its origin in group technology (GT). Since the initiation in the USSR in the late 1950s, the GT concept has been carried throughout the industrialised world, and has been used to reduce set-up times, batch sizes and material handling costs. The major facilitator for making group technology public was John Burbidge, who promoted and systematised this concept for 30 years [2], [3] and [4]. GT provides a systems approach to the redesign and reorganisation of the functional shop, and group technology layouts are now widely used in metal fabricating, computer chip manufacturing, and assembly work.

GT was developed in order to create effective flow in job and batch manufacturing [2]. GT was inspired by the efficiency and continuous flow in line manufacturing, typically built for mass production of high volume, standard products. The basic idea was to achieve effective flow, “not only in simple process industries and for single components in mass production quantities, but also for families of similar components” [2]. GT is an improvement approach that “identifies and exploits the “sameness” of items and processes used in manufacturing industries” [5]. It groups units or components into families of parts which have similar design or manufacturing sequence. There are many ways to do this, but three popular ways are through tacit judgement, or eyeballing, analysis of the production flow, coding and classification.

Over the years, the GT concept has been extended to create a variety of new improvement approaches, termed flow manufacturing [1], [6], or cellular manufacturing [7], [8]. However, the core building block in these approaches is still group formation, i.e. to assign parts and machines to operations areas in order to create flow.

3 THE RELATIONSHIP TO OTHER PERFORMANCE IMPROVEMENT APPROACHES

The objective of flow manufacturing is to change the organisation of tasks, procedures, equipment, and processes from a functional basis to a product-oriented basis. Operations areas are formed which complete all the set (or family) of products or components which they make. This can be through one or several processing stages, and are equipped with all the machines and other processing equipment they need to do so.

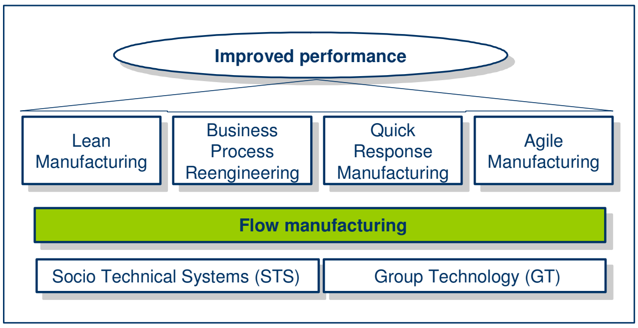

Figure 1 Relation to some other improvement approaches

The role of flow manufacturing compared to some other performance improvement approaches is illustrated in Figure 1. Flow manufacturing is closely related to several different types of performance improvement approaches. Flow manufacturing has as mentioned, its origin in group technology, which mainly targeted technical issues like rearranging equipment on the factory floor. However, early industrial experience discovered that human side of work is equally important to the success of flow enterprises [2]. Flow manufacturing is therefore also closely connected to socio-technical system design described below. The operations area can potentially create a positive environment for work. John Burbidge said in this regard "I believe that group technology holds out the improvement in the quality of working life and that in the long run this will be its major contribution" [2].

Furthermore, flow manufacturing is related to lean manufacturing, which uses flow manufacturing concepts (such as flow-oriented layout, operations areas and team-work) and pull control to create efficiency in repetitive manufacturing with somewhat stable demand. Flow manufacturing is also related to business process reengineering (BPR), which mainly is targeting office processes. Flow manufacturing provides principles and concepts that are more practical oriented in their application for office processes than the general principles of BPR, and can often be used to support BPR improvement projects.

Quick response manufacturing is an improvement approach that has its origins in time-based competition, and uses flow manufacturing as a foundation to create improvements in enterprises that operates in highly dynamic markets. Agile manufacturing also targets such dynamic markets, but is still an evolving concept. Examples of agile behaviour have been given, but core principles of how to implement are still being developed. Agile manufacturing may be viewed as an approach to take manufacturers beyond quick response manufacturing, but the principles to do so have to be better understood.

