A Method for Evaluating and Diagnosing Inventory Levels

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Abstract

Very few organizations have been able to realize the full potential of Materials Requirement Planning (MRP). Since the first implementations of MRP, a wide range of problems related to MRP have been reported by both practitioners and academicians. In this article the problem of losing control over inventories is addressed. A method is developed for evaluating the aggregate inventory level, and diagnosing single product inventory levels. As a help in the diagnosis phase a rule is developed for identifying products that probably have too many items in stock. In two production units of an organization using MRP the method of evaluation and diagnosis was tested and it was found to perform very well. Causes of exceeding the norm inventory levels were found and fed back to the organization in order to initiate actions for improvement in inventory control.

Keywords: Inventory control, MRP, Performance evaluation, Performance diagnosis, Operations management.

Introduction

In the last decade considerable attention has been given to all kinds of performance measurement systems (e.g. Andersson et al. (1989), Kaplan (1983), Maskell (1991), Pritchard et al. (1988), and Kaydos (1991)). The ultimate goal of all these performance measurement systems is enhancing the organizational performance on aspects such as quality, time, and business economics. However, measuring performances is not enough to get improvements. Effective improvement actions can only be initiated after a careful evaluation and diagnosis of the measured performance. Therefore, performance measurement is just the beginning of the total improvement process (see figure 1).
In a previous literature study of performance measurement systems for production and inventory control, it was concluded that only little attention has been paid to the evaluation and diagnosis stages so far (Stoop (1992)). The literature conveys the impression that evaluation and diagnosis are more or less integrated in the performance measurement phase and not considered to be separate phases, each with its own approach. It looks as if measurement alone automatically will lead to improvements. In our research we make an explicit distinction between the phases measurement, evaluation, and diagnosis, focusing our attention on the latter two phases. More specifically, we want to investigate which methods or models are appropriate for evaluating and diagnosing performances directed at production and inventory control.

The way evaluations and diagnoses are conducted depends on the sort of problem that is to be solved. It will be clear that methods for evaluating and diagnosing quality problems in a production unit will differ from methods directed at the evaluation and diagnosis of waiting time problems in a supermarket. As a part of this research on finding appropriate models for evaluation and diagnosis directed at production and inventory control, this article deals with an inventory problem that especially can be found in organizations using complex production planning and inventory control systems. As an example of such a system Materials Requirement Planning (MRP) has been chosen.

In the next section we describe the problem and the scope of this research. Then, the improvement process directed at the inventory problem is described. In the following sections the development of the evaluation and diagnosis method is described and a numerical example is given based on empirical data. Finally, results will be discussed and conclusions will be summarized.

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Figure 1. The improvement process.
Problem definition and scope of the research

Since the introduction of the MRP concept, many organizations have implemented an MRP system. In the literature, many articles have been written about successful implementations of the concept. After these implementations, improvements in the performance with regard to production planning and inventory control are reported (see for instance Ormsby et al. (1990), Knight (1992), Plenert (1990), Sykes (1992), and Trino (1991)). However, many other organizations are reporting problems with the implementation and use of MRP. Some of these problems involve:

- an insufficient production marketing interface;
- an invalid Master Production Schedule (MPS) caused by inadequate capacity planning;
- a lack of data integrity;
- the nervousness of the system;
- an improper use of the combination of MRP functions.

These and some other problems can be found in Orlicky (1975), Malony (1990), Wheatley (1989), Patterson (1989), and Piper (1988). It should be noted that a single problem may be the source of (an) other problem(s). Due to the complex nature of MRP it is not always possible to determine the causes of some problems.

In this article we want to deal with a specific problem related to inventories. Organizations using MRP may have lost control over their inventory control system, for example as a consequence of an improper use of MRP functions or a lack of data integrity. They may observe that the number of products in the depots is increasing without knowing the exact cause(s) of the increase. The problem is that they can not determine whether the observed inventory level is high or low. In other words, these organizations do not have an appropriate inventory norm to evaluate the inventory height. A directly related problem (especially in cases of norm exceeding) is that these organizations do not have a method by which the cause(s) of the excess can be found. Because it is likely that the problems described above are problems that may occur in every organization (but especially in organizations using MRP), we developed a method for evaluating and diagnosing inventories. The evaluation and diagnosis method was developed at an organization dealing with the problems mentioned above. Because of the size of the problem we decided to do the research in just two production units of the organization. In another section we illustrate the method by using empirical data of these production units.

