Master production scheduling: a function based approach

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Master production scheduling: a function-based approach

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Abstract

The Master Production Scheduling (MPS) function has grown from an MRP-driver to a management function which coordinates Production and Sales and translates the company's long term plans into detailed production decisions to control the goods flow. Therefore each company, though often implicitly, has an MPS function. The existing frameworks in literature however are not always valid to model the MPS function in different types of companies. In this paper the restricted validity is illustrated with a case and three examples. Based on the examples it is stated that the restricted validity of the existing frameworks is caused by insufficient separation of decision functions and the way they are performed. A function framework is proposed which is more suitable to model the MPS function in different types of companies.

1. Introduction

In the early days of MRP, independent demand was directly derived from forecasts. This approach increasingly caused nervousness in Material Planning for 2 reasons [1]:
- an increasing number of products led to a lower predictability of demand
- faster computers made it possible to update the MRP advises more frequently.

By means of Firm Planned Orders (Planned Orders which are fixed in timing and quantity) demand was decoupled from production to avoid nervousness. A set of Firm Planned Orders for a product can be interpreted as a first generation Master Production Schedule (MPS).

The use of an MPS made it possible to incorporate management decisions in determining production and delivery. Therefore Master Production Scheduling grew to an organisational function which coordinates Production and Marketing and translates the company's long term plans to goods flow control decisions. In literature [2-8] general frameworks were developed to model the MPS related decisions. Most of these MPS frameworks resemble the MPS framework from Berry et al. [3] (see Fig. 1). The framework is supported in most MRP software because of the stated importance of a realistic MPS for MRP-users.

Despite the considerable effort to model and to support Master Production Scheduling, only a limited number of companies actually determine what is going to be produced using an MPS function as depicted in the framework. This is amazing if one realises that every company, though often implicitly, has an MPS function. For every company has to decide when to make which products.

The restricted applicability of the MPS framework causes a problem for theory and practice. The problem for theory is that the MPS framework cannot be used widely as a model (or viewpoint) for the analysis of the way the MPS function is performed in different companies. The problem for practise is that the MPS framework cannot be used widely as a model for the design of the (information system for the) MPS function in different companies. This last problem can be illustrated by the fact that of all MRP users, only a small part actually uses a software supported MPS function which is based on the existing MPS frameworks.

In this article it is argued that restricted appli-
cability of the existing MPS frameworks is caused by insufficient separation of functions and the way they are performed. Based on research in different types of companies it is stated that a function framework is more suitable as a model to analyze how different types of companies determine what they are going to produce (MPS functions).

Section 2 of the paper describes the MPS framework as depicted in Fig. 1. In Section 3 an example is given of a company where the MPS framework is not applicable to structure the production control decisions, though the company’s production situation is in principle suitable for the use of MPS. In Section 4 the reasons for the lack of applicability of the framework are given. Section 5 suggests a function approach to model how companies determine what they are going to produce. The conclusions are presented in Section 6.

2. MPS Framework

Within production control systems, the MPS framework covers decisions which are made on a certain level of aggregation. Subsection 2.1 describes the levels within production control systems and thereby defines the environment of the framework. Subsection 2.2 explains the elements of the MPS framework.

2.1 Levels of decision making: environment of the MPS framework

In production control systems decisions are made on different levels of aggregation. The MPS framework covers the level on which the production of the company is determined. Within the framework an aggregate and a detailed level can be recognized. On the aggregate level, aggregate demand and aggregate capacity availability are confronted, resulting in an aggregate production plan. The major aim of aggregate planning is to coordinate capacity requirements and availability. At the detailed level, detailed market demand is confronted with the availability of critical capacities, which results in a production programme at item level, the Master Production Schedule. The major aim of this level is to determine in detail what the company is going to produce in the near future.

On a higher level of aggregation, top management coordinates the different company functions. The result of this coordination is a matched set of plans and budgets for marketing, manpower, investment in machines, etc. These plans and budgets are the top management input for the decisions in the MPS framework.