4 DESIGN PRINCIPLES IN FLOW MANUFACTURING

Flow manufacturing aims to obtain effective flow. This implies a progressive movement of materials and information through the entire manufacturing process of a product. Morris [9] defines a principle as: "simply a loose statement of something which has been noticed to be sometimes, but not always, true". The following principles have been observed to frequently result in effective flow and short throughput times [10]:

- Create product-focused operations areas
- Create a flow oriented layout with
- Create multiskilled and cross trained operations area teams
- Decentralize planning and control to operations areas

These four design principles are the overall guidelines for the modelling of the manufacturing system. A flow manufacturing reengineering based on these principles should be viewed as one (optional) approach to improve competitiveness. Each principle affects one or more decisions areas of an operations strategy and aims to support some performance objectives.

5 MODELLING, ANALYSIS AND DESIGN OF FLOW MANUFACTURING SYSTEM

For analysis and design of a manufacturing system many different methods and tools are available. Most of the methods used, include more or less sophisticated modelling tools. Models are useful representations of reality [11], and can be mathematical, graphical, descriptive or a combination of these. Models are useful for analyzing and visualizing as-is as well as to-be manufacturing systems. As [11] argues, a set of coarse conceptual models are faster and less resource intensive to implement. This is therefore especially well suited for SMEs, but also useful as additional tools for quality assurance of more complex tools such as discrete event simulation. In this paper, emphasis is put on simple deterministic modelling. The modelling and the following analysis will contain:

- Grouping of products according to GT principles, process routing and volume (ABC analysis)
- Spreadsheet model of Bill Of Materials with volumes, process flow and process cycle- and setup times.
- Initial targets for Overall Equipment Effiency (OEE), throughput times and automation level
- Graphical model of Material Flow with product-focused operations areas and multiskilled operations teams as well as decentralized manufacturing planning and control
- Graphical model of layout based on spreadsheet calculations and analysis of transportation intensity and need for storage space for Work In Process

5.1 Grouping of products

Group technology is described earlier in this paper. Core competences, current machine tools and equipment, market demands, volumes, automatisation potential are all considerations that need to be done when the group of products suited for a common manufacturing system in a common plant is chosen. To make sense, the products manufactured within one plant must have some similarities and not be too widespread. If the objective is to make a reengineering of a SME, there might be occasions where the manufacturing should be split into more than one (possible flow oriented) manufacturing plants with different focus because the differences are too large. These decisions should typically be a part of a manufacturing enterprise's long-term strategic considerations, and make–or–buy analysis might be helpful in this work.

An analysis of the sales volumes, both historical or prognosis for future sales is important. The Pareto 80-20 rule and grouping of products according to ABC analysis are useful. It is important to design the flow manufacturing system with focus on the 20% of the products that typically are responsible of 80% of the total sales. Too often the "special cases" on small volume products are given too much focus. It is better to focus on the few products with high volume to be sure that these are manufactured as effective as possible since these usually are the "money makers" of the enterprise.

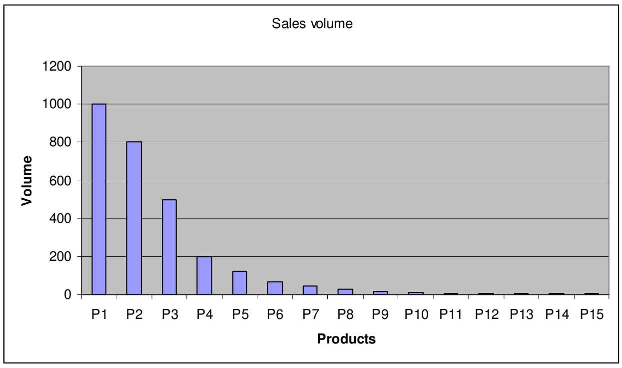

Figure 2. Typical Distribution of sales volumes

5.2 Bill Of Materials, process flow and process times

An overview of Bill of Materials (BOM) for the products, as well as process flow, cycle times and setup times are of course vital information. With additional information on setup frequency, volumes, expected OEE as well as the total available manufacturing time, this can be used for calculating the occupancy and setup time for each process. This is then a simple way of finding the bottlenecks, by the calculated occupancy and the total setup time compared with the total available manufacturing time for the given process. These calculations can be organized in a simple spreadsheet model, as shown in Figure 3. The model can be extended to include planned downtime etc. This model is also a tool for balancing the manufacturing and level the cycle times.

