BACHELOR THESIS

INDUSTRIAL ENGINEERING AND MANAGEMENT

TOWARDS AN IMPROVED PRODUCTION PLANNING AND CONTROL METHODOLOGY WITHIN BENCHMARK ELECTRONICS

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Preface

In the context of completing my Bachelor Industrial Engineering and Management at the University of Twente, I performed a research at Benchmark Electronics regarding production planning and control approaches. The period leading up to this opportunity was a hectic period. The opportunity of writing my bachelor thesis at ING on the M&A department was cancelled in a very advanced state. During a very short and intensive period of finding a new opportunity I contacted Ronald Rikmanspoel. I met Ronald during a study project I had done some years ago at Power Packer. I remembered Ronald for his deep understanding of supply chain management and his critical views. After I contacted Ronald to see if he could help me to find an opportunity in supply chain management at Power Packer he offered me an opportunity at his current employer: Benchmark.

Although my time frame to perform this research was, to put it mildly, quite uncommon. But not many days later the contracts were signed. After a period of trying to find where I could be of value and what my deliverable was going to be things got clearer and my research scope was defined. My goal became to assist on further developing and setting up a methodology to perform a capacity planning. Capacity planning at Benchmark is still in its infancy stage and at the time provisionally approaches were applied to generate insight in capacity plans and design production plans. During my internship a lot of managerial changes have taken place. Some reorganization regarding the supporting staff in the production planning had been done. A lot of new supply chain staff was brought in, including Marc Bakker who was brought in to focus on setting up a capacity requirements planning and produce according production plans. Marc has gained his thorough understanding of production planning during his time at VDL, and can be seen as one of the better planners around.

I want to thank Ronald in particular for giving me the opportunity for an internship at Benchmark Electronics. I have had great time working with him and enjoyed our conversations and discussions on various topics regarding the research. His critical view and thoughtful ideas have really been of great value to me. Even though my ideas were often very abstract and conceptual, and thus not directly applicable to practice, he always welcomed them. This has been a great motivation for me during this project.

Someone who also deserves to be thanked is Jana Pejchinovska, who operates as a manufacturing engineer at Benchmark. She received my ideas with great enthusiasm and was one of the internal ambassadors of my research. I also want to thank her for her critical remarks on my work.

Furthermore, I would also like to thank dr. Peter Schuur for his enthusiasm and great support form an academic perspective. I have had several meetings to discuss my progress, but we often ended up discussing everything there was. He has been a great motivator in bringing my academic ideas and models into practical use and getting me to focus on a real deliverables.

My appreciation also goes to dr. Hans Heerkens who is my thesis co-assessor. Hans joint at the very last moment of the research project, nevertheless his comments were very valuable. From a methodological perspective he provided me with thoughts that spurred me to further improve the report, and to rethink some aspects of the research.

It has become a comprehensive report, which I wrote with great pleasure. The main goal of this report is to provide Benchmark with new insights on how to precede on planning their production and in particular their capacity resources. The ideas in this report contradict in many ways with the current vision on how to manage the production planning and control process. I hope this report can be an eye-opener and that the ideas will help Benchmark to improve the PPC process further.

Sincerely,

Dirk Jonkman

Table of Contents

Management summary

At Benchmark Electronics business is soaring and large customer orders are received, and Benchmark corporate indicated it wants to improve its European footprint by expanding business in Almelo. Due to the increasing number of customer orders the workload in the production process significantly and lead to Benchmark needing to focus more on managing their capacity resources. In the past Benchmark was only focused on its material requirements planning [MRP], because long lead times and high quality standards of production parts are the main constraint on their production planning. But due to the new flow of incoming production orders also capacity is becoming a game-breaking constraint. To manage this new constraint Benchmark started applying capacity planning techniques by expanding the use of their ERP system from just MRP applications to MRP II modules.

Though Benchmark started on planning their capacity resources and control its production process, Benchmark still experiences difficulty on transforming their aggregated production planning and transform it into a detailed planning. This leads to lots of rescheduling actions and on-time-delivery dates not being met. Furthermore managing and controlling the work orders on the production floor is hard due to lack of insight in the production status and due to the fact that the production plan is adjusted and priorities changing on a daily basis. One of the main reasons for these problems is the absence of relevant and accurate information on many variables in the ERP system. Due to this production cannot be controlled using the system, and lots of human interference and actions are needed to control it.

The problems stated above are widely recognized in the literature on production planning and control. Lots of companies, mainly small and medium sized companies, experience similar problems. The purpose of this research is to identify the underlying causes of the problems, and develop a conceptual model based on suggestions in academic literature regarding production planning and control systems that will help solve these problems. This led to the following (main) research question that needed to be answered;

''Which logistical concept model can Benchmark Electronics use best to improve production planning and control manageability and on-time-delivery performance, and which recommendations (based on this model) can we make regarding changes that Benchmark needs to make?''

In this research we focused mainly on the Surface-Mounting-Device and Hand-mounting part of the production, and less on the box build and clean room departments. After reviewing the literature and analyzing the current Benchmark situation three causes for the problems regarding the production planning and controlling were identified. [1] The first is that there is a misfit between the production planning environment and the production planning and control method used to control the system. [2] The second is that Benchmark is making their production planning unnecessarily complex by fragmenting the process, by splitting the process and manage these parts independently. [3] And the third reason is the use of ERP for every aspect of the process, which makes managing the process very labor intensive.

Based on these suggestions from the literature a conceptual model is constructed, which is presented in chapter 6, that suggests that the use of ERP should be constrained to just material requirements planning. Furthermore the concept of

workload control approach should be used to plan production capacity and control the production process. This approach conceptualizes the job shop as a queuing system, and focuses on controlling the lengths of these queues.

In this report an attempt is made to transform the conceptual model in a production planning and control methodology and a set of associated heuristics and rules. The theory of constraints is used to replace the sophisticated heuristics from the workload control concept, to make the concept more applicable to Benchmark. Though a lot of research has been performed on the concept of workload control, academic professionals have to do some sufficient research to bring theory closer to practice.

The applicability of the workload control concept in the Benchmark environment is proven. A challenge for Benchmark regarding implementation is that no detailed roadmap is available in the literature. Lots of research regarding parameter setting still needs to be done. However this does not mean that implementation can be started. Regarding implementation we propose the following first steps that should be taken by Benchmark.

[1] Benchmark supply chain management needs to decide whether or not they want to adapt their production planning and control approach. Top management support is one of the key factors for successful implementation. Support from top management can be achieved by focusing on the improvements that can be achieved by implementing workload control. For better understanding the link between the well know philosophy lean manufacturing and workload control need to be emphasized. We advise Benchmark Electronics to find other companies that have already implemented the concept, so the concept is clear and implications are known.

[2] If Benchmark is willing to change this approach we advise an external consultant that helps to implement the presented approach. It is a major change within the Benchmark production planning and control approach, that requires a lot of effort from the Benchmark staff. The process of implementation takes around 2-4 years, and no implementation roadmap is available. This makes it very hard for Benchmark to successfully implement the proposed model. Some general implementation issues from other cases are gathered and mentioned in section 6.3.

[3] Get control over the work-in-progress levels by planning the main bottlenecks in the system. The provided conceptual model can help Benchmark to further improve the production process, but is not able to solve the imbalance between production in- and outflow of orders. Therefore this imbalance should be resolved, this should be done based on information that is accurate, and can be done using simple tools in Excel. More detailed methodology for this is presented in section 6.2.3.

Further recommendations are made regarding how the production planning and control processes should be managed. Even if Benchmark decides not to change their current approach some useful recommendations and suggestions are made in section 7.2.

Chapter 1

1. Introduction

This report is written in the context of completing my Bachelor Industrial Engineering and Management at the University of Twente. We have performed a research at Benchmark Electronics on their production planning and control approach. In this first chapter we will first present an introduction to Benchmark Electronics. We then, in section 1.2, give some background to the research project and define our problem statement in section 1.3. After this we define our research scope and discuss assumptions and preconditions underlying this research in section 1.4. The deliverables of our research are stated in section 1.5. In section 1.6 we present the desired situation and a summary of this chapter in section 1.7.

1.1 Introduction to Benchmark Electronics

Benchmark Electronics Inc. [Benchmark], formerly named Electronics Inc., began operations in 1979 and was incorporated in 1981. The company is a worldwide provider of integrated electronic manufacturing services. The plant in Almelo, which is currently the European headquarters, was an originally a subsidiary of Philips N.V. After a period of takeovers, demergers and partnerships, Benchmark Electronics eventually took over the Almelo plant. Benchmarks' mission is being the solution provider of choice for high technology original equipment manufacturers, anticipation their needs and rapidly delivering comprehensive value-creating solutions during the entire product life cycle by providing; innovative design engineering services, optimized global supply chain and logistics solutions, world-class manufacturing and after-market support. The organization currently employs 12,000 employees at eighteen plants world-wide, of which two are located in Europe. The Almelo plant currently has approximately around 300 employees who together focus primarily on the development and production of high-end electronic products (Benchmark, 2012).

Benchmark Electronics Inc. provides services to original equipment manufacturers [OEMs] of computers and related products for business enterprises, medical devices, industrial control equipment for aerospace and defense, testing and instrumentation and telecommunication equipment. In Almelo the focus lies the development and production of test- and measurement equipment. Benchmark offers customers comprehensive and integrated design and manufacturing services form initial product design to volume production including direct order fulfillment and post-deployment services. There manufacturing and assembly operations include printed circuit boards and subsystem assembly, box build and systems integration. A selection of their product offerings is presented below:

Figure 1: Samples of various Benchmark products

A distinctive service from Benchmark Electronics Inc. is their product feedback system [PFS], which offers their customers traceability services by closely monitoring and captures every production step. This system is already implemented at many other Benchmark plants, but in Almelo the company just recently began implementing the PFS. Benchmark is supplier to almost thirteen customers, three of the major customers include Thales, Airbus and ASML. At Benchmark operations is very customer orientated, which leads to separately managed operations. This approach has some adverse consequences as we show in section 4.2.1.

In the production process of Benchmark Almelo[1] four major departments can be distinguished, these include: the Surface-Mounting-Device [SMD]-lines, the Hand-Mounting [HMT] department, the Box Build [BB] department and the Clean Room [CR]. All four departments all have their own supervisor which is responsible for the order execution at their department. A more detailed description on these production steps is omitted, but relevant aspects are discussed in our assessment of the current situation in section 4.1.

1.2 Background on the research project

At the time of writing this report there are a lot of interesting developments taking place at Benchmark. The first one is that business is soaring and large customer orders[2] are received (e.g. Thales Hengelo). This development is further reinforced by Benchmark corporate that indicates it wants to improve its European footprint by expanding business in Almelo. This leads to an increasing number of customer orders, which significantly increases the workload in the production process. Therefore Benchmark Almelo needs to increase its focus on managing their capacity resources. In the past Benchmark was only focused on its material requirements planning [MRP], because long lead times and high quality standards of production parts were the only constraint on their production planning. But due to the new flow of incoming production orders[1] also capacity is becoming a game-breaking constraint in some departments. To manage this new

[1] We refer to Benchmark Almelo by using Benchmark in the rest of this report.

[2] When a customer confirms a forecasted order it is called a sales order, this sales order in then split up in several production orders for every production department.

constraint Benchmark started applying capacity planning techniques by expanding the use of their ERP system from just MRP applications to MRP II modules. A lot of new staff is hired to help managing the increasing number of customer orders and setting up the MRP II modules in the ERP system.

A second development is that Benchmark started with the implementation of the Product Feedback System [PFS], which is already implemented at other production facilities of the Benchmark Corporation [see section 1.1]. The PFS is primarily intended for traceability possibilities to diagnose causes of production errors, which is necessary due to regulation but also to improve quality. The system tracks each product throughout the whole production process. Each production step is monitored and data on which workers performed which the task, at what time, with what tools is collected. Though the system is intended for traceability purposes it has also interesting implication for controlling the production process.

The link between both developments is that due to the increasing workload Benchmark is experiencing some problems regarding the control of their production process. Due date performance is lacking, and work-in-progress levels are increasing. The planners at Benchmark need accurate information on the status of work-in-progress orders on the production floor in order to control the process and take controlling measures like for instance revising order due dates. Currently no accurate information of the status of various production orders on the floor is available, but the PFS will generate this information. Since the system provides almost real time information on the status of the production orders. This information thus makes the production process less opaque and more transparent, and by that it helps planners in making more informed decisions. For instance if yield or repair issues occur a planner needs to know they occur, since both heavily have big influence on due date delivery performance. Currently the planners do not receive accurate information timely on yield and repair issues and therefore the order due date is not revisited in time and customer orders are delivered late.

To provide some further inside in why the system is currently opaque we describe another aspect of this opaqueness is some more detail. For a planner the period between the starting and completion date of an order is a black box. This is caused by the way the ERP system is equipped, we illustrate this in a sketchy way in figure 2.

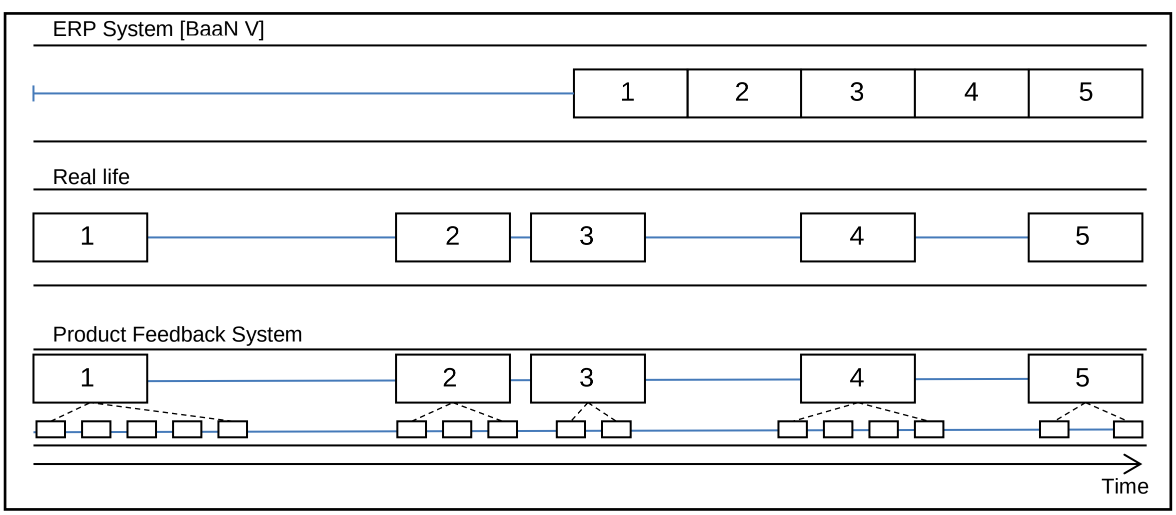

Figure 2: Representation of routing design in Baan V vs. Real Case

In figure 2 the boxes represent actual production steps at various workstations, the blue lines in between represent waiting (queuing) times. Since Benchmark does not control or in any way restricts the queuing times to a maximum they fluctuate over time [this is be explained more thoroughly in section 4.1.4]. This makes them hard to predict which is why Benchmark chose to set the production steps directly behind each other in the ERP and a fictive lead time is put in front of the production steps. This fictive lead time in the ERP system tells production planner to release an order in time so the due date can be met, this is called backward planning. As can be seen the fixed lead time aligns to throughput period by generating the same *expected* starting and *expected* completion date of an order. But the system does not tell when each production step should be executed. The implementation of PFS reports production steps complete and thus provide planners with more accurate information. However there are still some problems that are not solved with the PFS. Let us look at the two main problems that are not solved by the product feedback system.

One of the problems is the absence of a reference framework for planners to determine whether an order is behind schedule. According to the ERP system all production steps should be executed at the very last moment, without any waiting time between the steps. A planner might now know which steps were completed when, but he cannot determine if this according plan since the ERP system does not provide a realistic production plan [see figure 2]. Therefore a planner does not know if he must act until the due date is reached or if almost all production steps are completed. Because possible deviations are much easier to observe since the uncertainty and variety converges when more production steps are completed or if the due date is reached.

The second problem is also causes by the current design of the ERP system and relates to capacity planning. Capacity on the aggregated level is planned on a weekly basis. But because most of the throughput times are more than one week at most departments, some production steps are therefore executed in a week in which the system did not account for it. Let us illustrate this with a fictive example. Suppose a product with five production steps is scheduled with a due date of Friday in week 2. Then the ERP system will plan all the production steps on Friday [the sum of the production times is in almost any case less then one day] and thus planning all capacity demand in week 2. But due to the fixed lead time of one week the first production steps are executed in week 1. But in this week no capacity for this product was accounted for. This can be problematic when some machines are already planned to produce at maximum capacity, and these unaccounted orders also need to be processed. Or when this happens to large production orders pushing the capacity demand levels over the capacity available. Both these cases are present in the Benchmark leading to capacity issues that the ERP system itself does not accounted for.

1.3 Problem identification

In this section we first explain why we chose to focus our attention on changing the production planning and control approach. We then show why this is the appropriate choice by looking at what problems can be expected according to the literature when using the current approach in the Benchmark situation. We then comment on the presence of these problems in the Benchmark situations based on our interviews with various actors in the production planning and control process.

In the previous section we talked a lot about solving opaqueness problems and inaccurate information on the status of production order. This would imply that we need to address an information problem, which was how Benchmark views the problems. We were therefore initially assigned to become a member of the PFS implementation team. Our main focus was to design the product feedback system so it could effectively be used by the various planners at Benchmark to set revised due dates. For the system to do this, integration was needed between the ERP system and the PFS. The PFS reports even the slightest production step, but all this information might not be necessary and could cause an information overload. Our focus was to determine which steps in production should be reported back to the ERP system. However there are three reasons why we chose not to focus on solving this information problem but chose to improve the current production planning and control instead so it could operate with the information currently available.