At a lower level of aggregation, the Master Production Schedule must be translated to detailed production decisions. The translation can be divided over 2 levels of detail [11,13]. At the
higher level planned order priorities for the different production departments (also called Production Units [11,12]) and purchased materials are generated, based on the Master Production Schedule. This level coordinates the product flow between the different Production Units within the company and is referred to as Material Order Planning. A very familiar method of Material Order Planning is MRP-I. At the lower level, for each Production Unit the planned orders are released for actual production and the orders are assigned to men and machines. The order release and assignment decisions within each Production Unit are independent of the release and assignment decisions in other Production Units. This level is referred to as Shop Floor Control [3,8,9] or Production Unit Control [3,11,14].

2.2 Elements of the MPS framework

The MPS framework (Fig. 1) consists of 5 elements. In this section a short description of each of the elements is given.

Demand Management

Demand Management is concerned with the collection and coordination of all (potential) demand on manufacturing capacity. The activities of Demand Management are forecasting, order entry and order promising. Possible sources of (potential) demand are direct customers, distribution centers, other plants of the same firm, etc.

Demand Management provides the Production Planning element with long term aggregate demand information. This demand information can consist of a long term aggregate forecast based on historical information, market information, marketing activity plan, etc. As input for Master Production Scheduling, Demand Management provides detailed forecasts and booked customer orders. Demand Management can perform order promising based on Available-To-Promise information. The production schedule (MPS) from the Master Production Scheduling element is needed to calculate the Available-To-Promise.

Production Planning

Production Planning is concerned with the preparation of an overall Production Plan. The Production Plan specifies in aggregate terms (e.g., dollars, man hours, units per product group) the monthly or quarterly production of the company. The Production Plan must be in accordance with the budgets and plans from top management. Input for Production Planning is long term aggregate demand information from Demand Management. Resource Planning provides capacity availability information within the horizon where capacity is not adaptable. If the Production Plan is stated beyond that horizon, the Production Plan is input for Resource Planning to indicate capacity adaptations. The Production Plan provides guidelines for Master Production Scheduling. The sum of the MPS quantities must equal the Production Plan. Table I gives an example of a Production Plan scheme in a situation with seasonal demand and leveled production.

Resource Planning

Resource Planning determines the availability of capacity sources of the company. Within a horizon where capacity is not adaptable, Resource Planning provides Production Planning with capacity constraints. Beyond that horizon Resource Planning translates the Marketing Plan or, if specified, the Production Plan into capacity requirements. Based on these requirements capacity availability adaptation can be evaluated.

Master Production Scheduling

Master Production Scheduling, the key element of the framework, is concerned with making an anticipated production schedule, the MPS. The MPS typically specifies the weekly produc-
tion of end products or product options, within an horizon which is larger than the stacked lead-time of the products. The MPS is based on the forecasts of Demand Management and restricted by the Production Plan. The availability check for capacity to realize the MPS is done by the rough-cut Capacity Check. The MPS determines the production plan for specific items. Therefore the MPS is transferred to Material Order Planning for execution, typically using Firm Planned Orders. In Table 2 an example of an MPS scheme is depicted, derived from Everdell [4].

Rough-cut Capacity Check

The Rough-cut Capacity Check element checks the availability of critical capacities, necessary to realize the MPS. The input for the Rough-cut Capacity Check is the MPS. A capacity profile is calculated for every critical capacity typically using bills of capacity. A bill of capacity determines per MPS-item the average usage and offset for each critical capacity. The capacity profiles may indicate that the MPS must be adapted.

3. Production control concept of the tow bar manufacturer

In the introduction it is stated that the MPS framework is not always valid to model the way a company determines what is going to be produced. To illustrate this statement an example is given of a tow bar manufacturer with a production situation, suitable to use the MPS framework. Although the company has bought all modules of an MRP software package which supports the MPS framework, the package was adapted to support a custom designed production control concept. The tow bar manufacturer does not use the MRP module and MPS module of the package.

Subsection 3.1 describes the production situation and the production control concept of the company. Subsection 3.2 explains why the MPS framework cannot be used to fully model the production control concept of the tow bar manufacturer.

3.1 Situation and control concept

The tow bar manufacturer makes 1,800 different tow bars. The bill of material of a tow bar consist of 4 levels. There is a high commonality at purchased materials level (pipes and sheets of steel). Commonality at component and assembly level is very low.

The market, car dealers and garages, requires a delivery time of a few days for most end products. Only for products which have an average demand per year of less than 25 pieces, the delivery time equals the production lead time. The seasonality in demand is high. From April to August demand exceeds production capacity by 50%. The weekly demand of most end products has a very low predictability.