We consider a production unit manufacturing products out of raw materials. The concept production unit refers to a production department which in the short term is self-contained with
Figure 2. An example of a manufacturing organization to show the way the research is restricted.

respect to the use of its resources, and which is responsible for the production of a specific set of products from a specific set of materials and components (Bertrand et al., 1990). Having finished the required operations in the production unit, the products are transported to (different) depots. We assume there is an order release function that releases orders based on the suggestions of the MRP system. In this research we only take into account the depots that come directly after the production unit. This is depicted in figure 2 by the shaded objects.

Measuring, evaluating, and diagnosing inventory levels; a qualitative description

In this section we describe the process of measuring, evaluating and diagnosing related to the inventory problem stated above.

MEASUREMENT OF INVENTORIES

The first step in the improvement process is the measurement of the total (or aggregate) inventory level. This means that all the products in the depots that are processed in the
production unit are counted. It should be noted that this way of counting inventory levels is different from the conventional methods used by organizations. Whereas the conventional methods take the depots as a starting point for the counting of the inventories, we take the production unit as a starting point for the counting. When the measurement is done for all production units in the organization, the portion each single production unit contributes to the total inventory level can be determined. This may be very helpful in the evaluation and diagnosis phase, because it might be possible that the causes of having too many products in stock can mainly be found at only one or just a few production units.

The frequency of measuring (and thus also for evaluation and diagnosis) is an important issue and is very strongly related to the design of feedback systems of which the improvement process described in the introduction is an example. The choice of the frequency of measuring inventory levels depends on:

- a trade-off between the costs of measuring and the expected savings;
- the dynamics in changes of the inventory levels;
- the time period in which actions for improvement will be effectuated.

More information about considerations related to the frequency of measurements can be found in NEVEM Workgroup (1989).

**EVALUATION OF THE TOTAL INVENTORY LEVEL.**

The second step in the improvement process is the evaluation phase. In this phase the measured total inventory level is compared with a norm inventory level. Now there are three possibilities. First, the actual measured aggregate inventory level is about the same height as the norm inventory level. In that case it is not necessary to conduct a diagnosis, because it is expected that there are little or no disturbances. Second, the current total inventory level is much higher than the norm level. Here, a diagnosis will be required in order to identify the cause(s) of exceeding the norm level. Third, the observed inventory level is far below the norm inventory level. In this case it seems that it is useless to conduct a diagnosis. But, if many subsequent measurements result in a lower inventory level compared with the norm level, it would be very interesting to investigate why the inventory level stays at a relatively low level.

The norms for the total inventory level can be obtained from inventory control theory. The way the norms are being calculated for our problem will be explained in the next section. In our opinion, norm setting should be a part of the evaluation process, because a norm should also reflect the dynamics in an organization and its environment. In organizational practice, we see that norms are set in different ways. Just after implementing a measurement system it is common that
norms are "randomly" chosen by management. The norms will continuously be adjusted until one senses that a proper norm has been set. Norms can also be based on historical data. In that case, the average performance of the past on a certain aspect is used as norm. Another more recent development in norm setting is the Productivity Measurement and Enhancement System (ProMES) of Pritchard et al. (1988), where groups are setting their own norms.

It is interesting to notice that in practice norms usually are not based on theoretical results. Contrary to this finding, we strongly recommend the use of theoretical models in norm setting for the evaluation of inventories. The reasons for this recommendation will be explained in the next section that deals with norm setting in more detail.

**DIAGNOSIS OF THE TOTAL INVENTORY LEVEL**

When observing a difference between the actual inventory level and the norm level, a diagnosis should be conducted. The purpose of the diagnosis is to find the cause(s) of the observed deviation between the measured inventory level and the norm inventory level. In the remainder of this paragraph we assume that the actual inventory level is significantly higher than the norm level.