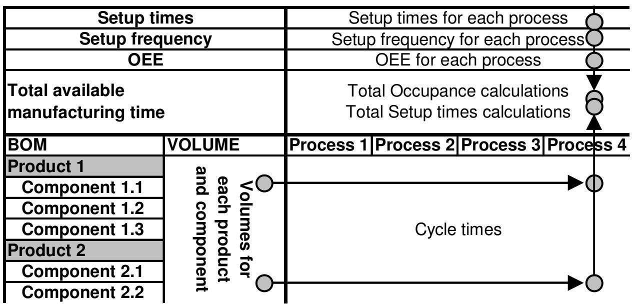

Figure 3. Spreadsheet model for BOM, volumes, occupancy and setup time

5.3 Initial targets

Initial targets for OEE, throughput times and automatization level as well as other performance indicators should be discussed and set initially, as a part of the operations strategy process. The targets must be set with a view to current performance, the need for investments vs. payback, competence on enterprise re-engineering and change management [11]. These targets can be given a ramp-up period typically OEE are lower in the beginning of a new manufacturing system, but will increase because the knowledge on machines and equipment increase.

By deciding initial targets for throughput times, this controls the target Work In Process (WIP), lot sizes and setup times. Since target WIP is decided, necessary storage space for WIP can be calculated, and serve as an input to the layout design. Since these are deterministic calculations, one should estimate a mean and a maximum value.

5.4 Material and process flow with product-focused operations

Modelling, Analysis and Design of material and process flow might follow these steps:

- Focus on the 20% of the products that are responsible for 80 % of the total volume
- Map the process flow and visualize it by process flow diagrams
- Find the most common process route - The main material flow path
- Find which processes can be integrated with one-piece flow, and where a buffer storage is necessary
- Decide manufacturing planning and control (MPC)
- Create multiskilled and cross trained operations area teams
- Design of supply chain

Cycle times and set-up times for each process and the bottlenecks are important issues in the material flow design. The most value-adding process should, if possible, be the bottleneck. To level the cycle times means that the bottleneck cycle time decides the cycle times on the other processes. Control focus would be on the bottleneck and there should be some slack in the manufacturing chain so that the bottleneck runs with the highest productivity. In continuous improvement work, the plant should aim for decreasing the cycle times trough improvements on the bottlenecks – since one minute saved on a bottleneck is one minute saved for the total manufacturing chain.

The manufacturing control method should allow decentralised planning and control. The material flow is usually divided into a number of operation control areas. Each control area have the necessary tools, machines and equipment to perform the tasks they need do in order to manufacture a group of components and/or products. The teams have power to make material planning and control (MPC) decisions within certain limits. There might be one-piece flow within each control area, and buffer storage between the control areas.

Guidelines for MPC system design have been discussed by many authors [10] and [11]. Pull systems and visual control systems such as KANBAN are particularly beneficial for Flow Manufacturing. KANBAN is, however, best suited for products with a fairly stable demand. For low-volume product with irregular demand, one should try to have short enough throughput times to allow make-to-order MPC.

The management of the supply chain is also an important issue [12]. As described in [13], [14] and [15], a transparent information flow is beneficial in order to avoid small changes in demands to be amplified upstream, the so-called Bullwhip- or Forrester effect. Bullwhip effects creates unnecessary large fluctuations in demands on tier 1 and tier 2 suppliers, and can be harmful to the flow in a pull controlled flow manufacturing system.

