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Analysis of lumpiness phenomenon in MRP

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Abstract

Occurrence of chaotic behaviors because of fluctuations creation and their intensified transfer along the chain is one of the main causes of inefficiency of Material Requirements Planning (MRP) based supply chains. One of the reasons of the inefficiency is the lumpiness phenomenon. Through this phenomenon, some parts have an irregular production schedule, with nothing produced in some periods and large batches released in other periods. In this paper it is tried via the mathematical models to analyze this phenomenon. Using the mathematical deduction it is shown that the inventory fluctuations in upper levels of Bill of Material (BOM) in creation of lumpiness phenomenon are more effective than the inferior levels.

Keywords: MRP; Lumpiness; Variance; Mathematical model

1. Introduction

The acronym MRP is used in three different but related contexts that each of them shows a stage in the development of MRP concepts (Fogarty *et al.*, 1991). These are MRP-1 or Material Requirement Planning, closed-loop MRP and MRP-2 or Manufacturing Resource Planning. MRP-1 calculates the exact quantity, planned release and planned order for each of the subassemblies, components and materials required to produce the final product. Closed-loop MRP was the next step in the development of MRP-1 and is a formal manufacturing control system. It includes capacity requirements planning and links the master production schedule to the production planning process. Closed-loop MRP compares the planned capacity utilization resulting from the MPS and the MRP to the available capacity to determine if the plan is attainable. Manufacturing Resource Planning or MRP-2 is an explicit and formal manufacturing information system that integrates marketing, finance and operations. The core part of the closed-loop MRP and MRP-2 is MRP-1 concept. MRP uses demand information from the master production schedule with a description of bill of material (BOM), the order times for components and the current inventory status. MRP uses information to determine the quantity and timing of orders to be placed or issued. The creation of MRP concept by Orlicky (1975), shows a great dependency to computer sciences. In the early 1960s, most of organizations used computers for their ordinary computation. With respect to the repetition and difficulty of computations that are related to inventory control and timing, tendency of using computers in these fields has been intensified. One of the first experiences in these fields conducted by IBM Company and Orlicky (1975) are designated to MRP-1. In 1972, American Production and Inventory Control Society (APICS) supporting the MRP-1, caused the development in this field. In 1989 the sales rate of MRP-1 software amounted to one billion dollars. During the time with development of MRP-1, MRPII system and after that Enterprise Requirement Planning system was developed (Hopp and Spearman, 2001). Before MRP-1, most of production control systems were based on statistical orders. In this system, a batch is ordered

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when its inventory level is lower than a defined level. This insight could be useful for the final product but not for pieces that form it. It is because the final product demand is shaped up out of the organization and normally is doubtful, while pieces demand is related to final product, that's why the role of BOM in MRP formation is important

In spit of potentials of MRP, there are some defects. The most important of them are:

- MRP-1 is not capacity constrained.
- MRP-1 uses constant lead times. In a real product system, lead times are not constant, so one must consider the most pessimistic among them.

Another difficulty with MRP-1 is its nervousness. Nervousness of MRP-1 means that a small change in MPS could sometimes result in severe changes in orders (Vollmann *et al.,* 1992). Despite that MPS could have monotonous distribution during the time, orders in lower levels of BOM, will highly fluctuate. This phenomenon is named lumpiness. The effect of batch production in MRP-1 is evident, and so, some parts have an irregular production schedule, with nothing produced in some periods and large batches produced in other ones. This lumpiness is not considered in the process of rough cut capacity planning. MPS does not exhibit the lumpiness. Because the lumpiness, production plan in the shop may be much more irregular than that predicted by rough cut capacity plan. The main reasons that are mentioned for lumpiness are the big amount of work in process and also the big amount of lot size. Raa and Aghezzal (2005) have studied the lot sizing problem in their static and dynamic forms and have proposed a method based on dynamic programming for generating robust plans.

Tang and Grubbstrom (2002) have proposed a method for defining the MPS with probabilistic demands that can be generate robust plans. Guide and Srivastava (2000) in their review paper have analyzed the methods to deal with uncertainty.

Mula *et al.* (2006) also have had a review on production planning models in the presence of uncertainty and introduce some MRP based models. The presence of the above problems and defects in MRP-1 will cause troubles, when they are used for production planning and in a production distribution system.

We may consider a supply chain as a network of autonomous or semi autonomous that work together for ordering, production and distribution of one or more category of products (Swaminathan *et al.*, 1997). Various units in chain activate under different sets of goals and constraints. However, all of them are significantly interrelated together and should have complete collaboration for achieving the goals. The presence of above problems and defects in MRP will make trouble, when they are used for production planning and in a production distribution system. We can consider a supply chain as a network of autonomous or semi-autonomous that work together for ordering, production and distribution of one or more category of products (Swaminathan *et al.*, 1997).

Lamouri (2006) has a discussion on the decisions made in a logistic chain based on MRP and ERP systems. He propose a new approach for robustness and stability in such systems. Selcuk *et al.* (2006; 2007) studied the role of lead times in the dynamic performance of hierarchical planning systems, such as MRP. Enns (2001) studied the effect of lot sizing and lead times simultaneously on the performance of MRP systems.