The production process can be divided in 3 Production Units: a component manufacturing shop and two assembly shops. Most operations
in component manufacturing are performed using machines. The machine utilisation is ± 60%. In assembly most operations are performed manually. The utilisation of man capacity for welding is high. The maximum daily production rate for welding in 1988, based on an 8 hour working day, was 1,725 tow bars. The overtime work level is determined per period and can vary from 60% (1,035 tow bars per day) to 120% (2,070 tow bars per day). In Fig. 2 the goodsflow structure of the tow bar manufacturer is depicted.

The tow bar company has developed its own production control concept with an aggregate and a detailed level. The aggregate level is used to handle seasonality. From April to August demand exceeds production capacity. Therefore the company needs to build up capacity stock. This buildup of capacity stock is realised by making a sales plan, a production plan and an inventory plan. These plans specify quantities of tow bars per period of 4 weeks over a horizon of 1 year. The planned quantities of tow bars are aggregated over all tow bars. Table 3 depicts the plans at the beginning of 1988.

The planning procedure begins with a sales forecast per period. Based on this forecast and the target turnover for the next year a sales plan is defined. The total sales plus the difference between beginning inventory and the planned inventory at the end of period 13 is the total production in 1988. The total production is divided by the total number of working days to determine the daily output rate. In 1988 the planned output rate was 1,709 tow bars per day. Since the maximum output rate for an 8 hour day is 1,725, no capacity adaptation is necessary.

Production must follow the sales pattern as close as possible, to minimize inventory. This is realised by setting the overtime work factor per period, which is defined as:

\[
\text{overtime work factor}(t) = \frac{\text{planned number of hours per day}(t)}{8 \text{ hours per day}}
\]

The overtime work factor determines the planned output rate per period, since the working days per period and the daily output rate are already defined. After the overtime work factor is set, the production plan and inventory plan are determined. There are 2 restrictions in setting the overtime work factor. The first restriction is that the sum of the overtime work factors over all periods must equal 13. The second restriction is that the aggregate inventory must be more than 86,875 tow bars in each period. This minimum aggregate inventory is determined, assuming that a certain safety stock level is necessary to guarantee the service level:

- safety stock of 1 of the demand per year: 52,125
- average lot size inventory \( \frac{1}{2} \times 1,035 \times 8 \times 600 = 34,750 \)
- minimum inventory 86,875

The latter factor of the minimum inventory is based on the lot size in production which is \( \frac{1}{2} \) the demand per year for each tow bar.

The plans are translated to detailed level for execution. This translation is realised by means of a safety factor. The column capacity + safety stock in Table 3, is used to calculate the safety factor. The safety factor expresses the minimum aggregates safety stock plus the aggregate capacity stock in terms of the minimum aggregate safety stock. The safety factor for each period \( t \) is calculated as follows:

\[
\text{min. aggregate safety stock} = \min \{ (\text{capacity} + \text{safety stock})(t) \}
\]

![Fig. 2. Goodsfow structure of the tow bar manufacturer.](image)
### Table 3

<table>
<thead>
<tr>
<th>Period</th>
<th>Days/period</th>
<th>Overtime work factor</th>
<th>Safety factor</th>
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<th>Production plan</th>
<th>Inventory plan</th>
<th>Lot size inventory</th>
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<td>417,000</td>
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</table>

**Safety Factor**

\[
\text{safety factor (t)} = \frac{(\text{capacity} + \text{safety stock}) (t)}{\text{minimum aggregate safety stock}}
\]

Notice that the minimum aggregate safety stock used to determine the safety factor is not equal to the calculated lower bound of 51,125 tow bars. The reason for this is that the overtime work factor is not determined by the system, but is set manually.

The safety factor is a direct input for Material Order Planning. The two bar manufacturer performs Material Order Planning by means of Statistical Inventory Control techniques at all 4 levels of the bill of material. The safety factor is only used for Material Order Planning at end product level.

For end products an S- Q system is used. Every week the material planner checks which end products have an economic inventory less than the re-order level. For these end products a production order with a fixed order size \( Q \) should be released. The planner checks whether the sum of the production order quantities to be required is not larger than the maximum weekly production rate taking the overtime work factor and actual backlog in production into account. If this sum exceeds capacity, production orders are cancelled for release in sequence of longest run-out time.