The first reason is that main purpose for Benchmark at this moment is managing their capacity resources more closely by generating a capacity. To generate a capacity plan you need to know three things. First you need to know how much capacity is available in a certain period. And second you need to know which products need to be processed in that certain period. And thirdly you need to know the processing times of the various products. We deem it impossible for Benchmark to reach a state of perfect information. Because at Benchmark the products are often changed, and the current system needs vast amounts of information per product. But also because some information like queuing times cannot be determined since they fluctuate heavily over time, and therefore are uncertain. It is therefore not possible for Benchmark to accurately produce a capacity plan with the current approach. Berry et al. (1982) suggest that execution of the master production schedule is handicapped because adequate capacity has not been planned at individual departments or work centers. Since Benchmark does not and cannot adequately plans is capacity this should based on the suggestion by Berry et al. (1982) that Benchmark is having trouble executing their master production schedule according to plan.

The second reason is that in the literature the applicability of ERP systems in the production planning and control environment of Benchmark [described in section 4.1] is questioned. We present the major conclusions here, but we discuss this in more detail in section 5.1. Betrandt & Muntslag (1993) concluded that many engineer-to-order firms have tried to implement MRP II systems, however, with little or no success. Because the production control concept underlying ERP cannot be used in these situations, since ERP is in fact a deterministic production control system that cannot function in a stochastic environment. Also Koh & Saad (2005) concluded that uncertainty disturbs production plans of SMEs in the manufacturing sector, which plan and schedule their production using MRP, MRP II and ERP systems. As we show in chapter 4 Benchmark falls in the categories of small and medium sized companies and has strong engineer-to-order characteristics. Based on this we should expect a lot of effort and techniques being applied to compensate for the uncertainties. Ho et al. (1995) developed a framework to dampen the system nervousness caused by these uncertainties. There framework suggests safety stocks, safety lead-time, safety capacity and rescheduling to tackle uncertainties. Also the use of firefighting approaches was identified by Koh & Saad (2005) in delivering critical orders timely. Most of these methods are widely applied at Benchmark. So rather than to compensate we should focus on finding a more robust production planning and control approach.

The third reason is that controlling the system in a situation of perfect information is still done in a reactive way. Since planners can only act when the problems that are already there which, as explained earlier, is only known in a very advanced state because of the absence of a reference framework. So controlling measures might be taken based on better information, but it does not prevent production issues to occur. In this research we aim for a proactive approach of managing the production planning and control processes.

In the literature some suggestions were made regarding problems that Benchmark might have. Based on interview with various actors we identified some problems, which are in line with the suggestion from the literature. The two main problems identified were:

[1] While Benchmark is doing a lot of effort putting together an achievable aggregated production plan, they are having a hard time to transform it into an executable detailed planning that could be met.

[2] The production planning needs to be revised often (almost on a daily basis), but could not be done based on good information.

According to various actors in the production planning and control process the first problem is caused by the absence of a thorough capacity check when sales orders are accepted. Within Benchmark there is the tendency to always accept customer orders, without performing an aggregated capacity check. At the time of the research provisionally methods were applied, but these were primarily used to get insight in the capacity problems. But not to take actions based on them, let alone solve them. That the absence of a thorough capacity check leads to problems with executing the master production schedule was brought up by Berry et al. (1982). So performing capacity checks is expected to improve the executing of the master production plan, but for making it possible to adequately perform capacity checks changes need to be made to the system.

According to the actors, the second problem is caused by uncertainty or dynamics. In section 3.1.1.3 we further describe these uncertainties and dynamics. Benchmark tries to tackle these uncertainties with the use of safety lead times and rescheduling efforts. The use of safety stocks is not an appropriate measure for Benchmark because there is some liability risk associated with it technique. Since the number of incoming order exceeded maximum capacity, safety capacity is also no option. This is in line with what we expect based on the suggestions from the literature of Koh & Saad (2006) and Bertrandt & Muntslag (1993). So based on this we should also reconsider the use of an ERP approach at Benchmark.

Now we have clarified why we chose to not to address the informational problem and justified the choice to focus on improving the production planning and control approach instead. We have addressed the problems that Benchmark experiences and linked them to the current production planning and control approach. In the next section we discuss the research scope, preconditions to the research and assumptions underlying our research.

1.4 Research scope, preconditions and assumptions

Within production planning and control literature the vast majority of capacity planning concepts are based on the principle of hierarchical plans. On the long term capacity planning is performed at a aggregated level and on the short term on a detailed level (Wortman et al., 1996). Production planning is mostly done based on three levels [see figure 3], in this report we address all elements but we focused on the following components; master planning, rough-cut capacity planning, capacity planning, scheduling / sequencing.

We chose to address multiple levels in the production planning and control hierarchy because in our view only addressing one level does not lead to the desired effect since it is highly dependent on how processes are structured at higher levels. And consistency between levels is an important concern (Wortman et al., 1996). To adequately address the problems all levels should be examined and the various levels should be aligned. Furthermore we chose to focus our attention on capacity planning and capacity resource management since this is fairly new to Benchmark and no adequate framework is present on how to manage these new functions.

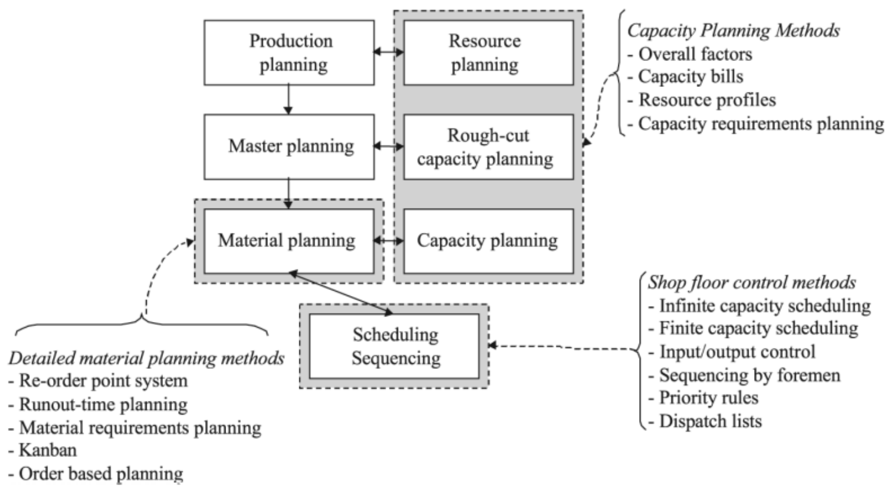

Figure 3: the three levels of the production planning and control hierarchy (Jonnson & Mattson, 2003)

In chapter 6 we present our new logistical conceptual model and we make some recommendations based on this new approach in chapter 7. Also a preliminary implementation roadmap is presented, which comprises some of the first steps management should take. What this report not addresses are the implementation issues that might arise. Since the literature only addresses the general and not the specifics we expect some problems when actual implementation is executed. Solving these issues requires some further research.

Underlying this report there are some assumption. For one we assumed that Benchmark is not going to change its environment and all the factors it comprehends. This means that we need to find an approach that can operate within the current Benchmark environment. Therefore an acceptable solution for us cannot be to keep using ERP and change Benchmark to a make-to-stock company, although a good fit between ERP and Make-to-Stock has been confirmed by Bertrandt & Muntslag (1993) and Stevenson et al. (2005). The second assumption is that Benchmark is willing to radically change its current production planning and control system. The approach that we recommend requires some major changes within the Benchmark situation.

There are three preconditions for the system that we propose in chapter 6. [1] The first is that Benchmark indicated that it wants to keep using is material requirements planning module. The main reasons for this include; one because it is a binding instruction from Benchmark corporate and second is because Benchmark is not able to organize all processes belonging to material purchasing without the ERP system. [2] The second is that the system should be able to function in the current Benchmark environment. So no additional information should be needed, and the system is able to manage and absorb the dynamics and uncertainties in the Benchmark environment. And [3] the third is that the system should be easy to understand and to manage. This precondition is also suggested by Land & Gaalman (2009), since complexity has a negative effect on implementation success.

1.5 Deliverables

In this section we will shortly present a list of the deliverables of this report. This report delivers;

- a new vision and new insights in the do's and don'ts for Benchmark regarding the improvement of their production planning and control process;
- a logistical conceptual model to design the production planning and control process with a practical translation to the Benchmark situation [which is described in section 6.2];
- a preliminary roadmap for implementation comprising the first steps towards implementation;

1.6 Desired situation

In the desired situation the production is effectively controlled, and thus meets all preconditions for effective control which are defined in section 3.2. As is further illustrated in section 3.2 this starts with the controlling body having the capacity to process all information needed to control the system. Since we deem it to be impossible to gather all the information to control the current system effectively, we chose to change the system. The system that we are going to construct should meet all three preconditions stated at the end of section 1.4. In the situation of effective control the planners can proactively manage the workload on the production floor, and the production plan disturbance is managed in a systematic way. This is expected to lead to Benchmark meet their on-time-delivery targets.

1.7 Summary

In this chapter we have presented a background on Benchmark Electronics as a company and also on the research project that we performed. We have defined a problem statement in which we justified our choice to improve the production planning and control concept. We did this by showing that the problems, we would expect based on suggestions in the literature regarding the use of ERP in an Engineer-to-Order of SMEs, are present at Benchmark. Furthermore we have clarified what this report comprises and what is does not, and presented a list of the deliverables. In the next chapter we construct the research model that we use to reach our research goal [section 2.1].

CHAPTER 2

2. Research model and methodology

In this chapter we aim to set our research goal [2.1] and construct the research model [2.2] that we are going to use to reach the stated goal. After the model is completed it should be clear what our strategy is, what questions need to be answered and how we are going to answers them.

2.1 Research goal

As we concluded in section 1.2 and 1.3 Benchmark is currently experiencing problems with their production planning and control process. Our goal is to assist Benchmark in solving these problems. We can do this by delivering the deliverables stated in section 1.5. The main purpose is to come up with a logistical conceptual model, the other deliverables are merely based on / a product of the proposed model. Based on this we have formulated the following main research question:

''Which logistical concept model can Benchmark Electronics use to improve production planning and control manageability and on-time-delivery performance, and which recommendations can we make regarding changes that Benchmark needs to make?''

In the next section we set out the model that we use to answer this main research question.

2.2 Research model and methodology

To answer the main research question we build a research model based on the ideas of Verschuren & Doorewaard (2007), which is presented below [figure 4]. In this section we describe the research model and derive our sub-research questions that help us to answer the main research question. We do this by walking through research model starting from the left hand side and work our way to the recommendations.

We first execute a small preliminary research (1) to construct the glasses through which we are going to look when assessing and analyzing the current situation at Benchmark. In the problem statement we saw that Benchmark has troubles with controlling its production planning and control processes. This preliminary research comprises two main topics. The first is the identification of production planning and control aspects and variables that help us to better describe the situation. The second is introducing system theory which helps us to identify problems regarding the controlling problems. The system theory offers a framework to describe the processes in an abstract way and provides preconditions to effectively control a system. The questions that we have derived from the above include:

[1] ''What does production planning and control include, what aspects are relevant from a production planning and control perspective and what variables influence production planning and control process?''

[2] ''How can current situations be described form a system theory perspective, and what suggestions does it provide for effectively controlling systems?''

The research method used to answer these questions is executing a literature review. After answering this question we have insight in all the aspects and variables of production planning and control [PPC] (2), and know how we can describe the current system using a system theoretical approach.

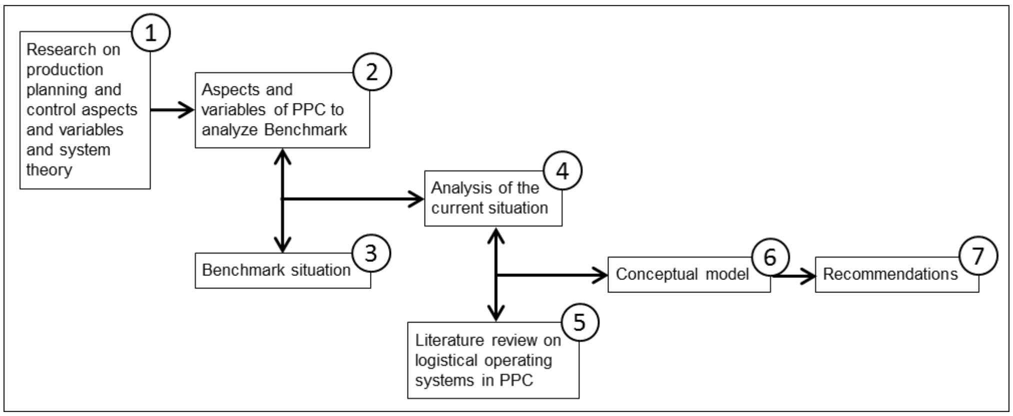

Figure 4: Research model

With these insights we analyze and review (4) the current situation (3) using a system theoretical approach and the production planning and control aspects and variables from our analysis (2). We describe the current methodology applied at Benchmark and identify the underlying causes to the problems described earlier based on the preconditions that are presented to us in the first literature review. The questions we have formulated for this section include:

[3] ''What is the current situation at Benchmark described in terms of the aspects and variables identified in sub question two?''

[4] ''What is causing the problems regarding production planning and control that Benchmark is experiencing, based on the preconditions stated by the system theory?''

Questions 3 is being answered by interviewing various actors by using systematic questionnaires in the production planning and control process and combining their sometimes conflicting views based on our own judgment. The preconditions for question 4 were assessed by our own analysis and judgment of the situation complemented by views of the actors.

After we thoroughly analyzed the current situation we perform an in depth literature review (5). Were the first literature review was focused on analyzing the current situation, this review aims to find solutions to the identified causes in answering question 4. Furthermore it provides us with recommendation/suggestions regarding structuring the production planning and control process given the Benchmark situation. Based on our findings in this literature review we construct a logistical conceptual model that Benchmark can use to manage the production planning and control process. We have formulated the following questions that we need to answer from our literature review:

[5] Which of the identified problems have been recognized by researchers and what possible solutions are presented in the literature?''

[6] ''Given the situation and typology of the PPC environment of Benchmark and the preconditions stated in section 1.4, which logistical management system will provide the best fit?''

Based on our findings in the literature we are able to answer our main research question. In order to provide the deliverables stated in section 1.5 we construct our logistical conceptual model (6), and translate it in a practical methodology and according heuristics and rules. Based on this model we provide recommendations (7) to Benchmark on organizing their production planning and control processes.

2.3 Summary and further outline of the report

In this chapter we have constructed our research model based on the research goal we defined at the beginning of this chapter. In the research model we have described what our research strategy is, which questions need to be answered and what methods are going to be used to answer them. We now present the further outline of this report. In chapter 3 we conduct our first literature review were we identify the key aspects and variables of the production planning and control process, as well as an introduction to system theory. In chapter 4 we describe the current Benchmark situation as we have stated in section 2.2. In chapter 5 we present our second literature review were we aim to find solutions for the identified causes to the problems Benchmark experiences. In chapter 6 we have presented our conceptual model and the translation of this model into a methodology and associated set of heuristics and rules. But we also present a preliminary roadmap towards implementation. In chapter 7 we present our conclusions and our recommendations. And in chapter 8 we presented a discussion and suggestions for further research.

Chapter 3

3. Literature review: defining the situation

The aim of this chapter is to construct the glasses through which we are going to look when assessing and analyzing the current situation at Benchmark in the next chapter. This literature research focuses on two aspects. The first is the identification of production planning and control aspects and variables that help us to better describe the situation. The second is introducing system theory to identify problems regarding the controlling problems. The questions that we are going to answer at the end of this chapter include:

[1] ''What does production planning and control include, what aspects are relevant from a production planning and control perspective and what variables influence production planning and control process?''

[2] ''How can current situations be described form a system theory perspective, and what suggestions does it provide for effectively controlling systems?''

The outline of this chapter is as follows; first we present an introduction to the theory on production planning and control [3.1]. We define production planning and control, but also identify all key aspects and other variables that are related to production planning and control. In section 3.2 we introduce the basics of a system theoretical approach towards business processes. We end this chapter with a summery on our findings by answering our stated research questions in section 3.3.

3.1 Introduction to production planning and control

A useful introduction that clarifies what production planning and control includes and what purposes it has is presented by Stevenson et al. (2005); typical functions of a production planning and control system include planning material requirements, demand management, capacity planning and the scheduling and sequencing of jobs. The key purposes of such functions include:

- Reducing work in progress;
- Minimize shop floor throughput time;
- Minimize lead times;
- Lower stockholding costs;
- Improve responsiveness to changes in demand and;
- Improve delivery data adherence.

These are important objectives, and choosing the right PPC system is hence a crucial strategic decision. Determining the applicability of PPC approaches is complex because of the increasing number of alternative approaches and the inclination of many software producers to suggest that an approach is universally appropriate. The latter is implied by a lack of indication of the type of company that could hope to gain wide applicability of the particular approach. However, through aiming for such wide applicability it is inevitable that industry-specific planning and control needs are not adequately met given that manufacturing environments are diverse in terms of characteristics such as levels of customizations offered, shop floor configuration, production volumes, and the way in which demand is met (Stevenson et al., 2005). From the above we concluded that it is important to make the right choice when PPC approach is concerned. The ability to accommodate customization is a key test of applicability of the PPC approaches. This fit between PPC methods and environments has been examined by Stevenson et al., (2005) and Jonsson & Mattsson (2003). The latter also presented a list of variables they deemed relevant from a production planning and control perspective. In their article Koh & Saad (2006) also discuss the influences of uncertainty on production planning and control. In the following sections we explore and discuss the aspects of production planning and control as identified above; environment, approach and influencing variables.

Based on these finding we conclude that we have to focus on aligning the production planning and control environment and the production planning and control approach. The identification of which methods is applicable in the Benchmark situation is presented in section 5.2.1, based on the work of Stevenson et al., (2005). But first let us look at variable of production planning and control environments [3.1.1], and the methods that are currently applied in managing and controlling production [3.1.2].

3.1.1 The environment and typology

As stated above, the manufacturing environment is [among other characteristics] characterized by the way demand is met (also customization) and the shop floor configuration. We [1] first elaborate on the way demand is met and [2] then we will then zoom in on the shop floor configuration. Thereafter we take a closer look at the variables deemed relevant from a production planning and control perspective by Jonsson & Mattsson (2003).