Various units in chain activate under different sets of goals and constraints. However, all of them are significantly interrelated together and should have complete collaboration for achieving the goals. So, the proper management of supply chain is the secret of their survival (Quayle, 1998) and for most organization it is a great advantage (Davis, 1993). Naturally the nature and structure of supply chain that cause a lot of relations is complex. In such complex systems, the use of MRP for planning of various supply chain units, can transfer MRP problems to these units and will add to their complexity (Wilding, 1998).

2. Mathematical model of MRP-1

In a supply chain we can assume that each production unit can be a BOM level. Since each item needs separate MRP table, actually each production unit in supply chain will have a special MRP table. Some authors have proposed the mathematical models for analyzing the MRP, for example Spitter *et al.* (2005) present the linear programming models with planned lead times. Also Makui and Sadjadi (2006) presented a mathematical model for studying MRP based on complexity theory. Assume an MRP table situated in jth level of BOM (Makui and Sadjadi, 2006):

D_t^j Demand of period t in j th MRP table.

Q_0^j	Beginning inventory in *j* th MRP table.
Q_t^j	Inventory at the end of period *t* in *j* th MRP table.
M_t^j	Planned order receipts in period *t* in *j* th MRP table.
X_t^j	The ordered amount of period *t* in *j* th MRP table.
LT_j	Lead time of the *j* th MRP table.
k_j	Consumption rate in *j* th MRP table .

The following relations are true:

$$(Q_t^j + M_{t+1}^j) - D_{t+1}^j = Q_{t+1}^j \tag{1}$$

We have:

$$X_t^j = M_{t+LT_j}^j \tag{2}$$

We also have:

$$D_j^t = k_j \times X_t^{(j-1)} \tag{3}$$

$$(Q_t^j + X_{t+1-LT_j}^j) - D_{t+1}^j = Q_{t+1}^j \tag{4}$$

$$X_{t+1-LT_j}^j = Q_{t+1}^j - Q_t^j + D_{t+1}^j \tag{5}$$

$$\frac{1}{k_j}(D_{t+1-LT_j}^{j+1}) = Q_{t+1}^j - Q_t^j + D_{t+1}^j \tag{6}$$

$$\frac{1}{k_j}[(Q_{t-LT_j}^{j+1} + (1/kX_{t+1-LT_j-LTj+1}^{j+1} - Q_{t+LT_{j=1}}^{j+1})$$
$$= Q_{t+1}^j - Q_t^j + D_{t+1}^j \tag{7}$$

By combining (1),(2),(3), and (7) we will have:

$$X_{t+1+\sum_{j=1}^{s} LT_j} = \prod_{j=1}^{s} k_j (Q_{t+1}^1 - Q_t^1 + D_{t+1}^j) \tag{8}$$
$$+ \prod_{j=2}^{s} k_j (Q_{t+1-LT1}^2 - Q_{t-LT1}^2)$$
$$+ \prod_{j=3}^{s} k_j (Q_{t+1-LT1-LT2}^3 - Q_{t-LT1-LT2}^3) + \dots$$

Or:

$$X_t^s = \sum_{l=1}^{s} \prod_{j=l}^{s} k_j [Q^l_{t+1+\sum_{i=l}^{s} LT_i} - Q^l_{t+\sum_{i=l}^{s} LT_i}]$$
$$(k_s = 1) \tag{9}$$

Actually, the difference between ordered amount in (*t+1*) th and *t* th period in *s* th MRP table is as follows:

$$X_{t+1}^s - X_t^s = \sum_{l=1}^{s} \prod_{j=l}^{s} k_j [Q^l_{t+2+\sum_{i=l}^{s} LT_j} - Q^l_{t+\sum_{i=l}^{s} LT_i}]$$
$$(k_s = 1) \tag{10}$$

It can be seen that the influence of a deviation in inventories on order quantities in the first levels of MRP is higher than next levels. On the other hand, if in the first levels of MRP we use the L4L system, the order fluctuation in the next levels of MRP will be limited.

3. Numerical example

Consider a final product that consists of two pieces. The BOM is as shown in Figure 1 and Table 1. We consider the problem in 5 periods and the final product demand (MPS) is shown in Table 2. Now, we solve the above example in various states and compare the results. To solve the problem we need three MRP tables for each 100,110,120, level. These tables have solved by MRP mathematical model by assuming the following objectives:

3.1. Minimizing the variance of order quantities in all three MRP levels

In this case, the optimal solutions for the beginning inventories in all the three levels of MRP tables and the optimal amounts of orders are as shown in Table 3.

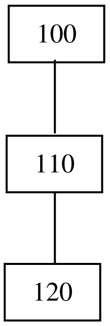

Figure 1. The BOM of the numerical example.

Table 1. The characteristics of the BOM of the numerical example.

Piece code	Consumption coefficient in final product	Lead time (LT)
100	1	1
110	2	2
120	3	3

Table 2. The MPS of the numerical example.

Period	100 demand
1	100
2	120
3	110
4	120
5	120

Table 3. Optimal orders.