SINTEF has developed a mapping tool termed the control model, described in [10]. The control model consists of the following building blocks:

- Main processes: ○ and buffer stores: ▽
- Operation areas – specifying which operations and buffers are one area of responsibility ○▽
- Material flow – specifying flow routes
- Information flow – specifying flow of customer orders and work orders
- Control Methods – specifying decision rules
- Customer order decoupling point – specifying which part of the operations are controlled by customer order

5.5 Layout design

The layout design should be made after information from the other modelling and analysis mentioned earlier are available. The layout should reflect the process flow, the need for WIP buffer storage etc. The process flow should be realized in a clean “laminar” material flow, with no “turbulence”. There should be short distances between the processes and buffers along the main material flow path. A sketch of the layout where the main material flow path is drawn by arrows is a useful model of the material flow.

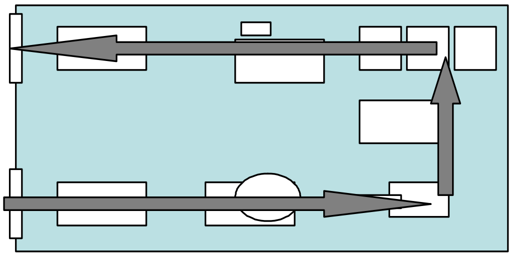

Figure 4. Coarse sketch of main material flow

Sophisticated tools that minimize the internal transportation distances in a work shop do exist. A more simple way is to make a transportation intensity matrix. This matrix shows which move have the highest transportation loads, and thus needs to be as short as possible. The move with highest intensity can be candidates for automated handling.

	TO warehouse/ process / buffer store	
FROM warehouse/ process/ buffer store	Number of transportation between FROM and TO [units /year]	SUM FROM
	SUM TO	

Figure 5. Transportation intensity matrix

6 CASE STUDY

A case study has been carried out to evaluate the potential of the flow manufacturing approach for Hydro Aluminium Structure (HAST). HAST manufactures bumper beams and other car parts in aluminium; AA 6XXX (AlMgSi) and AA 7XXX (AlZnMg) Age Hardening Wrought Alloys. This describes the initial analysis and the design to achieve flow manufacturing on a new plant at HAST.

6.1 Grouping of products

The products in question are small and medium size volumes for automotive OEM customers: From 500 pr year up to 200 000 pr year. The manufacturing processes include stamping, cold-forming, sawing, heat treatment, machining (milling), cleaning, welding and inspection. Most products will be welded, but spare capacity in cutting and stamping will be used for making components for other products as well. An ABC analysis (volume pr article or year) was made. The goal was that the 20% of the products typically having 80% of the total volume should follow a flow-oriented main material flow path, or a “highway” as it was named. In fact, it showed that it was possible to fit 95% of the total volume to the main “highway”. Along the highway, the handling should be as automated as possible.

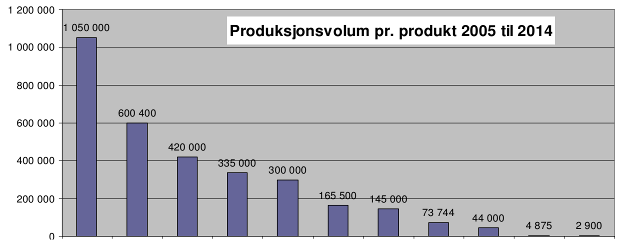

Figure 6. ABC / Pareto analysis of main products

6.2 Initial discussion of targets

There was a set of targets given for the new production. These targets defined the wanted average throughput time and turnover, a minimum OEE (Overall Equipment Efficiency) as well as maximum number of operators (in other words the automation level).

- Average throughput time : 1 week from raw material to finished products
- OEE: 75% the first year, increasing to 85% after three years
- Number of operators on each team/shift: Five at first, with possible decreasing to four – this implies quite high automation level

These targets should be solved with investment costs and future manufacturing costs as low as possible. Transportation, storage space, etc should be kept at minimum. Some of the processes allowed re-use of existing equipment, other processes needed investments in new machines.