3.1.1.1 How demand is met

Some manufacturing companies deliver from finished goods inventories as reaction on customers' orders; Make-To-Stock (MTS). Others however manufacture only in response to customers' orders; Make-To-Order (MTO) (Amaro et al., 1999). A general taxonomy framework is presented by Hill (1993); he presented the following five[3] categories:

[1] Design-to-order – new product response where companies design and manufacture a product to meet the specific needs of a customer.
[2] Engineer-to-order – changes to standard products are offered to customers and only made to order. Lead-times include the relevant elements of engineering design and all manufacturing.
[3] Make-to-order – concerns manufacturing a standard product (any customization is nominal and does not increase total lead-times) only on receipt of a customer order or against an agreed schedule or call-off.

[3] Hill (1993) originally presented six categories, but we chose not to include make-to-print since it was not relevant for this project, and the type is not widely used in the PPC theory.

[4] *Assemble-to-order* – components and sub-assemblies have been made to stock. On receipt of an order (or against an agreed schedule or call-off) the required parts are drawn from work-in-progress/component inventory and assembled to order.
[5] *Make-to-stock* – finished goods are made ahead of demand in line with sales forecasts. Customer's orders are met from inventory.

These various categories all vary in terms of their customer-order-decoupling-point [COPD], the stage at which a product is linked to a specific customer order (Olhager, 2003). An earlier COPD means that an increasing degree of customization being offered. We have presented a graphical representation of the concept below.

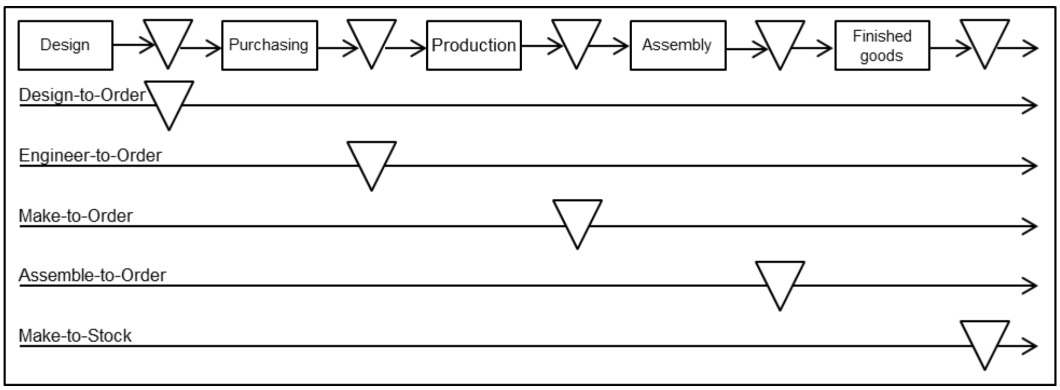

Figure 5: Graphical representation of the Order-Penetration-Point (Stevenson et al., 2005)

A more in depth approach on environmental classification [MTO specific] is presented by Stevenson et al., (2005). They further specify the MTO type by making the following classification; Repeat Business Customizers (RBC) and Versatile Manufacturing Companies [VMC]. A RBC provides customized products on a continuous basis over the length of a contract. Goods are customized but may be made more than once permitting small degree of predictability. The VMC market is more complex requiring more sophisticated solutions where each order is completed for individually and high variety of producing with variable demand are manufactured in small batches with little repetition. When plotting these types against a volume and variety scale you get the figure below.

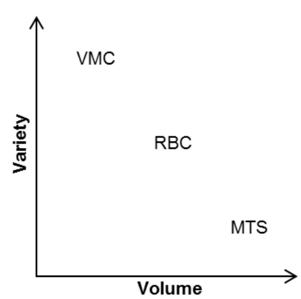

Figure 6: classifications based on volume vs. variety (Stevenson et al., 2005)

As we explain in more detail in chapter 4, Benchmark cannot be placed in one particular category. There is between customers and even within customers the presence of products that fall in various categories. The typologies in the Benchmark situation range from engineer-to-order to assemble-to-order.

3.1.1.2 Shop floor layout

The second aspect to describe the production planning and control environment is the shop floor configuration. Stevenson et al., (2005) considered four shop floor configurations these include;

[1] Pure Flow Shop [PFS[4]]

[2] General Flow Shop [GFS]

[3] General Job Shop [GJS]

[4] Pure Job Shop [PJS]

The key difference between the job shop and the flow shop is the direction of material flow:

[1] Pure Flow Shop - in a Pure Flow Shop work travels in one direction through a sequence of work centers in a strict order.

[2] General flow shop - in a general flow shop work still travel in one direction but jobs are allowed to visit a subset of work centers, permitting limited customization, relevant to RBC.

[3] General Job Shop - the general jobs shop is defined as providing for multi-directional routing, but with a dominant flow direction.

[4] Pure Job Shop - pure Job Shop routing sequences are random; jobs can start and finish at any work center allowing complete freedom and customization.

We have made an attempt on presenting a graphical representation of the various shop floor layouts [figure 5]. Though it is not possible to represent every form in an exact way, we hope you get a feeling for routing variations from the representation below.

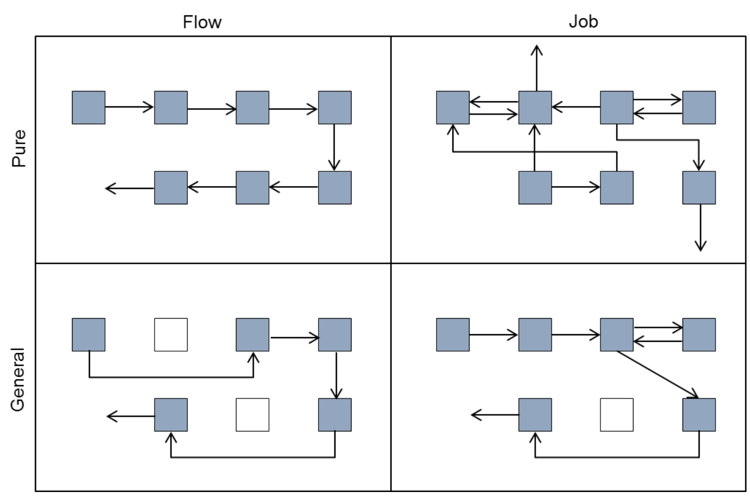

Figure 7: Graphical representation of shop floor layouts

4 Do not confuse with the product feedback system.

However, shop configuration is unlikely to lie at one of the extremes (Portioli, 2002). This is also the case in the Benchmark environment. Though in some parts in the production processes can by typified as a general flow shop, other parts show more similarities with the general job shop layout. This will be discussed in more detail in section 4.1.4.

Based on the literature there are two main aspects to typify a production planning and control environment namely based on how demand is met [the customer-order-penetration-point] and the shop floor layout. Let us now look at some more variables to better grasp the specifics of the Benchmark situation.

3.1.1.3 Variables to describe environmental dynamics and uncertainties

Now that we have identified the main components regarding the environmental typology, namely how demand is met and shop floor layout, we now focus on some detailed variables regarding the uncertainty and dynamics of an environment. As we stated in the problem identification, these aspects disturb the production planning. We therefore are going to take a closer look at these dynamics and uncertainties. Variables that help describe and better understand the uncertainty and dynamic of an environment have been identified by Jonsson & Mattsson (2003). These variables are related to the product, the demand and the manufacturing process, note that some variables related to the demand and the manufacturing process are already addressed:

The following product related variable are considered critical from a planning and control perspective:

- *BOM complexity*. The number of levels in the bill of material and the typical number of items on each level.
- *Product variety*. The existence of optional product variants.
- *Degree of value added at order entry*. The extent to which the manufacturing of the products is finished prior to receipt of customer order.
- *Proportion of customer specific items*. The extent to which customer specific items are added to the delivered product, e.g. the addition of accessories.
- *Product data accuracy*. The data accuracy in the bill of material and routing file
- *Level of process planning*. The extent to which detailed process planning is carried out before manufacture of the product.

The demand-related variables characterize demand and material flow from a planning perspective. The following variables are considered critical:

- *P/D ratio.* The ratio between the accumulated product lead time and the delivery lead time to the customer.
- *Volume/frequency.* The annual manufactured volume and the number of times per year that products are manufactured.
- *Type of procurement ordering.* Order by order procurement or blanket order releases from a delivery agreement.
- *Demand characteristics.* Independent or dependent demand.
- *Demand type.* Demand from forecast, calculated requirements or from customer order allocation.
- *Time distributed demand.* Demand being time distributed or just an annual figure.
- *Source of demand.* Stock replenishment order or customer order.

- *Inventory accuracy.* Accuracy of stock on hand data.

The third group of environmental variables characterizes the manufacturing process form a planning perspective. The following variables are included in this group:

- *Manufacturing mix*. Homogeneous or mixed products from a manufacturing process perspective.
- *Shop floor layout*. Functional, cellular or line layout.
- *Batch size*. The typical manufacturing order quantity.
- *Through-put time.* Typical manufacturing through-put times.
- *Number of operations*. Number of operations in typical routings.

These variables are used in chapter 4 to better understand and describe the dynamics and uncertainties in the Benchmark situation. A better understanding of the dynamics and uncertainties helps us to assess the model we constructed regarding to which extent it can cope with the identified dynamics and uncertainties.

3.1.2 The production planning and control approaches

Now that we have identified the various aspects of the production planning and control we now address the production planning and control approaches. During the last century a lot of production-planning approaches have been developed. They can be characterized as a pure pull, pure push or a hybrid form. Before we present examples of these methods let us first take a closer look and the concept of push and pull. For this we use the following definition presented by Hopp & Spearman (2004) to define push and pull. A *pull production system* is one that explicitly limits the amount of work in process that can be in the system. By default, this implies that a *push production system* is one that has no explicit limit on the amount of work in process that can be in the system. Harrison et al., (2005) suggest that a *push based* system should be used for products with small demand uncertainty, as the forecast will provide a good direction on what to produce and keep in inventory, and also for products with high importance of economies of scale in reducing costs. And that a *pull system* is suggested for products with high demand uncertainty and with low importance on economies of scale. Below we present five of the most popular production planning methods [categorized in push, hybrid or pull], that are being used in today's manufacturing environment.

3.1.2.1 PUSH systems

[1] Material Requirements Planning (MRP)[5]. The Material Requirements Planning is a periodic push-based system designed for complex production planning environments. MRP is one of the widely used packages due to its universalistic approach (Stevenson et al., 2005). But Bertrand & Muntslag (1993) recognized that the use of MRP in some cases is not successful. They argue that the underlying assumptions for the approach often result in problematic issues regarding the functionality of MRP/MRPII. Company size has been identified as important in implementation strategy and success. It may be possible, to an extent, to tailor the design of MRP systems to the needs of MTO companies; however this would

[5] In this report we use a variety of terms (MRP, MRP II & ERP) to describe this approach.

further add to the expense. The capital investment and the impact on SMEs of a failed ERP implementation strategy may be a barrier to entry for ERP into some SME dominated markets.

3.1.2.2 HYBRID systems

[2] Workload Control. Workload control (WLC) is one of the few concepts that has been designed specifically for SMEs production on receipt of a customer order, and has been extensively researched (Land, 2004). According to this concept, SMEs require simple PPC frameworks that are structured along the main decision points in the flow of orders, i.e. order acceptance, release, and dispatching. Besides, robustness is regarded as an important requirement for the PPC approach in SMEs (Land & Gaalman, 2009). Despite its applicability, the wide range of WLC concepts varying in sophistication and performance in different shop conditions does however add an extra dimension to the system selection problem. Further research on parameter setting and other aspects is still required.

3.1.2.3 PULL Systems

[3] Constant-Work-In-Progress (CONWIP). CONWIP is a continuous shop floor release methods. Cards regulate the flow of work, but are not ' part number specific' instead they are 'job number specific' staying with a product or batch through the whole length of the process, making it more manageable method when there is high variety. Though CONWIP is highlighted as an approach of greater applicability to the MTO industry than Kanban, it is again questionable whether the hierarchical control system can provide the necessary control at the customer enquiry, job entry and job release stage.

[4] Theory of Constraints. The theory of Constraints is a bottleneck-oriented concept. The approach was developed based on Optimized Production Technology, and is now more commonly known as the Drum-Buffer-Rope (DBR) approach. Under this philosophy, the production process is scheduled to run in accordance with the needs of the bottleneck(s), as the bottleneck (constraint resource) determines the performance of the whole production system. A research from Mabin & Balderstone (2003) shows that companies benefit from lead-time reduction, cycle time reduction and increased revenue.

[5] KANBAN. KANBAN is a card-based production system that aims to cut inventory and flow times, where the start of one jobs is signaled by the completion of another. There are many variations but in its simplest form, cards are part number specific. Determining the number of Kanban cards is a major strategic decision, balancing WIP, flow times and utilization. Kanban needs continuous flow or large batches, a limited number of parts, few set ups and low demand variability to be an effective system (Stevenson et al., 2005). It is clear that Kanban cannot cater for the routing variability and lack of repetition predominant in MTO manufacturing.

Now we have looked at the two main aspects in selecting an applicable approach namely, the environmental typology and the selected approach. We have identified various aspects of an environment and have looked at the most widely used methods.

3.2 Introduction to system theory

For identifying the problems regarding controlling the process of production planning and control we use, as stated earlier, the system theory. The reasons we chose to approach the production planning and control process as a system is one because it helps us to describe the processes in an abstract way to place it more easily in a literary context. And second because it presents a clear set of conditions that need to be met for effective control. Furthermore approaching the problem as a system helps Benchmark to see a process of change rather than snapshots when viewing the production planning and control process as a system (Senge, 1994) when they start implementation.

Before we present a further introduction we need to make an important note. Describing the Benchmark situation in an abstract and generalized way this leads to the ignorance of specific characteristics of the Benchmark environment. This, on the one hand, makes it easier for us to place it in a literary context, since theory only addresses the general and not the specific situation. But on the other hand will lead to some [practical and implementation] issues when we translate the conceptual model to the framework of methods, heuristics and rules that can be applied Benchmark [chapter **X**].

For the introduction on system theory we use the work of de Leeuw (1994). In its most simplistic form a controlling situations can be presented by a controlling body [CB] and a controlled system [CS] within an environment. In case the controlling system is in fact also a controlling body meta control is added to the situation. In case of production planning an effective planning requires a good planning and a good organization of the planning process. We have presented the two types of controlling situations in figure 8.

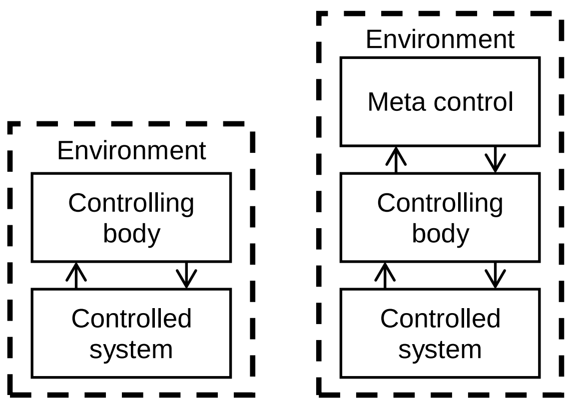

Figure 8: Basic representation of systems (de Leeuw, 1994)

When applying the controlling theory it is required to make a sharp distinction between the controlling aspect of the CS and the controlling ability of the CB. The controlling aspects relate to the solvability of the controlling task, and controlling ability relates to the capacity of the controlling body. If a CB does not meet the preconditions for effective control the control is likely to fail. The preconditions for effective control are presented below:

[1] Objectives. In any controlling situations there should be an evaluation mechanism to measure the effects of controlling measures. If this evaluation mechanism is not available no effective governing of the controlled system is possible.

[2] Model of the controlled system. To effectively control a controlled system it is required that the consequence of a controlling measure are known, since a controlling measure is selected based on its outcome.

[3] Information on the environment and the state of the system. The future state of a situation is determined, beside the controlling measure, by the environmental conditions and the actual state of the system. Therefore this information is required in selecting the most appropriate controlling measure.

[4] Sufficient controlling measures. For effective control you need to have access to a variety of controlling measures. This should be in reasonable proportion with the variety of environmental conditions that can emerge. This is also known as the law of the requisite variety.

[5] Capacity for information processing. It is required to process all the incoming information regarding the environment and the current state of the process with help of the model and taking objectives into account to transform all this into effective measures.

The precondition on capacity for information processing is linked to all other preconditions. For example evaluating the degree of goal achievement requires information processing or selecting the right controlling measure requires information as does keeping the controlling body up to date. Therefore we will now further evaluate the aspect of information processing. Suppose that we need an information quantity of K to effectively control our controlled system. It is possible to split the amount of K into n parts that can independently be processed. The information processing capacity 'C' is now increased to n*C. But for being able to split the information the various parts must be independent to each other, if this is not the case and information in one part is related to the other splitting is no option. Therefore it is much easier to process an amount of independent information that an amount of dependent information. In every controlling body the total available capacity should be used by four factors:

1) Information processing for external achievements of the system. F_o
2) Information processing for internal coordination. F_c
3) Information processing to filter incoming information. F_s
4) Information processing related to noise. F_n

If we return to our example of n elements, with each an information processing capacity of 'C', then applies the following formula: $F = n*C = F_o + F_c + F_s + F_n$. In this formula the required minima $F_{o,min}$ min and $F_{c,min}$ are determined by the controlled system as a result of the given objective and environmental conditions. What the controlling body does with all this is dependent on: 1) number and capacity of the constituting elements, 2) the quality of the organizational structure, 3) quality of the information supply and 4) the level of noise and disturbance created by itself. In a mathematical form the precondition regarding the capacity of information processing can be presented by $F_{effective} \geq F_{o,min} + F_{d,min}$. $F_{effective}$ can be increased by:

1) Increasing capacity by increasing the number of elements
2) Eliminate the production of noise and disturbance

3) Improve information supply
4) Optimize the organizational structure.