Period	X_1	X_2	X_3
1	0	0	0
2	0	0	0
3	0	0	0
4	0	0	0
5	0	0	0

$(QOH)_{100}=570$

$(QOH)_{110}=(QOH)_{120}=0$

Table 4. Optimal solutions.

Period	X_1	X_2	X_3
1	120	0	0
2	110	0	0
3	240	0	0
4	0	0	0
5	0	0	0

$(QOH)_1=100$

$(QOH)_2=940$

$(QOH)_3=0$

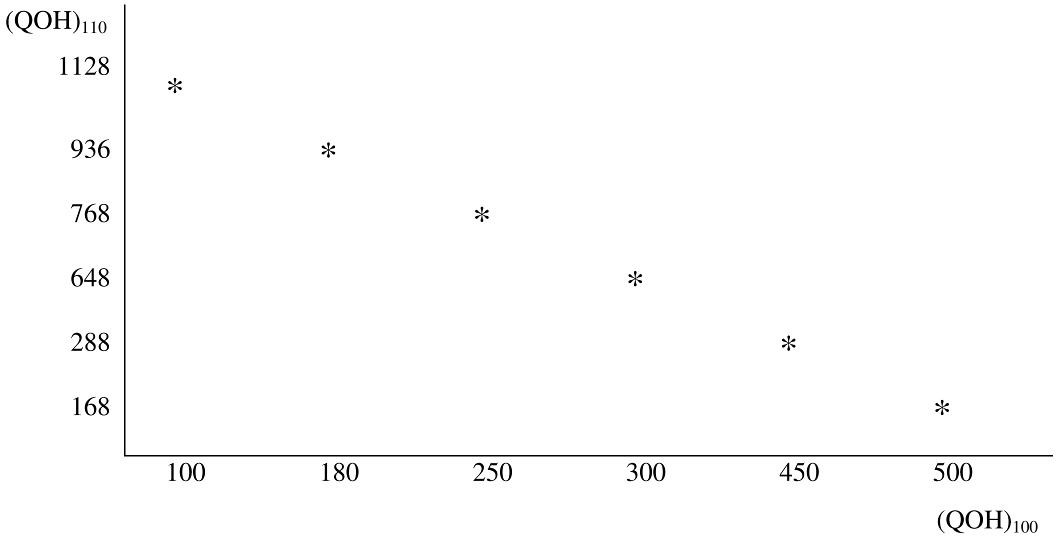

Figure 2. QOH $_{(100)}$ versus QOH $_{(110)}$.

Table 5. The orders and variances for case 3-4.

$(QOH)_1$	$(QOH)_2$	$(QOH)_3$	Total Variance
500	150	48	51.9
450	140	496	285.1
300	130	1983	4453.6

Table 6. The orders and variances for case 3-5.

$(QOH)_{100}$	$(QOH)_{110}$	$(QOH)_{120}$	Total Variance
500	150	45	52
490	145	40	45.5
480	140	38	692.8
470	132	35	3520
450	128	28	12687
390	124	24	65693

3.2. Minimizing the variance only in the third table of MRP

The optimal solutions are as shown in Table 4.

3.3. Controlled decrease in beginning inventory in the first level of BOM

In order to minimize the variance of orders in levels 110 and 120 and with compulsory decrease of (QOH) of item (100), we decrease the QOH of the final product (item 100) gradually from 500 to 100. In order to keep the variance minimized, inevitably the beginning inventory in the second levels of MRP (item 110) should increase. The beginning inventory and the orders of item (120) have been fixed at zero. Figure 2 shows the results. In all points of diagram the total amount of variance (total variance in all levels) is equal to zero.

3.4. Controlled decrease of beginning inventory in the first and second levels (items 100 and 110)

In this condition the $(QOH)_{120}$, that is the beginning inventory in the third level, is allowed to alter in order to minimize the amount of variance of orders. Table 5 shows the changes. It can be seen that in spite of increase in $(QOH)_{120}$, the variance increases gradually.

3.5. Controlled decrease of beginning inventory in all three levels of MRP (items 100, 110, and 120)

Table 6 shows the changes and the amount of variance with respect to any change.

4. Conclusion

As it can be seen, the purpose of this article is to study the lumpiness phenomenon in MRP-1 with respect to variance of orders. It has shown that the influence of fluctuation of beginning inventory in the primary levels of BOM on the lumpiness in lower levels is very considerable. So it is recommended that to minimize the lumpiness in lower levels of MRP, in the primary levels of it, the ordering systems like L4L to be used or to select a high amount of the beginning inventory in primary levels of MRP. Having high amount of inventory in the next levels of BOM, cannot help lumpiness phenomenon vanishing. Hence, the roles of WIP in all levels of BOM in the emergence of lumpiness phenomenon are not equal and when we close to the level of final product, the importance of this role intensifies. In this article, the role of other factors such as batch size and lead times have not been considered that can be studied in the future researches as individually or in the combination on lumpiness phenomenon. Another result that can be drawn by this article and from the different cases of the numerical example is that lumpiness phenomenon can cause an increase in the variance of orders in lower levels of MRP-1.

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