In searching for the causes of having too many products in stock, we should analyze the measured aggregate inventory in more detail. For our situation this means that we need to know which single products cause the excess of the aggregate inventory norm. Therefore, we need to know the inventory heights of each single product. After measuring all product inventories (for which the aggregate data of the first measurement can be used) each product inventory level should be evaluated. For this evaluation we also need a norm for each product's inventory height. In this way we in fact created "an evaluation within a diagnosis". The calculation of the single product's inventory level norms will be described in the next section along with the calculation of the aggregate norm.

The result of the "evaluation within the diagnosis" will be a list of products that have too much inventory at first sight. These products will be called "suspected products". The next step in the diagnosis is finding the reasons why the inventories of these products are too high. This process of finding the exact causes can not be formalized any more. Specialists within the organization (for example the order releasers) should study the product history of each suspected product in order to find strange fluctuations in the inventory level over time. The final result of the diagnosis phase will be a list of causes that is drawn up by organizational specialists.
ACTIONS FOR IMPROVEMENT

On the basis of the list of causes obtained from the diagnosis, decisions about proper actions for improvement can be made. No general rule can be given here for the kind of decisions that should be taken, because this all depends on the specific causes that are found.

Inventory norms

Inventories are the result of differences between supply and demand of products. In general, inventories consist of three components. One component of inventories is caused by the use of lot sizes. As a consequence of production efficiency considerations, products mainly are manufactured in lots. In organizations using MRP, the largest portion of inventory will be caused by the use of lot sizes. A second component of inventories is caused by the use of safety stock. Here, extra products are being stored in the depots in order to intercept uncertainties in supply and/or demand. The third component of inventories is the result of the use of safety time. Safety time is the extra time that is included in the planned lead times of orders for the purpose of completing an order in advance of its date of need. When an order is ready before the need date, the order will arrive a bit sooner in the depot, causing an increase in the inventory for that specific product. For considerations about the use of safety stock and/or safety time we refer to Wijngaard and Wortmann (1985). Because there is relatively little uncertainty in demand in MRP systems, the amount of inventory caused by safety stock and safety time is relatively low.

In figure 3a a graphical portrayal of the inventory level over time is shown for a single product. To make calculations easier to do in inventory control theory, this course is commonly being presented as in figure 3b (the sawtooth pattern). This simplified representation allows us to make theoretical calculations for norm setting that are very accurate. Because this simplified model of the development of the inventory over time is very reliable, we recommend the use of inventory control theories for obtaining norms. Whereas the other ways of norm setting may be biased by subjectivity of the persons that set the norms, the methods that

![Figure 3. Real and theoretical portrayal of the inventory level over time for a single product.](image-url)
are based on theories are unbiased. Another advantage of this way of norm setting is that it can automatically take into account the dynamics of the inventory level over time as will be shown in the remainder of this section.

**AGGREGATE INVENTORY NORM**

If one measures the inventory level of a single, arbitrary product at an arbitrary moment in time, the expected number of products in stock is half the lot size (see for example Silver and Peterson (1985)). This holds true for every single product, so the expected total inventory level equals the sum of all expected individual inventory levels. The larger the number of products involved, the more reliable the estimation will be. Because the number of products in organizations using MRP usually is very large, this estimate serves very well for an aggregate norm level.

**PRODUCT INVENTORY NORM**

In the description of the diagnosis phase it was concluded that the analysis should be carried on with an evaluation of the inventories of single products. A norm was introduced to determine which products probably have too many items in stock (the suspected products). The rule we developed for identifying suspected products is based on the following rough assumption: the total inventory of a product in a depot can never be higher than its lot size. This rough rule must be adjusted by two factors. First, the safety stock of a product should not be considered as normal inventory, because safety stock will only be used by sudden shortages. Therefore, the safety stock should be subtracted from the product inventory level. Second, the use of safety time may lead to deliveries of orders to depots that come too early. The average amount of products that are manufactured in a period equal to the safety time should therefore also be subtracted from the measured inventory. In formula, the inventory norm for a single product is: lot size + safety stock + amount delivered within safety time. Product inventories exceeding this norm will be marked as suspected.