The problem with increasing capacity by increasing the number of elements is that in some cases by adding extra elements the internal noise production and the increased coordination needed to control the system might be bigger than the capacity added ($F_n + (F_c – F_{c,min}) \geq C$. As stated in section 4.1.2 this applies also to the Benchmark situation and is why the current course of action is not the solution in the long run.

Now that we have discussed the need for information processing capacity, let us now look at another aspect of systems: complexity. Complexity of systems depends on their predictability and controllability. But also the amount of information processing needed to control them and the degree in which the systems are dividable into smaller parts. We address these aspects of complexity in a subsequent order.

[1] Predictability - The level of predictability is a key aspect of the level in which a controlled system can be controlled. If the systems behavior and the environment are predictable the system is less complex. There are various levels of unpredictability:

1) Certainty: the outcome is known.
2) Risk: the probability distribution of the possible outcomes is known.
3) Uncertainty: the possible outcomes are known.
4) Unstructured uncertainty: possible outcomes are unknown.

As suggested by de Leeuw (1994) literature wrongly suggests that in unpredictability, or unstructured uncertainty, is the most complex form. However this is not the case since in a situation that is totally unpredictable it does not make sense to make predictions. However this expression should be viewed in a more nuanced light, the key message is applicable to the Benchmark situation. For one because Benchmark is trying to predict certain variables that cannot be predicted like for instance the queuing times as we have shown in a more elaborate form in section 4.1.3. And secondly because this suggests that the system should be isolated from uncertainties, how this is done in the new system is discussed in section 6.1.1.

[2] Controllability - A low controllability goes with a low level of complexity. Much effort may be put into trying to control the system, but without any result. Complex is the situation that can be controlled but requires large amount of effort. So hard to control is the situation that can be controlled but is very difficult to control.

[3] Information required for control - This point has been addressed earlier. If high levels of information is required to control the system effectively than this inseparably requires large information processing capacity.

[4] Dividable - A controlling task is less complex if it can be divided in smaller parts. But as the number of parts grow the amount of coordination efforts needed also increases. The divide ability in system theory can be done in three ways: 1) subsystems, 2) aspect systems and 3) phase systems. To determine if a system is dividable the relations within the

controlled systems, in the environment and on objective level should be examined. The level of dependency between the relations is the most critical precondition.

We use these aspects of controllability to illustrate how complex the Benchmark situation is [made] in section 4.2. Complexity is, as we show in the next chapter, one of the main problems leading to an ineffective control.

3.3 Summary

In this chapter we discussed the main aspects and key variables from a production planning and control perspective. Furthermore we introduced the basis of the system theory. The questions that we formulated for this part were:

[1] ''What does production planning and control include, what aspects are relevant from a production planning and control perspective and what variables influence production planning and control process?''

[2] ''How can current situations be described form a system theory perspective, and what suggestions does it provide for effectively controlling systems?''

Based on the definition by Stevenson et al., (2005) we know that a PPC system includes planning material requirements, demand management, capacity planning and the scheduling and sequencing of jobs. The key purposes of such functions include; reducing work in progress, minimize shop floor throughput times and lead times, lower stockholding costs, improve responsiveness to changes in demand and improve delivery data adherence.

From the review can be concluded that it is important to make good choices on which production planning and control approach to use. This decision should be made based on how applicable the approach is within the specific Benchmark production planning and control environment. We have also seen that though a lot of software producers claim to have generated widely appropriately systems, this should be given a second thought because lots of ERP implementation failures have been recognized by various researchers Muntslag & Bertrand (1993) and Koh & Saad (2006).

We have identified some of the widely applied production planning approaches and placed them on a push-pull scale. Furthermore we identified various environmental aspects like 1) the way in which demand is met and 2) shop floor layout and 3) some variable related to dynamics and uncertainty have been identified. We have also discussed the basis of the system theory by addressing how a system can be represented, which preconditions there are for effective control of the controlled system by the controlling body. And furthermore we identified some aspects that influence the complexity of the controlled system.

In the next chapter we describe the current situation based on the identified variables and aspects from question 1. And try to find the causes for the controlling problem based on the preconditions for effective control in the system theory.

Chapter 4

4. Describing and assessing the current situation

In this chapter we describe the current situation, in this description we discuss the most relevant and important variables identified in section 3.1. After we have described the current situation we are going to assess the current situation to identify the underlying causes to the problems described earlier in section 1.3. For the assessment part we use the criteria form the system theory for effective control which are stated in section 3.2. At the end of this section we are going to present the identified causes, and we present a starting point in resolving these causes.

4.1 Describing the current situation

For describing the current situation we use the conceptual representation of the system presented in figure 9 [introduced in section 3.2]. We first discuss the environment (1), than we take a further look in the meta control (2). Thereafter we describe the controlling body, and last we describe the controlled system (4).

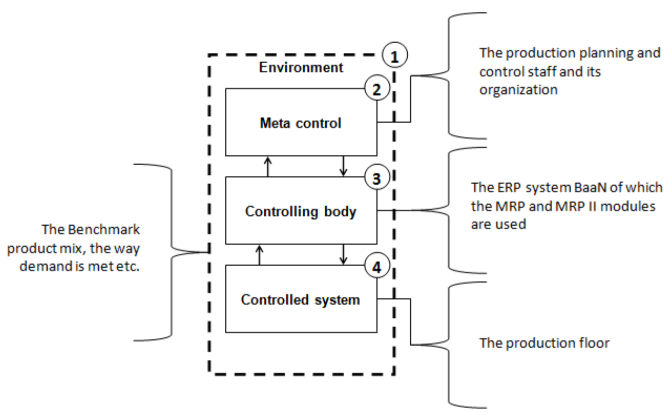

Figure 9: Schematic representation of the current system

4.1.1 The environment

In section 1.1 we presented a general description of Benchmark. In this chapter we focus more on the PPC specifics. In this section we describe primarily product and demand characteristics.

In this section we focus on the product related variables defined by Jonsson & Mattsson (2003) and how take a look at Benchmark meets demand plus the demand related variables from Jonsson & Mattson (2003). As stated in the introduction Benchmark offers customers comprehensive and integrated design and manufacturing services form initial product design to volume production including direct order fulfillment and post-deployment services. Their manufacturing and assembly operations include printed circuit boards and subsystem assembly, box build and systems integration. This means that there is a lot of variety within Benchmark regarding the various products it delivers, this variety increases the dynamics of the environment.

Besides variety in the products there is also variety in how demand is met. In some cases Benchmark develops the products for their customers, but sometimes the customer already provides a product design and appropriate Bill-of-Material. At Benchmark we can find a variety of customer-order-decoupling-points in the various products. Some are Engineered-to-Order, most are Make-to-Order and in some cases products are Assembled-to-order. With regard to the Engineered-to-Order and Make-to-Order process Benchmark has similarities with the Repeat Business Customizers described by Stevenson et al., (2005). It should be noted that in their typology Stevenson et al., (2005) describe RBCs who produce on a continuous basis over the length of a contract, this is not the case at Benchmark where no continuous demand is found.

At Benchmark new product introduction take place continuously, this means that in production there is a mix of various types of products. Some products are produced on a routine based in large volumes while others are in the infancy stages of introduction. All these products are alternately produced on the same production lines, creating a large variety for production.

Thus the Benchmark environment contains lot of dynamics and multiple ways in which demand is met. Therefore Benchmark cannot be placed in one of the typologies identified in chapter 3. Furthermore Benchmark falls in the category of a small and medium sized company that falls under the corporate legislation of Benchmark Electronics inc. Corporate has a big influence on the way processes are organized, and software packages are used. Some of the examples are the use extensive use of BaaN, the introduction of the PFS or the KPIs that are monitored. The impact corporate has on Benchmark Almelo results in some restrictions regarding reorganizing the processes.

Based on the above we can conclude that the Benchmark environment is very dynamic and consists a lot of variety. This is a challenge for manufacturing to comprehend. As stated in section 1.4 Benchmark is not going to change its current environment.

4.1.2 The production planning approach [meta control]

Generally each client at Benchmark has their own production planner, the larger client like ASML have two planners to plan their orders. All these planners use a hierarchical approach on their production plan. Planners produce an aggregated production plan, with a time frame of 1-4 months, based on customer projections or confirmed orders. After a projected order is confirmed sales orders are put in the ERP system, and with a time frame of 2-4 weeks a detailed production plan is made.

On the aggregated plan a rough cut capacity check is done to make sure the aggregated plan will not lead to capacity demand exceeding actual capacity in extreme amounts. Beside capacity also checks is done on possible MRP limitations [*some products parts have long lead times]*. These checks are done using a simulation tool called RapidResponse[6]. The simulation in RapidResponse is send to the buyers involved and the capacity planners for approval. The buyers or the capacity planners do their checks and can accept or decline the proposed production planning. Capacity planners will check if the capacity limitations are not exceeded, and buyers will focus on lead-time constraints for the various parts need for the specific production orders. If it is declined the planner needs to make adjustments until it is accepted.

The complex task of planning the production is divided in many parts, which are operated independently. So the production plans are assessed individually and little or no coordination effort is done to align the various production plans per customer. To clarify this situation we have presented a simplified representation of the situation in figure 10.

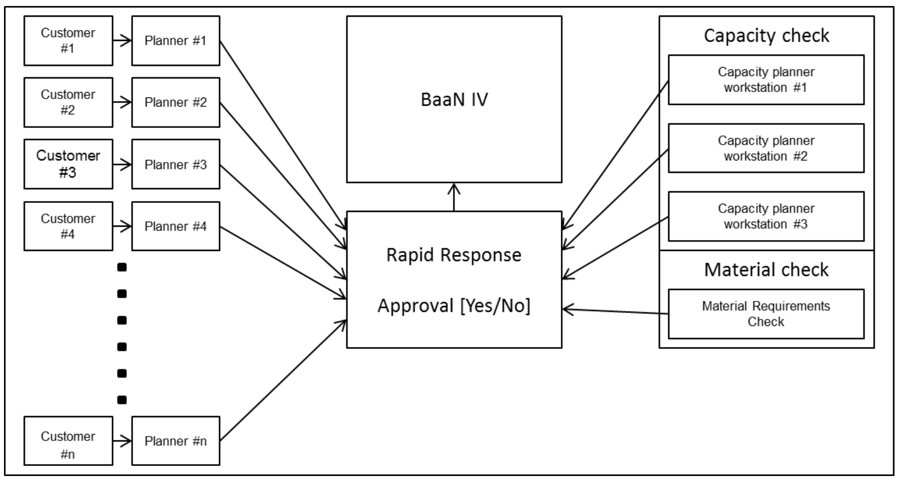

Figure 10: Simplified representation of planning methodology

4.1.3 The production planning method [controlling body]

For their production planning Benchmark is using the ERP system BaaN V. When a sales order is received from the customer this is divided in multiple production orders that all need to be scheduled, the scheduling of these production orders is done on the various production steps [these will be discussed in the next section]. Since these various production orders are dependent because one step cannot be started if the previous one is finished coordination is needed. This is the planners' responsibility, if one production step is not able to deliver in time the planner needs to reschedule the subsequent ones. Besides this a planner is also responsible for making sure his orders can be produced and thus needs to make sure they are all clear to build, if an order is not Clear-to-Build he must reschedule the orders.

The MRP approach in planning is a push based approach. The system applies backward scheduling, given its due date the system uses the products routing to determine when production should be started for production to finish on its due date. The system therefore will request for the release of a production order when the starting time of production is

[6] This is a simulation tool based on the ERP parameters, and is used to simulate various production schedules before putting them into the actual ERP system.

present. And by that pushing orders on the production floor without taken the current state of the floor into account. This leads to high levels of Work-in-Progress, since supervisors just produce as the system tells them to.

Within Benchmark the ERP system is used by various discipline but the most relevant for us are accounting and production planning. In BaaN the various products are defined by their routings, at Benchmark these routings are based on quoting models that are generated when a new product is going to be produced. Since the quote models have a strong focus on accounting the routings are often tweaked to account for indirect costs for example.

FORMS OF UNCERTAINTIES AND

[1] Inventory accuracy. The stock information is often not correct, because sometimes the routing information is incorrect. And the system declines the stock on the wrong parts, this is not critical for some smaller parts. But this can happen to more critical parts.

[2] BOM accuracy. Benchmark offers integrated design and manufacturing services, this means that products are engineered to order. Within Benchmark these products are the NPI, within these NPI BOM lists often change due to revisions to the design. This causes the BOM lists not to be accurate in the engineering stage, but they become more accurate when the engineering is completed.

[3] Product data accuracy – the routings are generated in the new product development process. At this stage the BOM is created and production steps and according production times are measured. Based on this a product specific quote model is generated. But production times in the routings may differ from actual production times. Within Benchmark the routings are primarily used for accounting purposes, which has also been recognized by Koh & Saad (2006). Less attention is paid on making them useful for production purposes [up till now]. Furthermore the routings do not accurately reflect the real world, because there is no waiting time assigned to each production step, but this waiting time is combined in a fictive lead time which is set at one week. This has some serious implications for the capacity planning. Based on conversations with involved staff I have identified the ones that are most relevant in the Benchmark situation. I have presented my main findings below.

[4] Routing accuracy. At this moment the routings are merely programmed with accounting purposes in mind. Though some workstations are programmed fairly accurate, most routings are very individualized and a lot of different workstations or defined which makes it hard to perform a capacity planning on certain workstations because they are defined in a variety of way.

4.1.4 Production [controlled system]

At the production floor four major parts of the process can be distinguished. These parts are the Surface-Mounting-Device [SMD]-lines, the hand mounting [HMT] department, the Box Build [BB] and the Clean Room [CR]. A detailed description on these production steps is omitted. All four departments all have their own supervisor that is responsible for the order execution at their department. The SMD lines and the hand mounting department also have their own capacity planners.

Based on various product routings and observations on the production floor, we observed a one direction flow of jobs but where some products only visit a subset of work centers due to customizations. Therefore we concluded that the shop floor layout is a *general flow shop* type. We have made an attempt on schematically present the production process in figure 11.

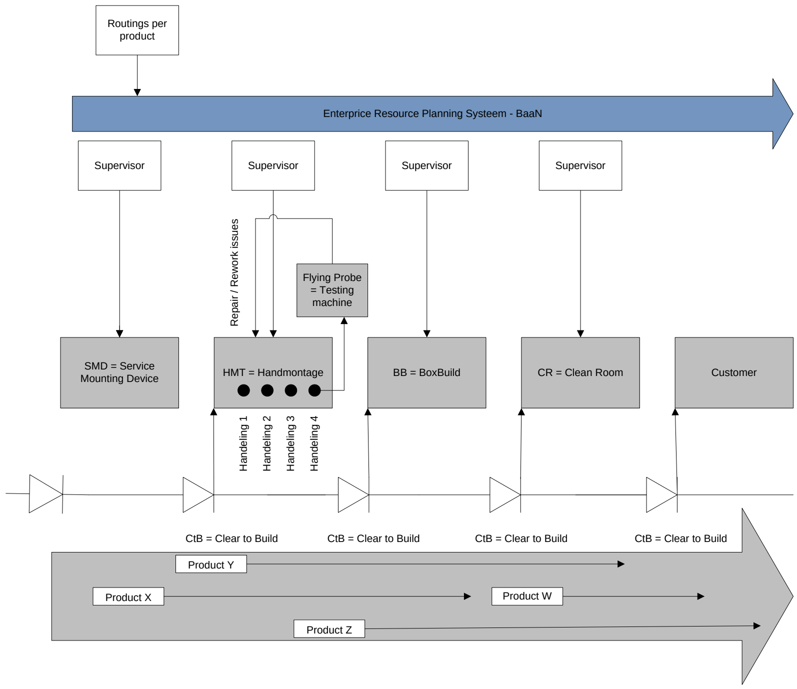

Figure 11: Generalized representation of the production flow

A distinction should be made to the SMD and HMT and the BB and CR. Most products visit only the SMD and HMT departments, or the BB and CR departments. Not often products move from the HMT to the BB department. An outflow of products is present at every department. As mentioned earlier the customer orders are split into multiple production orders, a production order can only be started if it is clear to build [however in practice this is not accepted as a hard constraint].

Another aspect that further complicates the process, besides the large variety of products, is that the products that Benchmark produces are associated with yield issues. Therefore a lot of testing is required to determine whether the printed circuit boards function properly. This on one hand makes the capacity demand on the testing machines very high, but also hard to predict since information on yield performance is not always know. In the current situation it is the testing machines that are the main bottlenecks in the process.

4.2 Identifying causes for the controlling problem

In the problem statement we have concluded that Benchmark has problems controlling the processes regarding production planning and control. As we have mentioned in section 3.2 this is caused by the fact that a controlling body does not meet the preconditions for effective control. As suggested by the system theory we need to make a sharp distinction between the controlling aspect of the CS and the controlling ability of the CB. The controlling aspects relate to the solvability of the controlling task, and the controlling ability relates to the capacity of the controlling body. In this section we first discuss the aspect of complexity in the Benchmark situation, and then we address the controlling ability of the controlling body. And we then bring those together and form our conclusions on where the main problems lie.

4.2.1 Controlling aspects of the controlled system

In section 3.2 we stated four aspects of complexity namely: predictability, controllability, information required for control and dividability. We briefly discuss these four aspects regarding the Benchmark situation.

Predictability – the level of predictability is a key aspect of the level in which a controlled system can be controlled. As we have seen in section 4.1 the Benchmark situation is full of uncertainties like for instance yield issues and supplier performance. Therefore the systems' state is hard to predict and therefore complex to manage. Benchmark is currently compensating for these uncertainties by adding high levels of safety lead time. Furthermore Benchmark is putting lots of effort in producing a production plan which is often disturbed due to the uncertainties. This disturbance is compensated by continuous rescheduling efforts.

Controllability – as stated earlier [section 4.1] much effort may be put into trying to control the system, but without any result. A situation is hard to control when it can be controlled but is very difficult to control it. The situation at Benchmark is hard to control since the high levels of dynamics, variety and uncertainties. But the misfit between the current system and the approach used makes the controllability even harder. This is addressed further when we address the preconditions for effective control.