6.3 Bill Of Materials with volumes, process flow and process cycle- and setup times

Bill Of Materials (BOM) and the process flow for each product was mapped and plotted into a simple spreadsheet model. Prognosis for sales volumes from 2006 to 2014 was added. With the given targets on OEE and throughput times, this was used to decide the maximum allowed set-up times on each process as well as suitable lot sizes. Figure 7 at the end of this paper shows an extract of the spreadsheet model. From this model it was found that machining and welding are the bottlenecks – Machining for one product, Welding for most of the other.

6.4 Material and process flow with product-focused operations

There are two main process routes:

1. Process route for components: stamping/cutting – machining – cleaning – Buffer before welding.
2. Process route for beams: forming – buffer before welding

The two material flows are joined in the welding process and the common further flow is: welding – inspection – packing.

Since welding was the bottleneck for most of the products and is a joining process between beams and components, it was decided to have a buffer before the welding and have one control area on welding and inspection/packing. The two other control areas are component manufacturing and beam forming, with buffers between each area. Within each area there should be one-piece-flow. The control principals within the plant are planned to be a mixture of make-to-order and KANBAN, but KANBAN will control the main material flow path, or the “highway”. The Control model is shown in Figure 8 at the end of this paper.

6.5 Layout

A transportation intensity matrix showing transportation intensity between the nodes was established. The matrix focused on the transportation volumes, since the components may vary a lot in size. This transportation intensity analysis was used to optimize the layout of the plant. The size of the buffer storage was calculated from the lot sizes derived form the throughput times decided.

7 CONCLUSIONS

A range of improvement approaches termed cellular manufacturing or flow manufacturing has their origins in group technology. What makes this "Norwegian" flow manufacturing approach different is the main focus on shop floor control and the use of "control models". The control models, in addition to the traditional planning hierarchy, also include the operations areas and how they are controlled. Four flow reengineering principles are proposed, each representing a broader design area in flow manufacturing. These are:

- Process design: Create product focused operations areas
- Layout design: Create flow oriented layouts
- Job design: Create multiskilled and cross trained operations area teams
- MPC design: Decentralise planning and control to operations areas

The principles are tested in a case study from the Norwegian car part industry. The experience from a range of Norwegian companies is that flow manufacturing has contributed significantly to increase the productivity in manufacturing and especially for batch manufacturing and manufacturing of relatively large variety of parts or products with repetitive demand in batch sizes. This is also partly demonstrated in this case study. In the Norwegian companies, the introduction of flow manufacturing has resulted in a reduction of move distances/move times, a reduction of throughput time, a reduction of response time to customer orders, a reduction in WIP inventory, a reduction in finished goods inventory, improvement in product quality, and a reduction in unit costs.