The \( Q \) of an end product is set at \( \frac{1}{2} \) of the yearly sales of the two bar. The re-order level of an end product is time phased and is equal to the sum of:

- the average requirement during the total production lead time. This requirement is based on the production level instead of the sales level,
- the time phased safety stock

\[
\text{safety stock (t)} = \frac{1}{2} \cdot \text{yearly sales} \cdot \text{safety factor (t)}
\]

The safety factor is used to enlarge the safety stock component of the re-order level of the end products. This results in a build up of physical inventory of all end products when the sales volume is less than the production level.

For assemblies and components also a S- Q system is used. The re-order level \( S \) is equal to 0 and the lot size \( Q \) is equal to 1. Every day the system reviews the inventory level of the components and assemblies, and issues orders for these items if the economic inventory is less than 0. Therefore, the behavior of the inventory in these points is similar with MRP controlled stock points for component or assembly.
results in a production order for this item with a quantity equal to the quantity of the requirement. At purchased material level an $s, Q$ system is used with a review period of a week. The reorder level $s$ is based on the average use of the material during the purchase lead time and the uncertainty in demand and supply. The lot size $Q$ is determined by commercial aspects.

3.2 Applicability of the MPS framework

The case can be projected on the MPS framework of Fig. 1. The aggregate production control activities of the tow bar manufacturer are performed by the Demand Management, Production Planning and Resource Planning elements of the framework. Demand Management is responsible for making a sales plan based on aggregate forecasts and the target turnover. The sales plan is checked for man capacity availability for welding. In principle, this is a Resource Planning activity. In the framework however, Demand Management and Resource Planning are not related. Setting the level of overtime work, which determines the production plan quantities per period, is a combined Resource Planning and Production Planning activity. The elements Production Planning and Resource Planning cannot be clearly separated in the case of the tow bar manufacturer.

At detailed level no production schedule (MPS) is made to determine the production of tow bars. The "MPS element" determines the weekly production based on a reorder point technique. Based on the production level from Resource Planning a Rough-cut Capacity Check is done to check the availability of capacity for the weekly release of production orders. Demand Management performs order acceptance based on information from Material Order Planning.

It is clear that the production control concept of the tow bar manufacturer cannot be fully modeled by the MPS framework. The most severe mismatch is that the production is not determined by using an MPS. The "MPS element" in case of the tow bar manufacturer determines the weekly production based on a reorder point technique. The aspect of time phased production priority determination, by using the Master Production Schedule and time phased availability representation to the market, by using the Available-To-Promise is totally absent in the situation of the tow bar manufacturer.

4. Nature of the MPS framework

Research in different types of companies has shown that the MPS framework is not always valid. In this section examples are given of three different types of production situations in which the MPS framework is not always suitable to model the way the production of the company is determined. After the examples the reasons for the restricted applicability of the MPS framework is given.

The first example is the generalised production situation of the tow bar manufacturer. Make-to-stock companies with a large number of end products and a low predictability of weekly demand have a severe task in maintaining a production schedule (MPS) for each end product. Differences between forecast and realised demand makes frequent adaptation of the production schedule of most products necessary. Therefore, production priority determination in these companies (when they have sufficient mix flexibility) could for instance be performed using Statistical Inventory Control techniques with a capacity check. There is no obvious need for Master Production Scheduling in this situation.

In engineer-to-order companies which produce complex products, customer orders cannot be related to an existing product at the moment the order is accepted. Engineering based on customer specifications is needed to specify the product. After engineering and process planning the order can be produced. In this situation each customer order can be seen as a project [12]. Based on an aggregate network with estimated capacity requirements for engineering, process planning, component manufacturing and assembly a delivery time is promised. During the project the aggregate network is detailed by replacing aggregate activities by detailed activities. These detailed activities can be released to the engineering and production departments. Production Planning determines in this situation the time phased (monthly) capacity usage per department. Master Production Scheduling is replaced by (aggregate) multi project planning.
A third example are companies with a very low volume and mix flexibility in a certain part of their production process; for instance companies with a mechanised assembly line with very high, sequence dependent set up times. In this type of companies a schedule of the production of the different products is often determined by a fixed sequence. Master Production Scheduling and Shop Floor Control decisions are highly interdependent in this situation. These elements are no longer separated as suggested in the MPS framework.