Information required for control - to control a system by using an ERP system all detailed information about products and production processes have to be known in advance. The logic thus assumes the availability of all required information. If high levels of information is required to control the system effectively than this inseparably requires large information processing capacity. The processing capacity of the controlling body is discussed later, but as we show later is not able to process all information accurately.

Dividable - a controlling task is less complex if it can be divided in smaller parts. An important aspect to determine whether a controlling task can be split is that both parts are independent of each other. In the Benchmark situation a split is made based on customers and between the four departments of the production process. However these parts are highly dependent on each other. Thus a large amount of coordination effort is required to control the process. This coordination also increases the amount of information needed to be processed.

From the above we conclude that the complexity of the controlled system in the Benchmark situation is high. The new approach should attempt to lower the complexity of the controlling task. Let is now look at the in section 3.2 presented preconditions for effective control.

We evaluate the preconditions subsequently in the next section. After assessing the current situation based on these preconditions we identified the reasons why controlling the system fails, and thus know which problems we need to focus on and resolve. For each precondition we state what it means, then we discuss whether or not this precondition is met at Benchmark and we conclude by stating what it means for our model.

4.2.2 Controlling ability of the controlling body

In this section we discuss the five preconditions stated by the system theory for effective control.

[1] Objectives.

As stated in the introduction of the system theory there should be an evaluation mechanism to measure the effects of controlling measures in any controlling situation. If this evaluation mechanism is not available no effective governing of the controlled system is possible.

We observed a lot of KPIs being measured within Benchmark, so there is no lack of evaluation parameters. However the parameters that are currently used are focused on sub-optimalisation and do not reflect the performance of production as a whole. Therefore the planners and department supervisors are encouraged to disregard the rest of the production process and merely focus on their own performance indicators. But by that they lower the performance of the floor as a whole.

When constructing our new logistical model we have to come up with a set of performance indicators that reflect the performance of the whole system, but are also directly linked to the controlling measures that actors can take to evaluation mechanism less complex.

[2] Model of the controlled system.

To effectively control a controlled system it is required that the consequence of a controlling measure are known, since a controlling measure is selected based on its outcome.

At Benchmark the ERP system is supposed to form the model of the production floor. However in the current situation the ERP system is not a representative model of what is actually happening on the production floor. This makes it for a production planner hard to come up with the right controlling measures. As Bertrandt and Muntslag (1993) have indicated it is not possible for the deterministic ERP system to ever become a good reflection. Furthermore the whole process of production planning and control is divided into very small parts that are operated independently. However these parts are not independent at all, a decision made by one planner effects the production plan of other planners. In the Benchmark situation where the production planning is planned fairly accurate in respect to the uncertainties and dynamics. Actions taken at time T will have consequences for production at time T+1, T+2 and theoretically forever (Wortman et al., 1996). In the current situation planners do not account for the consequences of their actions on the whole production plan, only the state of their order is considered.

For the construction our model this means that for we should bring the different sections of the production process together so that the consequences of controlling measures get more insightful.

[3] Information on the environment and the state of the system.

The future state of a situation is determined, beside the controlling measure, by the environmental conditions and the actual state of the system. Therefore this information is required in selecting the most appropriate controlling measure.

This means that for one we need to have insight in the actual state of the system, and also account for the environmental conditions. As stated earlier, insight in the actual state of the system is not available because the ERP system does not provides any insight due to the way it is currently equipped [section 1.2]. Furthermore the ERP system is, as we mentioned earlier, not able to cope with the environmental conditions [uncertainty and dynamics] in the benchmark situation. As we explain in more detail in section 5.1 for using an ERP system, all detailed information about products and production processes have to be known in advance. The logic thus assumes the availability of all required information. It is in fact a deterministic production control system that cannot cope with any form of uncertainty. In the literature researchers have identified two definitions of uncertainties that are both relevant. This first is form Galbraith (1973) who defines uncertainty as: *''the difference between the amount of information required to perform a task and the amount of information already available in the organizations.''* And the other definition is provided by Koh & Saad (2006) who define uncertainty as: *''any unpredictable event that disturbs the production process.''* As we have stated in section 4.1.2 both forms of uncertainty are present in the Benchmark situation. This means that it is not possible for the ERP system to become a realistic reflection of reality and thus never can be the appropriate governing tool.

This means that for effectively controlling the production planning and control process Benchmark should limit the use of the ERP software. Furthermore the new system should make it possible to accurately understand the current state of the system based on the information currently available. Furthermore it should be able to cope with the environmental conditions.

[4] Sufficient controlling measures.

For effective control you need to have access to a variety of controlling measures. This should be in reasonable proportion with the variety of environmental conditions that can emerge. This is also known as the law of the requisite variety.

As we can conclude from the description of the current situation in the previous section there are a lot of possible environmental conditions that can occur. However the number of controlling measures is not sufficient with respect to the variety of environmental conditions. Controlling measures at Benchmark are limited to rescheduling, speeding up shipments and occasionally adjust capacity by working extra shifts or purchase new machines.

For the model this means that we should align the number of controlling measures with the variety in environmental conditions. For one by limiting the number of environmental conditions or to increase the number of controlling measures.

[5] Capacity for information processing.

It is required to process all the incoming information regarding the environment and the current state of the process with help of the model and taking objectives into account to transform all this into effective measures.

In the current situation Benchmark is using an ERP system to control the production planning and control process. Since, as we indicated earlier, the ERP system needs a lot of information to control a system. This inseparably means that a lot of information processing capacity is required. Currently Benchmark is compensating for this increased demand for information processing capacity by hiring more staff and by splitting up the processing tasks in smaller parts.

However as we concluded earlier, the process cannot be divided into smaller parts since they are dependent on each other. Therefore a controlling effort is required to align the various parts. However in the current situation this coordination is not present. As we have also shown in section 3.2 there is a limit to how many controlling elements can be put in the controlling body. Since the amount of extra coordination needed might be greater than the processing capacity of the added element.

As can be concluded form the above the controlling body clearly does not meet the requirements to effectively control the controlled system, the two major problems include:

[1] The current system requires a large amount of information to be processed so effective controlling measures can be taken.

[2] Though the total process is divided into smaller parts that are interrelated to each other but are managed like they are not leading to the absence of coordination.

We have now identified the causes of the problems that Benchmark is experiencing; we can in the next chapter look for solutions in resolving these causes.

4.3 Summary

In this chapter we have assessed the current situation by first describing it, and then identifying causes for the controlling problems currently present at Benchmark. The questions that needed to be answered in this section were:

[3] ''What is the current situation at Benchmark in terms of environment type and production planning and control approach and methodology described by the aspects and variables of production planning and control?''

[4] ''What is causing the problems regarding production planning and control that Benchmark is experiencing, based on the preconditions stated by the system theory?''

Regarding the first question we have shown that Benchmark cannot be placed in one of the types identified by Hill (1993). There is lots of variety between the customers and even between the products delivered to a certain product. Furthermore we have looked at the shop floor layout, and we concluded that it is a general flow shop with some general job shop characteristics for some product routings. Furthermore we have provided some insight in the methodology that is currently applied.

In the second part of this chapter we have assessed the controlling problems. Based on our analysis we can conclude that the controlled system is very complex, and that all preconditions are not adequately met. The main issue lies in the amount of information needed to be processed due to the current approach used, and how the controlling task is split into smaller parts.

Chapter 5

5. Literature review: Finding solutions

In this chapter the goal is to look at what the literature suggests in solving the problems at Benchmark given its current environment. The questions that need to be answered by this literature study include:

[5] Which of the identified problems have been recognized by researchers and what possible solutions are presented in the literature?''

[6] ''Given the situation and typology of the PPC environment of Benchmark and the preconditions stated in section 1.4, which logistical management system will provide the best fit?''

In section 1.4 we presented three preconditions to the new system, the first was that Benchmark wants to keep using their ERP system for their material management. Our analysis and the literature we reviewed however suggested that the use of ERP was not applicable in the Benchmark situation, and that the use of ERP should be limited in these situations. Since we assumed that Benchmark is not going to change their current environment we chose the possibilities of ERP in the Benchmark situation as the starting point for our literature review.

5.1 ERP systems in the Benchmark Environment

As mentioned in section 3.1.2 the use of ERP, MRP (II) systems in the production environments like the one at Benchmark has been widely discussed by various researchers and many reservations and concerns have been expressed. Bertrand & Muntslag (1993) concluded that in the past decades many engineer-to-order [ETO] firms have tried implementing MRP II systems, but many implementations had little or no success. Though they are specifically conducting their research with regard to ETO environments, the characteristics of the ETO environment are also present in the general Benchmark situation [e.g. important role of the customer order, the customer-specific product specifications and the product and production uncertainty]. They state that the MRP II has specifically been designed for the Make-To-Stock production environment, and showed that the production control concept underlying MRP II cannot be used in ETO production environments. To use a MRP II system, all detailed information about products and production processes have to be known in advance. The logic thus assumes the availability of all required information. It is in fact a deterministic production control system that cannot cope with any form of uncertainty. A more in depth study on this has been done by Donselaar (1989). Since Benchmark stated the precondition [section 1.4] that it want to keep using the MRP approach we need to answer the following question:

''What possibilities do software packages have with regard to production planning and control in the Benchmark situation, and what are the shortcomings of these possibilities and what requirements to these systems have?''

Koh & Saad (2006) found that lots of SME companies, in conjunction with using ERP systems as a planning and scheduling tool, combine ERP with other production planning and control concepts. This combinatorial technique shows that MRP / MRP II might be a good planning system, but might not be a good control system. In the literature we review various planning techniques available in standard software packages to determine which is most suitable in the Benchmark situation. Wortman et al., (1996) and Berry et al., (1982) have both performed an analysis on the techniques available. We have chosen to use the set of Berry et al., (1982) because these techniques are supported by BaaN V and therefore are more relevant. We presented a short introduction to the methods and discuss their information requirements below. It should be kept in mind that Benchmark has, as we observed earlier, no disposal to lots of accurate information. This is thus a critical and therefore decisive selection criterion. In their article Berry et al., (1982) discuss the following four techniques.

Capacity planning using overall factors [CPOF]. CPOF is based on planning factors involving direct labor standards for en products in the MPS. The overall manpower is estimated and allocated to individual work centers based on historical data. The planning technique, or variants of it, is found in number of manufacturing firms. The data requirements are minimal, involving primarily accounting system data instead of information such as product routing files and detailed time standards. As a consequence CPOF plans provide only approximation and not the actual time needed.

Capacity bills. The capacity bill method requires multiplying two matrices namely the ''bill of labor'' and the ''master production schedule''. This leads to an insight in capacity demanded per defined workstation over a period per of time. The capacity bills technique provides a much more direct linkage between individual end products in the MPS and the capacity required at individual work centers that does CPOF. The capacity bills technique also require more data than does CPOF. Bills of material, routings, and operation time standard data are all necessary inputs in order to develop the capacity plan using capacity bills technique.

Resource profiles. Neither the CPOF nor the capacity bills technique takes into account the time-phasing of the projected workloads at individual work centers. In resource profiles, production lead time data are added to the capacity bills data base in order to provide a time-phased projection of the capacity requirements for individual production facilities. Thus for resource profile, lead time for each end item and component part is required.

Capacity Requirements Planning [CRP]. CRP differs from resource profiles technique in for aspects. First, [1] CRP utilizes the information produced by the MRP explosion process which includes lot sizes, as well as leas times for both open and future shop orders. Second, [2] the gross to net feature of MRP system takes into account that production capacity already stored in the form of inventories of both components and assembled items. Third, [3] the shop floor control system accounts for the current status of each open orders, so that only capacity needed to complete the remaining work on open shop orders is considered in planning work center capacities. Fourth [4] CRP takes into account the independent demand for service parts. The CRP technique requires detail input information for all components and assemblies, including: MRP planned orders receipts, on-hand quantities and the current status of open shop orders at individual work centers, routing data and time standard information.

As can be concluded from the above descriptions both CRP and resource profiles are not applicable at Benchmark because the information requirements are not met. Though it is the most complete planning tool, Wortman et al., (1996) also state that: ‘’many firms are using CRP systems answering questions that could be analyzed at far lower computational cost with rough cut techniques’’. And Berry et al., (1982) state to take into account what questions need to be answered by the system. Also the CPOF is not a very appropriate method based on the fact that it does not have a direct link between end products and capacity requirements. This leaves us with capacity bills as the appropriate way of building an aggregated planning, and Benchmark does have access to the required data.

An important pitfall / problem mentioned in the literature is that the execution of the MPS is handicapped by inadequate capacity planning at individual work centers. This might lead to a situation in which the rough cut capacity check does not raise any red flags, but that in practice this is MPS can never be executed. A practical description regarding a problem with parallel machine is described by Wortman et al., (1996). This is a relevant problem since the production process at Benchmark also has a work center [called the Flying Probe] that exists of multiple parallel machines but there are routing restrictions on which product can be tested on which machine. This work centers happens to be also one of the key bottlenecks in the process, so an accurate balancing of capacity demand and capacity availability might be needed even in an aggregated phase. In appendix C we have presented a numerical example of this.

As we have identified, based on the findings of Koh & Saad (2006), ERP [MRP / MRP II] approaches might be a good planning tool and not a good control. Though not using the ERP system for all aspects might feel like a loss to many firms [due to high capital expenses on the system]. But deservedly Wortman et al., (1996) comment: ‘’planning problems in practice cannot be seen as mathematical problems only. For their solution, negotiation communication risk assessment and other human activities are essential’’. And highlight the importance of human interaction and involvement regarding production planning’’.

To answer the research question we defined earlier there are some possibilities in using the ERP system in the Benchmark situation. As Koh & Saad (2006) concluded the use of ERP should be limited to aggregate planning. There are four main techniques available to perform an aggregated production planning and as we have concluded the most appropriate technique for Benchmark would be the use of the capacity bills. This it is not the most complete method, but it answers the questions that need to be answered as we show in chapter 6. Now that we have found a solution for the planning part we need to add control to the system. This will be addressed in the following section.

5.2 Adding control to the controlling body

Now that we have identified the proper technique to use for generating an aggregated planning, we need to add a control mechanism to our controlling body. For this we need to answer the following question:

''What control approaches are currently applied in manufacturing, which one will offer the best fit with Benchmark environment and what are its informational requirements and preconditions for proper functioning?''

5.2.1 Selecting the appropriate control method

In section 3.1.2 we have presented an overview of the most widely used methods that are currently in use, also including techniques applicable in the Benchmark environment. These include the concepts of MRP [ERP, MRP II], the Theory of Constraints [TOC], Workload control [WLC], KANBAN, Constant WIP, and Paired cell overlapping Loops of Cards with Authorization [POLCA].

In selecting an appropriate approach we used the excellent review of the applicability of PPC concepts to MTO industry by Stevenson et al., (2005). They discuss the concepts that are mentioned above and their fit with various types of PPC environments. To determine the fit between the PPC environment and the approach Stevenson et al., (2005) propose five criteria:

[1] Inclusion of the Customer Enquiry stage for delivery date determinations and capacity planning.
[2] Inclusion of the Job Entry and Job Release stages, focusing on due data adherence.
[3] Ability to cope with non-repeat production, i.e. highly customized products.
[4] Ability to provide planning and control when shop floor routings are variable, i.e. general flow and job shop.
[5] Applicability to Small and Medium sized Enterprises.

The result of the analysis of Stevenson et al., (2005) is that in the PPC environment of Benchmark, which is extensively described in section 4.1.1, all the methods described are applicable. But in the opinion of the authors, workload control is the most appropriate PPC approach for MTO companies[7]. A summary of justification of preferred methods in the system selection matrix by Stevenson et al., (2005) is presented below.

MTO company type and configuration	Possible PPC methods	Reasons for preferred methods
RBC, general flow shop	WLC	WLC addresses the PPC levels required by a RBC, with some methods particularly effective in the flow shop, while WLC is likely to be cheaper than ERP
	CONWIP	CONWIP is designed for the flow shop, but does not address all PPC levels and needs some standardization of products, a RBC may not have enough standardization for CONWIP to work well
	TOC	The bottleneck(s) in a general flow shop are likely to be relatively deterministic with lower routing variation and customization than the general job shop allowing TOC to be effective, however not all PPC levels are addressed
	ERP	ERP is based on MRP and persistent issues for MTO companies apply, for example a lack of capacity planning whilst determining DD quotations at the customer enquiry stage
	POLCA	POLCA is for high routing variability, but it only addresses the shop floor and further research may be required to determine its wider applicability to the general job shop
RBC, general job shop	WLC	WLC addresses the PPC levels required by a RBC; in the job shop it will be superior to CONWIP as it can accommodate greater routing variability; in addition, some WLC methodologies are designed specifically for the job shop
	TOC	TOC buffers the bottleneck, and may be less effective in the general job shop than in the general flow shop, but routing variability is likely to be lower for a RBC than a VMC
	ERP	ERP is based on MRP and persistent issues apply, for example the lack of capacity planning whilst determining DD quotations at the customer enquiry stage
VMC, general job shop	WLC	WLC addresses the PPC levels required by a VMC; in the job shop it will be superior to CONWIP as it can accommodate greater routing variability; in addition, there are job shop specific WLC methods applicable to both RBCs and VMCs
	TOC	TOC buffers the bottleneck, although this can be applied, it is considered that, for a VMC, TOC is likely to be adversely effected by 'wandering bottlenecks'
	ERP	ERP is based on MRP and persistent issues apply, for example the lack of capacity planning whilst determining DD quotations at the customer enquiry stage; also, given that many VMC job shops are SMEs, this PPC method may be prohibitively costly

Review of production planning and control

Figure 12: Justification of preferred methods in various systems

[7] Though Stevenson et al. (2005) deem WLC to provide the best fit with almost all environments, no specific reasons are presented on why WLC provides the best fit rather than it is their opinion.