In MRP different lot size methods can be used, for example Economic Order Quantity (EOQ), Period Order Quantity (POQ), fixed period requirements, and lot for lot (see Orlicky (1975)). Some lot sizing techniques result in lot sizes that may differ from time to time for a single product (for example POQ and lot for lot). In our rule for the inventory norm of a single product we then should replace "lot size" by "average lot size". This will be the average lot size over a long period of time (for example a year). By using lot size techniques that lead to variable lot sizes for single products, there is always a possibility that the latest lot size that arrived in a depot is larger...
than the average lot size of the product. As a consequence, this may result in more products that will be marked as suspected.

Case / example
The production and inventory control department of an aircraft manufacturer had the feeling that their inventories of manufactured products were too high, and they had no idea of how to test their suspicions. The company used an MRP system for their production planning and inventory control. The lot size technique they used was the fixed period requirements. Under this technique, it is specified how many periods of coverage every planned order should provide. Safety stock was held only for some critical products, whereas safety time was fixed at 1 week for products that are transported to depots at the same location as the production unit, and 2 weeks for products that are transported to depots at another location. In the past, when the company had no MRP system, different information systems had been used for the production planning and inventory control. Due to bad interfaces between the different systems, a cover system was necessary. Therefore, an MRP system had been bought and implemented in the organization. The current MRP system was still fed by data coming from the different information systems. As a consequence, a lack of data integrity could still be observed.

The order planning department fulfilled an essential role in the control of the inventories. Order planners were responsible for a set of products to be manufactured by a single production unit. They released orders to the production units, and therefore were considered to be the direct responsible persons for the inventories. They could change parameters such as lot sizes and minimum order quantities of orders, and might deviate from release suggestions by the MRP system. In the current situation, order planners relatively strictly followed the suggestions made by MRP to release orders, thereby not (or at least inadequately) taking into account the current inventory level of a single product and the progress of any other orders of the same product that already were in production.

To investigate whether there were too many manufactured products in stock, we chose two production units as a subject of research to develop a method for inventory height evaluation and diagnosis. The first production unit manufactured all kinds of interior parts of aircrafts, for example luggage racks and cockpit parts. Most of the products manufactured by this unit were delivered to the depot from which the products are delivered to the final assembly. The second production unit was a job shop structured turnery. Most products coming from this production unit were used in subassemblies or components. So, the turnery was one of the first units in the
total production chain and was therefore farthest away from the final assembly. Examples of products manufactured by the turnery are guards, screws, and pins.

INTERIOR SHOP

The analysis of the inventories was initiated by taking a sample of products to investigate whether the inventory level patterns resemble the pattern of figure 3b. After this check we started measuring the aggregate inventory and gathering relevant data for the evaluation (including norm setting). All these data are listed in table 1.

Table 1. Aggregate data of the interior shop.

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of different products:</td>
<td>1052</td>
</tr>
<tr>
<td>Number of orders in half a year:</td>
<td>2073</td>
</tr>
<tr>
<td>Sum of average lot sizes of all products:</td>
<td>20,910</td>
</tr>
<tr>
<td>Measured number of products used for safety stock</td>
<td>67</td>
</tr>
<tr>
<td>Measured number of products in stock:</td>
<td>11,495</td>
</tr>
</tbody>
</table>

The aggregate inventory norm was calculated by halving the sum of the average lot sizes of all products, thus in this example: $20,910 / 2 = 10,455$ products. The observed total inventory level was (with an adjustment made for the safety stock) 11,428 products. By comparing this number to the aggregate norm we reached the conclusion that the actual aggregate inventory was about 9% higher than the norm level. Taking into account all dynamics in the total inventory height, this deviation was found to be acceptable. So, we concluded that the measured total inventory was as high as could be expected. However, we will stress that this does not imply that the inventories of single products are exceeding their norm levels. Because no diagnosis was necessary for this shop, the analysis was concluded here.

TURNERY

After checking a sample of products on their inventory pattern over time, we started to measure all data that were required for the analysis of the aggregate inventory level. These required data are listed in table 2.
Table 2. Aggregate data of the turnery.

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of different products:</td>
<td>1103</td>
</tr>
<tr>
<td>Number of orders in half a year:</td>
<td>1358</td>
</tr>
<tr>
<td>Sum of average lot sizes of all products:</td>
<td>58,771</td>
</tr>
<tr>
<td>Measured number of products used for safety stock:</td>
<td>308</td>
</tr>
<tr>
<td>Measured number of products in stock:</td>
<td>55,059</td>
</tr>
</tbody>
</table>

The norm for the aggregate inventory was: 58,771 / 2 = 29,385 products. It can easily be seen that for this production unit far too much products were in stock (55,059 - 308 = 54,751 compared to 29,385). So, a further analysis at the product level was required.