The examples are given to illustrate that there are different ways to make the same kind of decisions. Or in other words, there are different ways to perform the same function. For instance, determining production priorities which is a function, can be performed using an MPS, using multi project planning, using the re-order advises of a Statistical Inventory Control technique, etc. So the function, or kind of decision, is relatively common and the way the function is performed is relatively specific for different production situations.

The MPS framework can be seen as a model of decision support systems for specifying a Master Production Schedule. Each element of the framework is a transaction or set of transactions to support the construction and maintenance of the Master Production Schedule. As a consequence the framework does not clearly separate functions and the way these functions are performed. This statement is illustrated for the Master Production Scheduling, Production Planning and Rough-cut Capacity Check element:
- the MPS element in the framework, does not only imply that a function must be performed which establishes production priorities, but also prescribes that a production schedule should be made;
- Production Planning performs the function of determining the total production output of a company. The production output however should be specified in a Production Plan. The Production Plan is defined as a time phased output statement for the whole company;
- the Rough-cut Capacity Check is not a function but only an activity. This element calculates the capacity consequences of the Master Production Schedule for critical workcenters.

The transaction oriented nature of the framework limits its applicability as a model for analysis and design of the way companies determine what they are going to produce. Only those companies which determine their production as prescribed in the framework can be modeled with the framework. Therefore in the next section another model is suggested, which is based on functions. For the functions themselves are more general than the way they are performed.

5. Function approach

A function model is proposed for the analysis and design of the way companies determine what is going to be produced. This model is a set of functions with their interrelations. The way a company determines the production can be projected on the functions of the model. The generality of the function model makes it possible to compare the way each function of the model is performed in different production situations. The objective of defining the function model is to determine the relationship between the characteristics of a production situation and the way the functions are performed.

In this section the function model is described. The set of functions is described in Section 5.1. The dependency of the framework structure on the characteristics of the production situation is explained in Section 5.2.

5.1 Framework of functions

Before the functions are specified, a definition is given of what is meant with the term function. A function is defined as a decision or a set of decisions to solve a (potential) conflict in assigning scarce resources.

To define the set of functions for the model the environment of this set must be determined. This environment is defined in the same way as described in Section 2.1. Top management coordinates the different functions of the company and makes budgets and plans which are input for the set of functions. On the level beneath the set of functions the Production Units are coordinated by Material Order Planning. Input from the set of functions is the determined production of the
company. Still at a lower level planned orders are released for production and assigned to men and machines. Input for this level from the set of functions is a detailed assignment of capacity, necessary to make order release decisions. The environment is depicted in Fig. 3.

The functions of the set and the relations between the functions are defined, based on 3 requirements:

1. The problem of determining the production of a company must be decomposed over functions. These functions, as a result are concerned with a part of the problem;
2. The functions should have a clearly defined responsibility, which allows each function to take decisions without iterations of decisions between functions;
3. The functions should be recognisable in as many different kinds of companies as possible.

The first requirement is actualised by decomposing the problem of determining the production to 2 viewpoints:

- level of aggregation. An aggregate and a detailed level are distinguished. The aggregate level is concerned with the capacity coordination between Production and Sales. The detailed level is concerned with the product coordination between Production and Sales;
- kind of decision. There are 3 different kinds of decisions which are distinguished: determining the sales output, determining the capacity availability and determining the production.

The second requirement is actualised by defining functions and relations in such a way that 2 function never use each others decision as input.

Aggregate Sales Determination determines the (time phased) aggregate output of the company over a horizon of 1 or more years, taking the maximum capacity level of throughput-critical capacity groups, financial targets (e.g., target profit), and market information into account.

Capacity Level Setting determines the (time phased) capacity availability level of all capacity groups over a horizon of 1 or more years, taking the aggregate sales output from Aggregate Sales Determination, the maximum capacity level of throughput-critical capacity groups, the capacity budget and capacity inventory budget into account. As a consequence this function also determines the size of the capacity inventory. Possibly, the function can make an aggregate production plan per product group. The function also negotiates with suppliers and subcontractors to determine the level of capacity that will be obtained from other companies.

Detailed Sales Determination determines the planned (time phased) sales in end product terms.