As can be derived from the above figure, also TOC might be a preferred method if routings do not vary a lot. At Benchmark we observed that in there are some workstations that are clear bottlenecks. This is because almost all product routings included these workstations are because they perform large amount of work per product. The theory of constraints provides a clear set of rules that are easy to apply and might therefore be useful to replace some of the more complex heuristics used in WLC. With combining these two methods create an approach applicable in situations with multiple / changing bottlenecks but which can be operated based on simple heuristics and rules. These heuristics and rules will be discussed later on in section 6.2. The approach of combining the TOC and WLC has been done in several other cases (Park et al., 1999 and Fry & Smith, 1987)

Though Stevenson et al., (2005) do provide some reason for the applicability of WLC to Make-to-Order / General Flow Shop environments we tried to find empirical evidence for their statement. Empirical evidence that supports the opinion of the authors is presented by Land & Gaalman (2009). On *workload control* they comment the following: ''*workload control* is one of the few concepts that has been designed specifically for SMEs producing on receipt of a customer order, and has been extensively research. According to this concept, SMEs require simple PPC frameworks that are structured along the main decision points in the flow of orders, i.e. order acceptance, release, and dispatching.'' Besides, robustness is regarded as an important requirement for the PPC approach in SMEs. Based on these findings we have selected *workload control* as the appropriate approach for PPC at Benchmark Electronics. Advantages of the system include that fluctuations in the incoming order stream are absorbed by the pool and improving lead time and due date performance due to short and predictable flow times (Bertrandt, 1983).

5.2.2 An introduction to the selected control method

In this and the following section we perform a critical assessment on the selected method; we give a detailed description, look at the disadvantages and reservation we hold toward the method and identify the key decisions that should be made when implementing the approach. For this we use the in depth analysis on the concept of workload control of Gaalman & Land which was published in (1995).

WLC conceptualizes the job shop as a queuing system. In front of each workstation, an arriving job finds a queue of jobs waiting to be processed. The principle of WLC concepts is to control the length of these queues. The main instrument for this purpose is the release decision. The release decision allows a job to enter the queue of its first workstation in the shop. Once released, a job remains on the floor until all its operations have been completed. The progress of jobs on the shop floor is controlled by priority dispatching at each station. WLC concepts do not release jobs to the shop floor if they are expected to cause queue lengths to exceed certain workload norms

It results in a pool of jobs waiting for release, as illustrated by figure 13 the waiting time in the pool is referred to as pool time and the interval between release and completion of a job as the shop floor flow times. The pool is a new object of control. Unrestricted acceptance of jobs at the entry could cause excessive pool times.

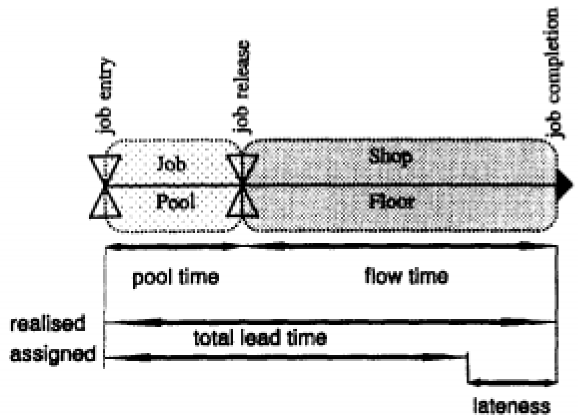

Figure 13: Lead time components

A hierarchical control concept emerges (Kingsman et al., 1989), with three levels which respectively relate to job entry, job release and priority dispatching [figure 13]. At each level two means of control are distinguished, input control and output control. Input control regulates the allowance of jobs to the next stage, respective accepting jobs for entry into the pool, releasing jobs to the shop floor, and dispatching jobs for processing. On the output side, capacity management contributes to the control of workload through regulation of the outward flow, by means of respectively medium-term or short-term, daily capacity adjustments (e.g. Park & Bobrowski,1989) In addition due date assignment or due date acceptance takes place at job entry.

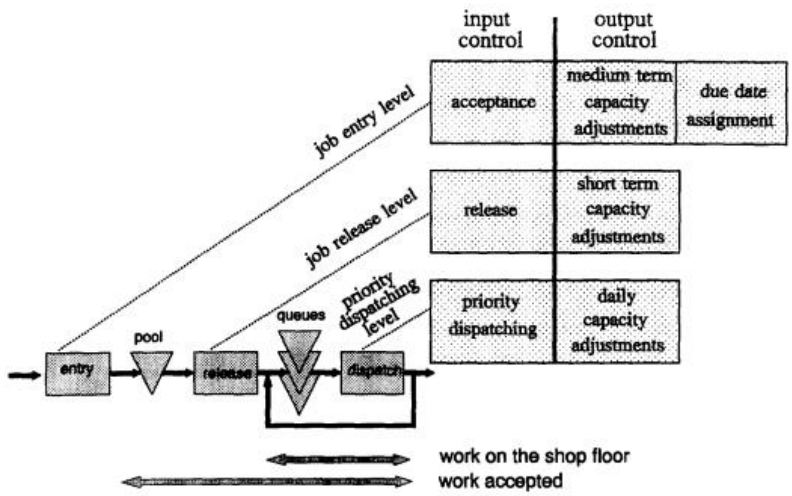

Figure 14: the hierarchical workload concept

The job entry level is very important, if one can influence the incoming orders. In that case, order acceptance and due date assignment/acceptance can support the release decision, providing it with a 'releasable set' of jobs, thus keeping pool times small. In fact, the job pool between entry and release acts as the visualize imbalance between job supply and production capacities. The role of priority dispatching in WLC is a very modest one, because the choices among jobs is limited due to short queues. Generally, WLC concepts favor dispatching priorities such as first-come-first-served [FCFS] which stabilize operation flow times or due date oriented priorities which correct progress differences among jobs. These kinds of priorities facilitate a good timing of job release. At the release level the use of workload norms controls the work station queues. The control of queue lengths, resulting in sort and predictable flow times, is the key to both lead time and due date performance (Bertrand, 1983). However, the major strength of WLC concepts is withholding jobs from the shop floor, reducing average queue lengths. Besides a reduction of work-in-process, withholding jobs from shop floor has numerous additional advantages as it enables management to delay final production decisions (Irastorze & Deane, 1974). It reduces waste due to cancelled orders, facilitates later ordering of raw materials, takes away the need of expediting of rush order, tec. Fluctuations in the incoming order stream should be absorbed by the pool. Altogether, it should create a stable stationary situation on the shop floor. Only restricting queue lengths is generally not sufficient. If average queue lengths decrease but variance do not, the idle time at work stations will increase. This situation is not allowable for the common job shop, where many workstations can be temporary bottlenecks. The loads of potential bottlenecks should be kept close to a norm level instead of below a norm level. The release function which aims to short queue lengths and a reduced variability of queue lengths will be called load-balancing. Simulations of release rules with limited balancing qualities of show a deteriorated lead time performance. This had made the influence of 'controlled release' a topic of scientific research (Melnyk et al., 1991; Kanet, 1988). In practice, WLC concepts prove to have a positive effect on lead times (Wiendahl, 1992).

Various WLC concepts have been developed, Gaalman and Land (1993) have described three concepts that all differ in their release decision. The concepts that they assess include: *Bechte's WLC Concept*, *Bertrand's WLC Concept, Tatsiopoulos' WLC*. All WLC concepts use norms for the quantity of work allow on the shop floor. Though principally the objective is to control the load in the queue of each station, we observe the use of extended workload norms. Bertrand includes the work content of work upstream and Tatsiopoulos all work on the shop floor, both upstream and downstream. See figure 15, below:

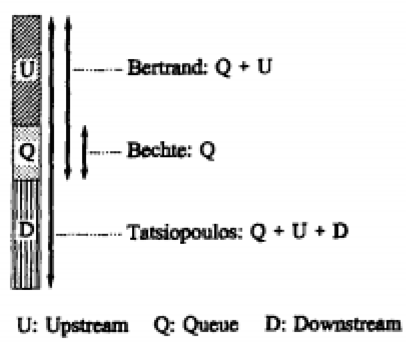

Figure 15: Three workload definitions

5.2.3 Disadvantages and reservation on the selected method

Though the WLC concept is the most appropriate concept for the Benchmark PPC environment, there are some disadvantages or issues regarding the method. We will discuss the disadvantages most relevant to Benchmark.

The first is that results after implementation might not always be an improvement. Stevenson et al., (2005) refer to this problem as the workload paradox. They stated that despite successful implementations some simulations have shown an increase in lead times when a pre-shop pool is used. Also very few successful implementations of workload control in MTO SMEs have been described in the literature (Stevenson et al., (2011).

The second reservation is linked to the precondition on easy understanding. As stated by Stevenson et al., (2005) is that probabilistic approaches tend to perform well in job shop simulations, but can over complicate planning and control in the general flow shop, while simpler representation of workload, such as the aggregate method, tend to perform better in general flow ship simulations but may lack control in the simulated job shop. Hendry (1989) & Hendry et al., (1993) have highlighted the need for the end-user to be appropriately trained so as to ensure that the planning system is used appropriately and does lead to changes in the work begin released to the shop floor. In an empirical study performed by Hendry et al., (1993) companies used for the study indicated that despite the simple logic of the WLC approach, calculations appear to be rather complicated for planners to understand.

The third issue is also discussed by Hendry et al., (1993) and regards the IT-system. They discuss both the integration with the WLC planning system and the ERP system, and also indicate that some initial problems might occur due to low IT-integration and problems with filling the database. How to deal with these issues and problems will be discussed in section 3.4.

5.2.4 Improving the selected method

During the research we had contact with an associated professor of the University of Groningen: dr. M.J. Land. He has done much research on the concept on workload control and has some experience with implementing the approach in real life. According to Land (2014) even though the system has lots of disadvantages and reservations the WLC system has not to be implemented in its pure form. In practice most companies are just using the underlying concept to gain control over their production process, and replace the complex mathematical estimations on for example the workload per work center by simple heuristics to make decisions. This was also the case in most of the implementation studies (Bertrand & Wortman 1981, Park et al., (1999), Fry & Smith (1987), Wiendahl (1995), Hendry et al. 1993, Bechte 1988, 1994).

Since we chose to combine the WLC with the ideas from the TOC, an introduction to the basic ideas developed by Goldratt & Cox (1992) is presented. The basic ideas of the TOC were initially presented in their book ‘’the Goal’’. They provide some basic approaches / principles that form the important basics for a productive production environment. Some of these will help us to replace some of the workload control heuristics [1], and the others are more of a reminder because Benchmark seems to be forgotten these, counter intuitive, rules [2, 3 and 4].

[1] ‘’The bottleneck determines the throughput of the whole system’’

In the workload concept the workload at every single work center has to be measures and when the release decision is made the workload increase for every work center should be compared to the norm. But since I have identified two clear bottlenecks, and the bottlenecks determine the throughput of the whole system, it might be sufficient to just focus on the workload of these work centers. Furthermore this implies that it is important to focus on the system as a whole.

[2] ‘’Balance flow, not capacity’’

At this stage Benchmark indicated that it wanted to use the MRP II module to, based on the aggregated planning make an capacity requirements planning. So that at every workstation capacity demand would be balanced with capacity required during that period. But though it might seem luring to isolate each process and look at it separately and analyze if it satisfies the market demand, the system should be looked at as a whole. Therefore demand should not be balanced with capacity but with flow. The flow is determined by the capacity of bottleneck. Therefore the capacity of the process is determined by the bottleneck. The bottlenecks should be placed at the beginning of a process to regulate the flow of the process. The pooling principle of the WLC approach will help Benchmark on balancing flow rather than capacity. This also implies that it is not necessary to specifically know what the capacity demands are at the other workstations.

[3] ''Just because one step does things quickly might not matter''

What matters is throughput. Machines that are the bottleneck are always struggling to keep up, and those seem like the most efficient because they are fully utilized. This on the other hand leads to that non-bottlenecks are not struggling to keep up and are therefore not fully utilized and seem to be less efficient.

[4] ''A plant in which everyone is working all the time is very inefficient''

Trying to make non-bottleneck efficient and thus keeping everyone at work is very counterproductive. Benchmark has in multiple situations during my research tried to keep performance optimal. At the SMD line some batch had been made that were not necessary at the moment, but were made to occupy the machine. And at another workstations staff was given the job of folding boxes to keep them occupied. This is not productive!

5.2.5 Information processing needs of the selected method

From a research perspective we have seen that WLC can be applied in the Benchmark environment based on the analysis of Stevenson et al., (2005) and empirical evidence from Gaalman & Land (2009), Bertrand (1983). Based on the critical assessment of Gaalman & Land (1995) the following set of rules, informational requirements and preconditions for WLC can be derived.

As stated by Gaalman & Land (1995), [1] once a job is released it remains on the floor until all its operations have been completed. This means that products should not be released that are not clear-to-built (means: that all the resources are available to produce the order). To do this accurate data is required on inventory levels and on the BOM lists, inaccuracy might lead to unjustified releases which will disturb the system. Secondly [2] they state that orders should not be released when this leads to the workload exceeding the norms. This will lead to a stationary situation of the shop floor. The need for a stationary shop floor situation will be discussed in the next section. The [3] third important aspect relates to the incoming orders. Order acceptance and due date assignment/acceptance can support the release decision when it provides a 'releasable' set of jobs. The forth [4] important aspect is that the job supply and the production capacities are balanced, which prevents the pool size from growing and pool times to increase. For this accurate information on jobs and on capacities are required.

Based on the above we can conclude that workload control will best fit with the production planning and control environment. And that some preconditions and information requirements, as stated above, are inextricably connected to the work control approach. There are also some problems and concerns stated in the literature that we need to solve.

5.3 Linking theoretical suggestions to the identified problems

In this section we reflect on the problems that we identified and the solutions are suggestions that have been provided in the literature. At the end of this section is should be clear how the suggestions from the literature are going to help solve the problems that we identified. We first look at the problems identified in the problem statement [section 1.3], we than look at the causes of these problems and then we are going to link the suggestions to these problems and elaborate on how these are going to resolve these problems.

Problems identified in the problem statement

[1] While Benchmark is doing a lot of effort putting together an achievable aggregated production plan, they are having a hard time to transform it into an executable detailed planning that could be met.

From the work of Wortman et al., (1996) we know that the execution of the MPS is handicapped by inadequate capacity planning at individual work centers. This might lead to a situation in which the rough cut capacity check does not raise any red flags, but that in practice this is MPS can never be executed. Based on this we can conclude that it is needed to adequately plan capacity at individual work centers. From the work of Goldratt & Cox (1992) and our analysis of the current situation we can conclude that we need to focus on planning capacity the bottleneck machines. How this capacity planning check should be executed is discussed in the next chapter.

Furthermore it is hard to perform an adequate capacity check in the current situation. During a capacity check the capacity available in a certain period is compared to the amount of work scheduled in that same period. However due to the high levels of work-in-progress and the way the ERP system is equipped [section 1.2] it is hard to perform such a capacity check. The workload control concept aims at controlling the levels of work-in-progress by limiting the queuing times and lowers throughput times and thus makes it possible to lower the throughput times in the ERP system making it possible to perform an capacity check.

[2] The production planning needs to be revised often [almost on a daily basis], but could not be done based on good information.

Furthermore we know from the work of Koh & Saad (2005) that uncertainty disturbs production of SMEs in the manufacturing sector, which plan and schedule their production using MRP, MRP II and ERP systems. However as we concluded form the work of Bertrandt & Muntslag (1993) we know that ERP systems are not able to cope with this uncertainty. From this we know that Benchmark should not plan and control its production by using the ERP system, and should instead use a method that can dampen this uncertainty and dynamics so a robust production planning and control approach is created. Based on the work of Stevenson et al. (2005) we know that workload control is deemed to be the most appropriate method.

The workload control concept helps to absorb external uncertainties by the pool mechanism, and also lowers the work-in-progress and by that lowering the amount of information needed to be processed to make take effective controlling efforts. However there are some reservations and disadvantages as stated in section 5.2.3.

Causes to the identified problems in the problem statement

[1] The current system requires a large amount of information to be processed so effective controlling measures can be taken.

As we concluded based on the work of Muntslag & Bertrandt (1993) we concluded that for appropriately using ERP all detailed information on the product and production should be know in advance. Leading to the large amount of information needed to be processed. From the review of Berry et al., (1992) we know that the methods of capacity bills might be appropriate for assessing the capacity checks on the individual workstations, were we can primarily focus on the bottleneck machines. Also the complex information processing from the workload control concept is replaced by simple heuristics we derived from the TOC (Goldratt & Cox, 1992) to lower the amount and the complexity of information processing, and thus lowering the information processing capacity needed for effective control. Furthermore the workload control concept creates a stationary state of the production floor. This also lowers the amount of information need to be processed to understand the current state of the system.

[2] Though the total process is divided into smaller parts that are interrelated to each other but are managed like they are not leading to the absence of coordination.

Based on the aspects of complexity stated by the system theory we concluded that the complexity of the Benchmark situation is high. Therefore dividing the controlling tasks into smaller tasks is needed. From the system theory we know that a precondition for effectively dividing the control task is low levels of dependency. In the literature a hierarchical approach is highly recommended by Wortman et al., (1996) and dividing the process along these lines simplifies the controlling task but also keeps coordination efforts needed low.

5.4 Summary

In this chapter we have built our literature framework from which we can construct our new model. The questions that we needed to answer include:

[5] Which of the identified problems have been recognized by researchers and what possible solutions are presented in the literature?''

As we have shown in the problem identification [section 1.3] the problems that Benchmark is dealing with are not uncommon for SMEs in the manufacturing industry. As we can conclude from the literature review many suggestions on how to resolve these problems are presented. In section 5.3 we have presented an overview on what suggestions the literature does regarding the identified problems and the underlying causes.

[6] ''Given the situation and typology of the PPC environment of Benchmark and the preconditions set by Benchmark, which logistical management system will be the best fit?''

Based on the literature we have concluded that for the planning part of the PPC processes the capacity bill methods is the most appropriate. And for the control part we have concluded based on the work of Stevenson et al., (2007) that workload control is the most appropriate method.

In the next chapter we are going to incorporate these systems in one conceptual model, which we translate into a practical framework of methodologies, rules and heuristics.