By using the formula for identifying suspected products, we found as much as 307 suspected products. In table 3 we listed three examples of suspected products. The number of orders and the number of demands were based on a history of half a year (that is 24 weeks of production). An example is worked out now for calculating the norm level. This will be done for product C. The norm level is calculated by adding the mean lot size, the amount of safety stock, and the amount of products that can be delivered within the safety time, as was demonstrated in the foregoing section. The mean lot size and the safety stock can be obtained from the data in table 3. To calculate the amount of products that can be delivered within the safety time, we need to convert the total amount delivered in half a year (52 * 4 = 208 products) to a period of 2 weeks (the safety time for this product). Thus, in this case (208 products * (2 weeks / 24 weeks) = 17 products. So, in sum the norm level for product C should be: 90 + 14 + 17 = 121 products.

Table 3. Three examples of suspected products.

<table>
<thead>
<tr>
<th>Product</th>
<th>Number of orders</th>
<th>Average lot size</th>
<th>Safety stock</th>
<th>Inventory height</th>
<th>Norm inventory level</th>
<th>Number of demands</th>
<th>Average demand quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>2</td>
<td>22</td>
<td>0</td>
<td>48</td>
<td>24</td>
<td>10</td>
<td>2</td>
</tr>
<tr>
<td>B</td>
<td>1</td>
<td>1535</td>
<td>0</td>
<td>2228</td>
<td>1604</td>
<td>83</td>
<td>10</td>
</tr>
<tr>
<td>C</td>
<td>2</td>
<td>90</td>
<td>14</td>
<td>239</td>
<td>121</td>
<td>52</td>
<td>4</td>
</tr>
</tbody>
</table>

Order planners were asked to investigate what happened in the past with these products in that they caused such a relatively high inventory. Some causes that were found are:

- some very large variations in lot sizes;
- unreliable inventory transactions;
- timeliness problems (some orders were finished far too early).
It is now up to the organization to decide what actions are needed to prevent inventory problems in the future caused by the factors that were found in the analyses.

Discussion
The experiences gained with the development and use of the method for evaluating and diagnosing inventories in the two production units are quite positive. Especially the rule for identifying suspected products seems to work very well. A strong advantage of the proposed method for evaluation and diagnosis is its simplicity; every person in the organization can understand the way the method works. Further, the "formula" used for identifying suspected products is easy to understand by non-specialists. A last advantage of the proposed method is that it makes it easy to automatize the required measurements and norm setting procedures. Besides the positive experiences and the advantages of the method, there are some residual issues that we will now address.

The norm for the aggregate inventory level can only be used for a set of products having the same inventory pattern as depicted in figure 3b. For products having the same lot size as the demand quantity, this calculation of the norm is not appropriate. However, the rule for identifying suspected products can be used independently of the individual patterns of inventory levels.

When the aggregate inventory level is much larger than the aggregate norm we said a further analysis at product level was required. However, an important cause of this exceeding may be the lack of smoothing MPS variations. Bertrand (1986) showed the effects of MPS variations on production and inventory variations. This cause can not be found in the diagnosis at the product level.

Finally, it is advised to do the measurement, evaluation, and diagnosis of the inventories twice a year. This frequency is based mainly on the dynamics in changes of inventory levels (partly due to changes in lot sizes). Only just after the implementation of the method is it recommended to do the analyses more frequently (for example once a month) in order to quickly reduce the inventories by identifying most of the suspected products.

Conclusions
In this article we demonstrated the use of a method for evaluating and diagnosing inventories. The method was developed and tested in two production units of an aircraft manufacturer. In the two production units the method worked very well with regard to the identification of inventories of single products that seemed to be too high (the so-called suspected products). A further analysis of all suspected products led to a list of causes by which the height of single inventory
levels could be explained. This list then served for launching appropriate actions to avoid high inventory levels in the future. The proposed method of evaluation and diagnosis is again one step further ahead in the coping with problems of MRP systems.

References