---

**Fig. 3. Environment of the set of functions.**
over a horizon which is at least equal to the stacked leadtime of purchasing and production. Within this horizon Detailed Sales Determination only determines the sales volume which is not already assigned to customer orders. In determining the sales, the function takes market information and restricted capacity, often obtained from the aggregate sales output statement of Aggregate Sales Determination, into account.

Order Acceptance determines which customer orders are accepted and which delivery lead time is given to each order. In a pure make-to-stock environment a (time phased) availability of material is input for this function. In a pure make-to-order or engineer-to-order environment the aggregate sales output, often in terms of capacity, from Aggregate Sales Determination is input for Order Acceptance.

Production Determination determines the (time phased) production in makeable product terms. The production statement is based on the sales plan of Detailed Sales Determination for the forecast driven part of the production and based on accepted orders for the customer order driven part of the production. Further the production statement is based on the capacity availability and planned capacity inventory of throughput-critical capacity groups, determined by the function Capacity Level Setting.

Capacity Assignment to Production Units determines the (time phased) detailed availability of capacity per capacity group in each Production Unit, based on the capacity availability budget per capacity group of Capacity Level Setting and based on a detailed production statement from Production Determination. In some situations the function has also the possibility to use capacity from sub-contractors or to make use of temporary workers, based on the budget of Capacity Level Setting.

5.2 Situation dependency of the function framework

The content of the function framework is determined by the production situation of a company. Dependent on the situation, functions can be absent or clustered and relations between functions can differ. In this section some examples are given of the influence of the production situation on the structure of the framework.

In some types of companies one or more functions of the framework are absent. For instance, a company which assembles simple products
manually can easily make use of temporary workers. Because of the large capacity flexibility there is no obvious need for capacity coordination. The functions Aggregate Sales Determination and Capacity Level Setting can be absent in this situation. A second example are companies in which each capacity group only occurs in one of the Production Units. These companies do not have to assign available capacity per capacity group, as determined by Capacity Level Setting, to different Production Units. Therefore the function Capacity Assignment to Production Units is absent. The capacity assignment decision is taken at Production Unit level. The third example are make-to-order and engineer-to-order companies. In this situation the function Detailed Sales Determination is absent, because the detailed sales are determined by the function Order Acceptance. The function Detailed Sales Determination only occurs if at least a part of the production is forecast driven.

In some companies functions of the framework are clustered. For instance, companies which do not allow a structural difference between sales and production level, resulting in a constant level of stored capacity, must equal their capacity output (aggregate sales) and capacity input level. So, the capacity output decision of Aggregate Sales Determination cannot be determined independent from the capacity input decision of Capacity Level Setting. Therefore the functions Aggregates Sales Determination and Capacity Level Setting are clustered in this situation. A second example are make-to-order companies which want to finish customer orders in production, at the order due date. In this case the functions Order Acceptance and Production Determination are fully interdependent. By determining the production of the customer order, the delivery time is defined. The functions Production Determination and Order Acceptance can be clustered to one function.

Another framework element which is dependent on the situation is the relation between functions. In the case of the tow bar manufacturer for instance, no relation exists between making an aggregate sales plan and determining the average sales during the production lifetime per tow bar. If the case is translated to the function framework, no relation should be defined between the function Aggregate Sales Determination and Detailed Sales Determination. A second example are assemble-to-order or make-to-stock companies which always receive orders within the fixed time fence of their Master Production Schedule and never want to adapt this MPS within the fence. In this case no relation is necessary between Order Acceptance and Production Determination, because the MPS decision is never influenced by customer orders.

The examples are given to illustrate that not only the way each function is performed, but also the structure of the framework is dependent on the situation. The framework however is likely to define a maximum of functionality, which makes it possible to model each situation with the set of functions described in Section 5.1.

6. Conclusions

A function framework is developed to model the way companies determine what they are going to produce. This model is used to analyse differences in the way companies perform the functions in the framework. The intended result is to find relations between certain characteristics of the production situation and the way a function is performed. These relations can be used for the design of the part of production control systems which determines the production in a specific situation.

Further research is needed to determine the relationship between the characteristics of the production situation and the way a function should be performed.

References


6 Plossl, G.W. and Welch, W.E., 1979. The Role of Top Management in the Control of Inventory. Reston.