Chapter 6

6. Conceptual model and practical framework

In this section we construct our conceptual model that provides production planning and control manageability and on-time-delivery performance [6.1]. For this we use the knowledge from our literature review. After that we transform it into a framework of methodologies, heuristics and rules that are applicable in practice [6.2]. With regard to the translation of the conceptual model based on the theory to the framework with practical implications two notes need to be made. The first is that, as we indicated earlier, some problems might arise during implementation or some changes need to be made. Since the selected approach is based on our generalized situation. The second is that a translation cannot easily be made, since there are still gaps between the theory and practice. Lot of research is deemed to be required to bring theory closer to practice and to bring practice closer to theory (Stevenson et al., 2011). Especially some academic guidance on parameter setting is needed (Stevenson et al., 2007). We conclude this chapter with presenting a roadmap towards implementation [6.3].

6.1 Construction our conceptual model

In the literature the workload control concept is often presented like in figure 16. But since we also want to include the governing body and the communication and feedback that go on between the controlling system and the governing body we choose to combine this representation and the basic representation from the system theory presented earlier. This representation can be found in figure 16.

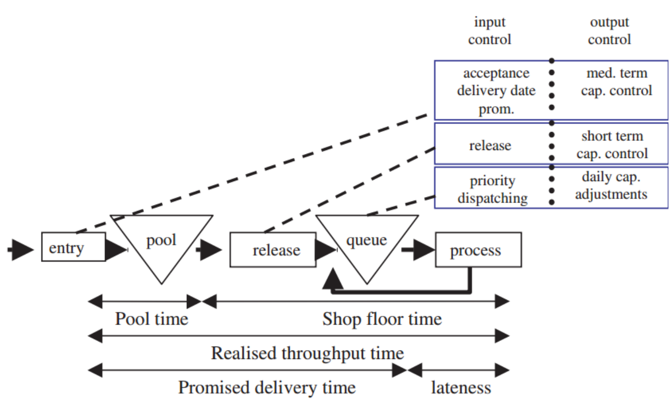

Figure 16: Representation in the literature of the WLC concept (Soepenberg et al., 2008)

We first review the new model on a very abstract level [6.1.1], and then in more detail translate the various parts of the conceptual model [figure 17] in the practical framework.

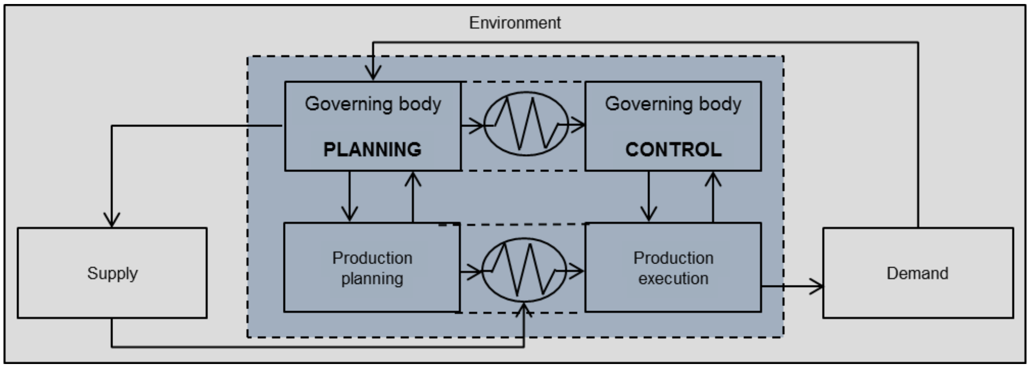

Figure 17: Systematic representation on the new concept

6.1.1 Protection from external uncertainties and dynamics

It should be recognized that we have changed the names of the controlling system into production planning and intro production execution. Both parts still form the old controlling system, we made this distinction for clarifying reasons as we explain shortly.

As can be seen we have made a clear distinction between the production planning and the production control part, these parts represent the input and output part of the system as it is described in the literature. Between both parts we have placed a suspension mechanism (or the pooling mechanism) that connect both functions. Where in the old situation the actual production was connected to the supply and demand boxes, uncertainty and dynamics thus directly influenced the production planning and continuous rescheduling efforts are needed. Now the external uncertainties and dynamics are linked to the pooling mechanism, this means that uncertainties in the demand or supply do not influence the production process directly since these uncertainties and dynamics are absorbed by the pool. This will lead to the production to be much easier to control.

In section 6.2 we describe the proposed system in more detail. For every section of the system we define the main purpose, the approach to reach its purpose, what information is required for effective performance, and what rules absolutely need to be honored for the system to operate appropriate. The concept is simplified in many ways because lots of refinements to the concept still need to be made in the literature (Hendry et al., 2008; Thürer et al., 2008).

6.2 Translating the conceptual model

In this section we make an attempt on translate our conceptual model to a framework of methodologies, heuristics and rules. We have divided the conceptual model in three sections, these include the production planning, the pooling (or suspension) mechanism and the production execution.

6.2.1 Production planning

This first part of the system [figure 18] is representing the input part of the WLC concept.

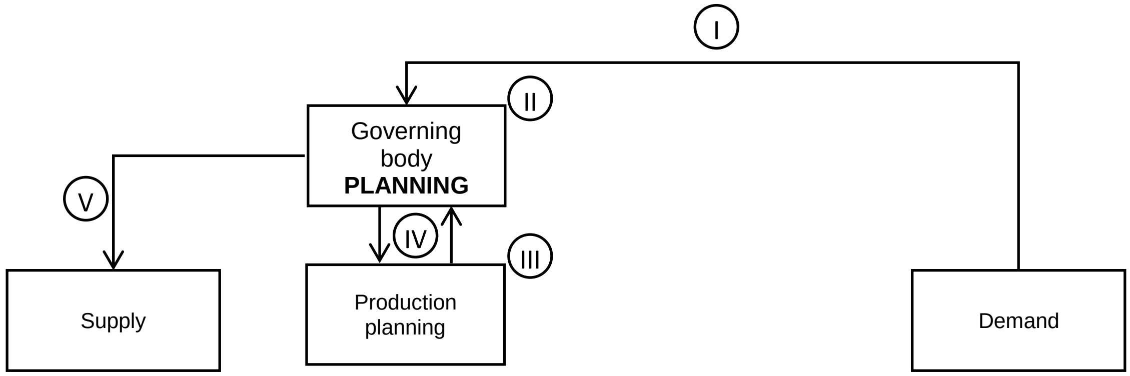

Figure 18: Production planning part of the system

Subsystems' goal / purpose

The main purpose of this part of the system is to transform customers demand (I) into and production planning (III) that is achievable based on the capacity resources available[8] at the production floor, and startup the supply process (V) on time given the supply lead times.

Approach / methodology

As concluded in the literature review the production planning can be performed using an ERP system, the best technique to do this is the capacity bills technique (II) that was described earlier. Since there are many planners that all produce their separate planning to test is, using Rapid Response, on capacity resource constraints and material requirements it is important that these various separate plans are review as a whole[!] and aligned if needed (IV).

If situations arise in which capacity demand is higher than the available resources decisions regarding priority should be made and rescheduling is needed until these problems are solved. The most critical capacity resources at Benchmark (at this moment) include the Flying Probe and the Boundary Scan workstations. This means that the capacity for these two machines is critical to plan, the rest is all secondary. Specifically for the Flying Probe this means that the workstation should be defined as three separated workstations and in the product routings it should be defined how much time is needed on every machine so they can each be reviewed separately. This will prevent problems when the aggregate planning is executed on the floor. I have explained this earlier in more detail in appendix B using an example. Though this approach is more time intensive at first, it saves lots of time rescheduling and dispatching at a later stage and prevent rescheduling actions that will increase complexity as was describe in 4.2 [2].

When the customer demand is transformed in an achievable production plan, based on the main bottlenecks this planning can be accepted and it is up to the planners to make sure that all these orders have their clear-to-build status so production can be started accordingly.

Subsystems information requirements

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[8] This does not have to be a fixed limit, but can be changed based on a human decision to increase capacity to meet certain customer demand that cannot be spread over a longer time horizon.

Capacity bill approach: Bills of material [BOM], routings, and operation time standard data are all necessary inputs in order to develop the capacity plan using capacity bills technique. Especially the operating times on bottleneck workstations are important [Flying Probe and Boundary Scan] or other workstations at which capacity cannot be easily adjusted. Also rework should be accounted for in the routings.

Capacity check: Accurate information on the routings regarding capacity requirements is needed. But also accurate information on capacity resources should be known, this does not mean that capacity should be estimated on 2 times 8 hours [16 hours] a day. But some room for uncertainty should be accounted for. A good estimation on real capacity could be checking actual output in the last 6 months, and calculate how much capacity was needed on the main bottleneck stations. Should lie somewhere around *80%* of the maximum capacity in the implementation stage.

Material check: Accurate information should be known on actual supplier lead times, and actual stock levels especially the most critical parts. Frequently reviewing and checking these is a good way to minimize uncertainty.

Important rules

[1] In the final production plan capacity demand can never be, at any moment, higher than the capacity resources. [This does not imply that capacity resources are fixed]

[2] The minimal planning horizon has to be greater than the largest routing length.

This will avoid the problem that capacity demand for certain workstations or production steps do not fall outside the planned period on which capacity is balanced.

[3] Never set available capacity at 100%, since response time will increase significantly when this is the case. To illustrate this we have plotted capacity utilization against response time [figure 19].

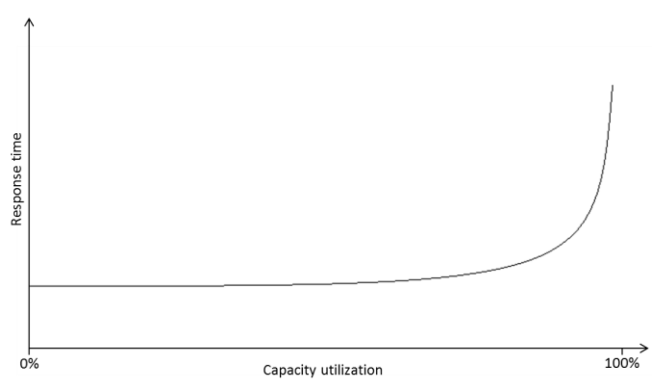

Figure 19: Capacity utilization vs. response time

6.2.2 Suspension mechanism / pool principle

This second part of the system [figure 20] is representing the pooling part of the WLC concept.

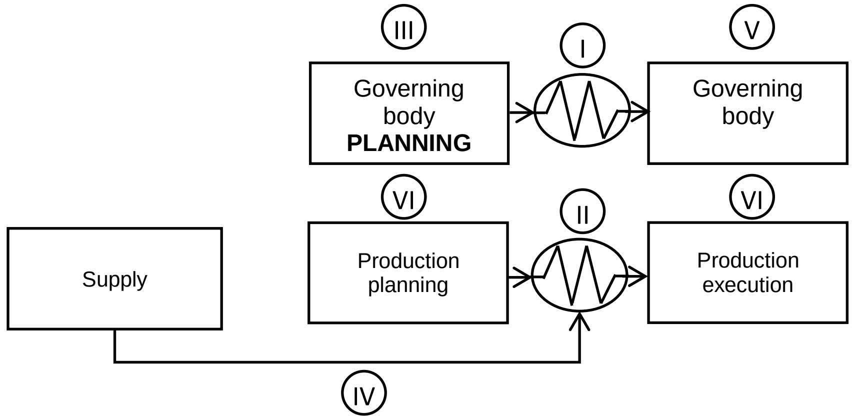

Figure 20: Suspension mechanism / pool principle

Subsystems' goal / purpose

The main purpose of this part is to link the *order push* (VI) from the production planning to the *production pull (VII)* from the production floor. The main goal here is to make sure that every production order that is planned can be executed, and thus all materials are available in time.

Approach / methodology

All control and steering is done based on the pool, the planners have to make sure that all their planned orders are clear to build (IV). If, and only if, the planned order is clear to build (III) it is put into the 'pool' (II). So the planners' goal is; to *fill the pool with a releasable set of production orders*. If a production order should be, based on its due date assignment, in the pool but is not clear-to-build this should be indicated and the responsible planner should set this as an high priority. This should both be checked in the system (I) and physically (II). This pool is the main point of control, because it visualizes the imbalance between job supply and production capacities. When the pool is expanding and increasing pool times the capacity on the production floor needs to be increased. [If the pool expands even when capacity cannot be increased, the capacity utilization is set to high in the production planning part of the system].

(I) Based on the delivery due dates and the orders in the pool accurate estimations on how much capacity is needed in a certain period can be made. In the pool the last decision regarding job sequence / priority can be made. It is important to give one person to control the pool to prevent contradictory signals sent to production, and to make final decisions based on the input of the various planners.

Subsystems information requirements

For this part of the system accurate information on whether or not orders are clear-to-build. To determine if an order is clear-to-build accurate information on the BOM and stock is required.

Important rules

[1] A planned production order can only be put in the pool if it is clear-to-build status is both checked in the system and physically.

6.2.3 Production control

This third part of the system is representing the output part of the WLC concept.

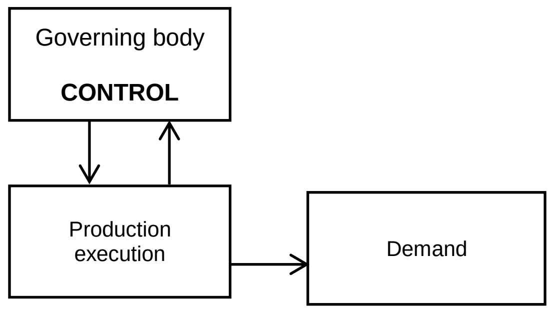

Figure 21: Production control process

Subsystems' goal / purpose

The main goal for this process is keep the production floor stationary, so that throughput times and waiting times (at the bottlenecks) are kept as constant as possible, and control the flow so pool times will not grow too big.

Approach / methodology

The most important thing in this part of the system is to only release new jobs when they do not cause the waiting times to exceed the norm. Every time period the actual number of orders in the queue before the bottlenecks has to be measured, and based on the discrepancy between the actual queue length and the norms new orders can be released on the production floor. When WLC is implemented in its pure form workload limits should be set at every workstation. But since Benchmark has two clear bottlenecks I deem it to be sufficient [especially in the first stages of implementation] to only monitor the queue lengths for the Flying Probe and Boundary Scan workstations. There are two important variables that need to be set, these include the 'workload norm' and the 'review period'. The workload limit needs to be defined as the time from the workstation is needed to process all the jobs in line. We would advise to only consider the jobs on hand (Bechte) and not the jobs downstream (Bertrand), since the load in transit is much more difficult to evaluate because it cannot be simply computed as load on hand because it is not at the work center yet, but it cannot be neglected either because sooner or later it will reach the work center (Perona & Portioli, 1998. Although research has been done regarding the impact of parameter setting (Perona & Portioli, 1998), no methods are presented to determine the optimal values. Therefore I will discuss issues regarding these norms, and will propose some initial values based on my observations at the production floor. These initial norms should be evaluated and refined in a further stage of implementation. But it should be kept in mind that parameter and norm setting is a very important issue as was concluded in the literature review.

Time period. The length of the time period greatly influences the shop performance thus it is necessary to careful set this parameter. In the literature a variety of time periods are used. In most of the case study's I found periods ranging from 1-7 days, while in most simulations release decisions were made continuously (add reference)**.** The time period on which release decisions are made is strongly dependent on how fast accurate feedback from the production floor can be generated. At the moment Benchmark has a lot of transparency issues, so almost no feedback is generated at the moment. But with the PFS system information feedback will be provided in real time, which will be of great value when using this approach. When the system operates the release decision could almost be made continuously. It should be taken into account that if the time period is to small it may cause large production orders to be delayed, releasing parts of an order might provide a solution for this problem (add reference).

Workload norm. The workload norm has a big influence on the throughput time, high workload norms lead to high throughput times and vice versa. At the earlier stage of implementation a higher workload is advised to prevent bottlenecks become idle, in later stages the norm should be lowered gradually. At Benchmark the current throughput time is, based on this I would advise to set the norm as was proposed in a case study by Perona & Portioli (1998):

$$LL_m = [\ PP + PLT_m\ ]*100/PP$$

LL_m = the load limit at work center m, expressed as a percentage of its capacity during PP

PP = the planning period for order release

PLT_m = planned lead time at work center m

Based on the pool size adjustments need to be made to the capacity resources. Since the bottlenecks are pure machines options like multi-job skilling (Koh & Saad, 2006 and Stevenson, 2006) will not be helpful. So make extra hours or putting in extra shift will be the most obvious option. The necessity of making over time should be know at the order acceptance stage.

Subsystems information requirements

For a workload system to operate accurate feedback on the completion of jobs is necessary. Based on this information the workload at the bottlenecks [and at a later stage, for every working station] can be observed, and release decisions can be made. Furthermore, if a stationary situation on the production floor has been created, throughput times will be stable. Accurate throughput times are available urgencies to release certain jobs can be made more accurately (Soepenberg et al., 2008).

Important rules

[1] Never release a job that will cause the workload to exceed the norms that are set.

[2] Once released do not change the production plan, and apply First-Come-First-Served dispatching rules.

Once released no changes should be made. Because this has consequences for the complexity (Wortman, 1996) and as is stated by Soepenberg et al., (2008) once an accurate release decision has been made the impact of dispatching and prioritizing will be minimal[9].

[9] Some dispatching rules have been examined that still improve the average lateness, for example SPT and WINQ, and some that reduce the variance of lateness like EDD and ODD (Land, 2004)

6.3 Implementation strategy, issues and roadmap

In this section a preliminary roadmap towards implementation is presented. Though it has been argued that WLC is particularly suitable for SMEs with limited financial resources, very few successful implementations of WLC in MTO SMEs have been described Stevenson et al., (2011). This means no detailed roadmap towards successful implementation is present in the literature. However Stevenson et al., (2011) have identified some key issues for successful implementation and present an implementation strategy for the workload control concept. The issues that were identified relate to general aspects of implementation, but are also directly linked to workload control. Before we present some first steps towards implementation for the Benchmark cases based on our analysis we first discuss the findings of Stevenson et al., (2011).