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Look-up ID	Art. nr	Beskrivelse	Num	Volume	Sub supplier	Raw materials	Cutting 1	Cutting 2	Cutting w/ angle	Washing	Punching eccentric	Mech. forming (the	Machining (rundbo	Drilling jig	Milling Uni 5	Milling Uni 6 & 7	Machining (udefine	Washing (beising)/(	New welding cell
				Look-up ID	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
		Shifts pr. week		*num*	5	5	5	5	9	5	5	5	5	5	21	5	5	5	18
		OEE		*%*	100%	100%	75%	75%	75%	80%	80%	80%	80%	80%	85%	85%	85%	80%	75%
		Avalilabe manufacturing hours pr year		*hours*	1,840	1,840	1,380	1,380	2,484	1,472	1,472	1,472	1,472	1,472	6,569	1,564	1,564	1,472	4,968
		Totel net manufacturing hours pr. year		*hours*	0	0	138	0	2,186	693	679	417	1,261	822	5,703	0	1,171	155	4,531
		Totel net manufacturing time %		*%*	0%	0%	10%	0%	88%	47%	46%	28%	86%	56%	87%	0%	75%	11%	91%
		Setup time		*hours*	0.00	0.00	0.00	0.00	0.80	0.00	0.50	0.00	0.00	0.00	0.50	0.50	0.50	0.00	0.25
		Number of setups pr year		*num*	0	0	0	0	100		50	0			130				506
		Total sum of setup.time pr year		*hours*	0	0	0	0	80	0	25	0	0	0	65	0	0	0	127
		Total gross manufacturing hours		*hours*	0	0	138	0	2,266	693	704	417	1,261	822	5,768	0	1,171	155	4,658
		Total gross manufacturing time %		*%*	0%	0%	10%	0%	91%	47%	48%	28%	86%	56%	88%	0%	75%	11%	94%
		Process number					53	55	52	34	54	53						IMASA	1/50
1	**103705**	**Product 1**	**1**	**30,000**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**717**
1		Beam ECE	1	30,000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1		Box	2	60,000	0	0	0	0	133	50	0	250	0	0	0	0	0	0	0
1		Crash Box plate	2	60,000	0	0	0	0	0	50	133	0	0	0	0	0	0	0	0
1		Tow eye boss RH only	1	30,000	0	0	0	0	0	25	0	0	83	0	0	0	0	0	0
2	**103705**	**Product 2**	**1**	**20,000**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**478**
2		Beam NAS	1	20,000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2		Box	2	40,000	0	0	0	0	89	33	0	167	0	0	0	0	0	0	0
2		Crash Box plate	2	40,000	0	0	0	0	0	33	89	0	0	0	0	0	0	0	0
2		Tow eye boss RH only	1	20,000	0	0	0	0	0	17	0	0	56	0	0	0	0	0	0
3	**103520**	**Product 3**	**1**	**50,000**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**694**

Figure 7. Exteract of spreadsheet model with BOM, cycle times, occypancy, OEE and setup times

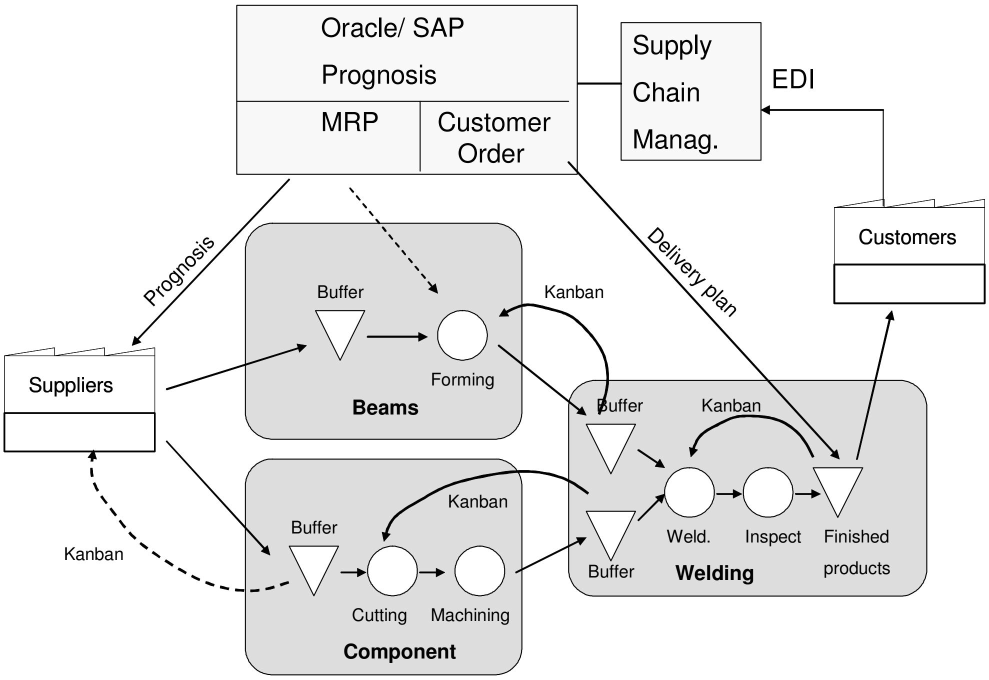

Figure 8. Control model