6.3.1 Implementation strategy

Stevenson et al., (2011) propose a three stage implementation strategy; the initial pre-implementation stage; the implementation process; and post-implementation [figure 22]. The strategy they propose is merely a starting point for the development of the more detailed roadmap to support WLC implementation.

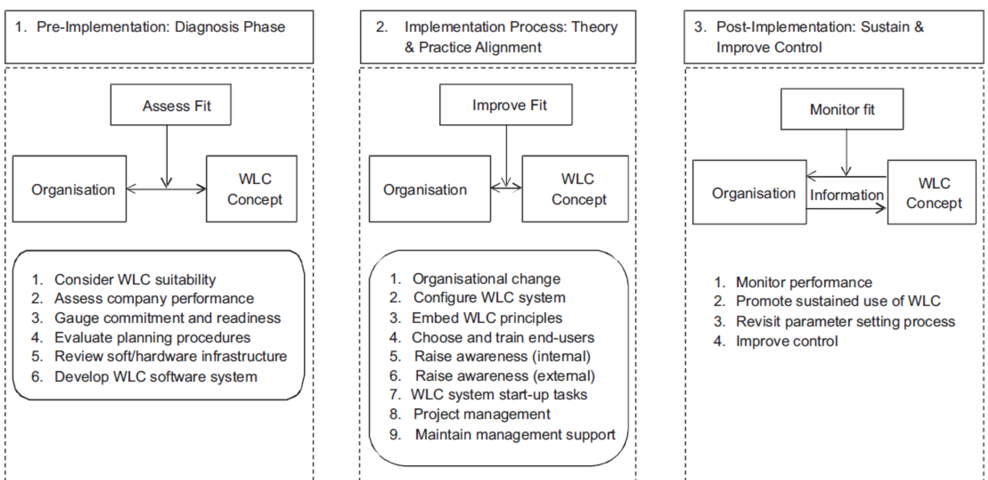

Figure 22: Implementation strategy

Pre-implementation phase: The fit between the company and concept should be assessed. This may involve evaluating the current soft- and hardware infrastructure and developing WLC software to support implementation. Commitment to the project, current business processes and prior logistic performance should also be considered.

Implementation process: If implementation is to go ahead, this should include closing gaps between theory and practice. Organizational changes may include grouping machines into a manageable number of work centers [based on interchange-ability], improving follow of information and reducing setup times. Appropriate aspects of the concept should be selected and configured for example: order release mechanisms [considering, e.g. bottlenecks, flow direction etc.] and initial parameters. WLC principles bay be embedded within existing procedures [e.g., ERP, DBR, etc.] while appropriate end-users must be chosen, trained and given access to the system. Raising awareness and training employees at all levels of the organization.

Post-implementation: This must focus on: monitoring the performance of the company and WLC system in terms of WIP throughput, throughput times, ease of use etc. Sustaining use of WLC over time and revisiting parameters as appropriate.

In this report we have addressed mostly part one of the implementation steps. And based on suggestions from the literature regarding the problems we have identified we know that workload control is an applicable production planning and control approach. Regarding to the second part of the implementation process we have provided a translation of the conceptual model to a practical framework of methodologies and heuristics. But some serious research is need to, as also stated by Stevenson et al., (2011), bring theory closer to practice and vice versa. Especially regarding setting parameters on for instance workload levels, capacity estimates etc. This report therefore is merely the start of a possible implementation process. And lots of research and effort might be needed for implementation can be a success. In the next section we discuss some of the preconditions for successful implementation and implementation issues/pitfalls that might arise.

6.3.2 Implementation issues

To improve the likelihood of successful implementation, awareness of WLC in practice should be increased. High lighting similarities between WLC and the universally recognized lean philosophy may encourage practitioners to engage with the concept. The most important factors for successful implementation defined by Stevenson et al., (2011) based on an excessive empirical study included:

- Strong leadership and championing
- Selecting an appropriate end-user for the system
- Clear understanding of the concept within the company
- Regularly monitoring the performance of the project and PPC system

In addition, top management support and anticipated benefits were the two most cited reasons for adopting a new initiative. So based on this study we can conclude that for improving implementation success it is important to gain top management support and ensure key actors are aware of the benefits WLC would bring to them and the company as a whole.

Besides these more or less preconditions a key implementation start-up challenge identified in the same study is how to set WLC parameters, particularly workload norms, for two reasons. First, because practitioners may be unaware of WLC or because they are unfamiliar with the process of setting WLC norms. And second, because the shop may be overloaded prior to implementation, meaning tight norms can be difficult to introduce. Furthermore as indicated earlier limited research into WLC parameter setting has been conducted. This is the case at Benchmark, which in combination with the culture of always accepting customer orders might pose a implementation issue that needs to be managed adequately.

6.3.3 Implementation roadmap

In the previous section we presented a implementation strategy and stated the most important preconditions for implementation and the issues that might arise during implementation. In this section we present our view on the first steps that Benchmark should take towards implementation.

[1] First it is important that Benchmark meets the preconditions stated in section 6.3.2. This means that Benchmark should first focus on involving top management for support. Some major changes are needed which are not likely to succeed without the support form top management. Support from top management can be achieved by focusing on the improvements that can be achieved by implementing workload control. For better understanding the link between the well know philosophy lean manufacturing and workload control need to be emphasized.

[2] The second step that Benchmark should take in our view is getting control over the work-in-progress levels. This is important for two reasons. The first is that whatever method is applied, it does not solve overload issues but just provides guidelines for effective control. As we have stated at the beginning of this chapter the information for adequately control the order input is available. The second reason is that, as stated in section 6.3.2, overload poses a major challenge in effectively setting workload norms. Since the workload norms lie at the foundation of the workload control concept.

Further steps and recommendations are provided in the next chapter. But achieving these first steps are crucial for successful changing the Benchmark production planning and control approaches.

6.4 Summary

In this chapter we have combined all the suggestions from the literature on the Benchmark case, and build it into our conceptual model. The main changes that it suggests is limiting the use of the ERP system and adding control in the form of the workload control concept. Furthermore we have presented a implementation strategy based on the work of Stevenson et al., (2011) and mentioned the first two steps that we deem most crucial towards successful implementation.

Chapter 7

7. Conclusion and recommendations

In this chapter we present our conclusions and provide recommendations derived from the conceptual model. It should be noted that these recommendation are mostly constructed from a academic perspective.

7.1 Conclusions

Based on our findings we conclude that the problems that Benchmark Electronics is experiencing are not uncommon in small and medium sized manufacturing companies. In the literature the problems are widely recognized and suggestions to address these problems are presented.

With regard to the workload control method a lot of simulation studies have been done, and many attempts have been made on implementing but both the simulations and the implementation reviews do not provide sufficient academic foundations for WLC in practice. Parameter and norm setting is still hard to do when applying workload control approaches in practice in a pure form. In the literature very advanced release decisions are developed and analyzed using simulations, but in practice they are often replaced with simple heuristics to make them easier to understand for the end-user. As was recognized by Stevenson (2011) a lot of research is required to fill the gaps between theory and practice. Although research has been done regarding the impact of parameter setting (Perona & Portioli, 1998) some academic guidance on parameter setting is still required (Stevenson et al., 2007).

Furthermore we can conclude that the implementation of a workload approach is a long process which requires a lot of internal will and support to succeed. A lot of resistance is present on changing PPC approach and often companies do easily slip back in their old methods. The implementation of the workload control will take at least 2-4 years according to Stevenson (2006).

7.2 Recommendations

Based on our conceptual model we now state recommendations with regard to reorganizing their PPC approach and methodology.

[1] Do not try to make BaaN V a representation of reality and accept that perfect information is not possible but also not needed within Benchmark. Though improving the current information that is available in BaaN V is nice to have, it should never become a goal. The Benchmark environment is full of uncertainties and product are high in variety, because of this a perfect information situation can never be reached (e.g. waiting times cannot be estimated, and flaws in the information will always be present). All the information that is needed to produce an aggregated is processing times of

the various products at the bottlenecks and available capacity at the bottleneck. The other information is nice to have, but is of vary low value to Benchmark but is very time consuming to estimate accurately and keep up to date.

[2] Benchmark should only act and make decisions on information that is correct. Since Benchmark has to deal with a lot of inaccurate date on which the production depends heavily like for instance inventory levels, therefore Benchmark should minimize the input need to perform its production planning and control system. Implementing the proposed model will require only accurate BOM lists, inventory levels and processing times on the bottleneck machines. Benchmark should focus its efforts on trying to make this information as accurate as possible before trying to optimize all other inputs like processing times of non-bottleneck machines or optimizing product routings.

[3] Benchmark should strive to control the process without using the ERP system before it tries to control it with the ERP system. The algorithms behind the interface are not visible and make it hard to understand what really happens. Another reason to start using simple methods rather than the ERP system is because most of the systems that Benchmark Almelo uses are not fully understood by the people. It also forces Benchmark to simplify the system as much as possible.

[4] Try to manage the system as a whole, and not as separate islands. At Benchmark a lot of measures have been made to make the job of production planning easier, by just splitting it up. But the overall control is not present at the moment. The four main production steps are planned and evaluated separately, each customer has its own planner who makes a production planning just for his client and production orders are split in various production orders (one for every main production step). Benchmark treats them all as separate parts but they are all interrelated to each other. All this makes the system very hard to manage and almost impossible to control. Benchmark should start to focus on planning the system as a whole, and this are some steps that could help in doing that:

[4.1] create the function of Master planner, one person that manages the entire pool of planners. This will help aligning the various production plans. At this moment when a planner makes a change to his production schedule this will influence that production planning of other planners, but currently the planners do not receive accurate feedback on how and to what extent.

[4.2] only produce one production order for an end product rather than a production order for every individual step. This is also needed when applying a pull method for a production planning, but will simultaneously make the throughput time more stable and predictable and lower the Work-In-Progress.

[4.3] stop measuring the efficiency at every single workstation. Sub-optimalisation does not improve the performance of the factory as a whole. According to the TOC a plant in which everyone is working all the time is very inefficient and if one workstation does its work fast might not matter for the systems throughput. Measuring efficiency will only motivate people to be less efficient. Instead new KPI’s should be set up.

[5] In this report one of the preconditions for effective control is a monitoring the consequences of controlling measures. This is also a important aspect during implementation, especially with regard to parameter setting. A tool for measuring the consequences of parameter settings is provided by Wienadahl (1988) and Soepenberg et al., (2008). The methodology

/ tools that they presented can help to diagnose causes of bad due date performance, and by that linking delivery reliability and PPC decisions (Soepenberg et al., 2008) figure 23. This can be used to test the effectiveness of parameter setting.

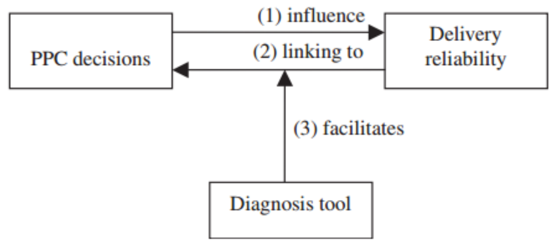

Figure 23: Relation of average lateness and variance of lateness on due date performance (Soepenberg et al., 2008)

Chapter 8

8. Discussion

In this chapter we reflect on our research and present some suggestions for further research that is needed.

When reviewing the literature we noticed that a lot of researchers are developing advanced models to optimize the production planning and control system, and assume that a state of control is present. But as we have seen in this situation, and also all case studies we have reviewed, this however is not the case. In practice a lot of companies are still struggling implementing the basics of the production planning and control research.

Furthermore we assumed for this report that Benchmark is willing, and able, to radically change the way it approaches production planning and control. However the conceptual model is applicable from an academic perspective and lots of simplifications have been made to improve the implementation success, there is a big change not the concept will never be applied. Implementation of the workload control concept is a very complex process, and based on the comments of Land (2014) during our interview and the low number of successful implementation we may conclude that implementing the proposed model might not succeed without the conditions stated in 6.3.2.

Our conclusions are drawn heavily based on the work of Bertrandt & Muntslag (1993) and Stevenson et al. (2007). From the work of Bertrandt & Muntslag we conclude the inapplicability of ERP systems in the Benchmark environment. However no other researchers were identified that complied and supported their conclusion, and much research on managing uncertainty and dynamics in ERP systems was found. For us this research it means that Benchmark is able to further improve the current state of the processes even if no radical changes are made. This approach was rejected in this research. Furthermore we chose the approach of workload control based on the analysis of Stevenson et al., (2007) but in their article they assume clearly defined PPC environments. As we have seen in our analysis the Benchmark environment cannot easily be placed in the framework they apply. Therefore our choice is selecting the workload control might require some further investigation.

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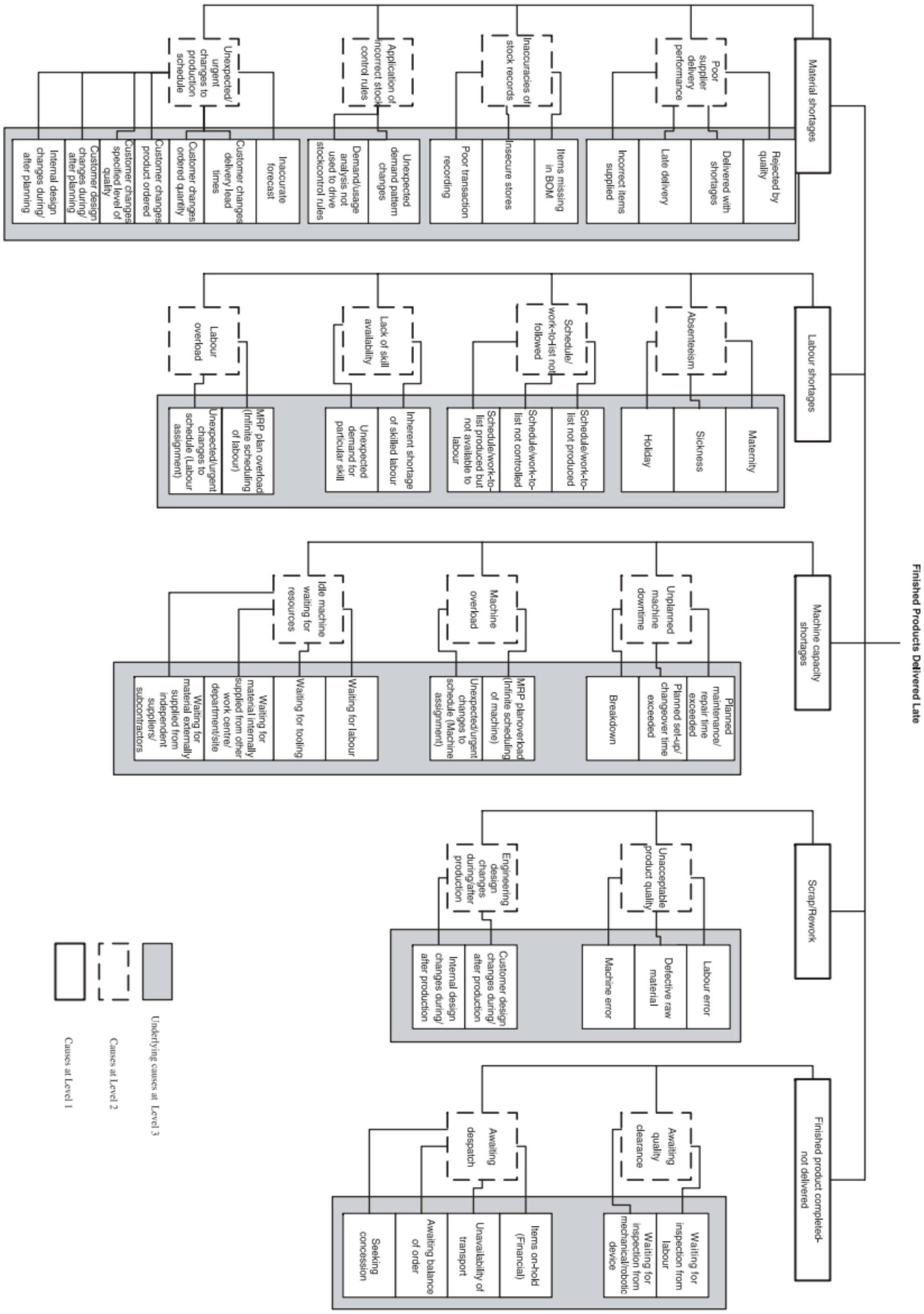
Appendix

Appendix A – Uncertainties identified



Appendix B – Example of planning problems

Before we give an example of the problems it is important to understand the Flying Probe workstation a bit more. The workstation consist of three Flying Probe machines (these test the connections on the circuit boards). These machines need to be specifically programmed to be able to test certain printed circuit boards. This means that every board can only be tested on the machines that are programmed to do this. For some circuit boards all machines are programmed, for others only two or one are programmed to test the boards.

Assume the available capacity is 16 hours a day (in real life this is less). This means that if we define the three machines as one total capacity would be 3 x 16 = 48 hours a day, or 240 hours a week (80 hours per machine). Now assume that the following products need to be produced in a given week:

		Flying Probe 1		Flying Probe 2		Flying Probe 3	
Order	Quantity	Capacity p/u	Total demand	Capacity p/u	Total demand	Capacity p/u	Total demand
Order 001	150	x		x		0.05 hours	7.5
Order 002	200	x		x		0.07 hour	14
Order 003	20	0.1 hours	2	x		x	
Order 004	1500	x		0.05 hours	75	x	
Order 005	600	0.08 hours	48	x		x	
Order 006	100	0.06 hours	6	x		x	
Order 007	800	x		0.06 hours	48	x	
Order 008	140	x		0.07 hours	9.8	x	
Total	3510		**56**		**132.8**		**21.5**

Table 1: Example of a Flying Probe production plan

If the Flying Probe station would be reviewed as one workstation than availability would be 240 hours, and if a planner would check the proposed plan in table 1 he would approve it, since total capacity available is 240 hours, and total demand asked is (56+132.8+21.5) is 210.3 hours. But when we start with this production we will see that at the end of the week we did not finish order 008 and a part of 007, because the demand on Flying Probe 2 (132 hours) exceeded the available capacity (80 hours). This would lead to backlogged orders which should be prevented as much as possible.