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The use of MRP and LRP in a stochastic environment

K. VAN DONSELAAR

Abstract. In a multi-echelon production/inventory system the material flow between successive stages has to be coordinated. A number of concepts are available for this material co-ordination. Material requirements planning (MRP) is a well-known example. Unfortunately, the MRP concept also has a number of disadvantages. Especially in a stochastic environment, the MRP concept is not very efficient. An alternative concept for material co-ordination will be introduced and evaluated.

1. Introduction

A multi-stage production system consists of a number of subsequent manufacturing stages. In this article it is assumed, that these stages are decoupled by order release points; to get material from one stage to the next, an order has to be released. One of the tasks in the multi-stage system is to make sure that the right amount of the right product is released at the right time. The activity which co-ordinates the order releases for the subsequent manufacturing stages is called material co-ordination (See Bertrand 1985).

Originally multi-stage systems were controlled without (formal) material co-ordination: the order release decision for a particular product was based solely on local information for this product. In the 1950s it was recognized that it might be beneficial if the order release decision would be based also on information with respect to other products. See Vazsonyi (1955) and Magee (1958).

In the 1960s MRP-I was developed; an algorithm which provides a time-phased planning of future orders. These future orders are used to take into account the inter dependencies between products, when the order releases are planned. The MRP algorithm is described in Orlicky (1975). Unfortunately, the MRP concept can be very inefficient in a stochastic environment. In this paper an alternative concept for material co-ordination will be introduced: line requirements planning (LRP). LRP is an extention of base stock control (see Magee 1958 and Timmer *et al.* 1984). Compared with MRP, LRP gives insight to the actual flexibility in the system. This insight can be used to deal efficiently with uncertainty.

In Section 2 the logic of MRP is discussed, including the way MRP treats safety stock. This discussion leads to the conclusion that the MRP concept does not always support the planner in making the right decision. As an alternative LRP is introduced in Section 3. In Section 4 MRP and LRP are compared, and conclusions drawn in Section 5.

2. MRP

MRP is a well-known planning model for material co-ordination. The main element in MRP logic is the determination of the (gross) requirements for components, based on the planned orders of the parent products (see Figure 1 for the bill-of-material for the component). In

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KAREL VAN DONSELAAR studied econometrics at the Erasmus University Rotterdam in the Netherlands. From 1984 to 1991 he worked with Prof. Wijngaard at Eindhoven University of Technology, resulting in a dissertation on 'Material Co-ordination under Uncertainty' in 1989. This dissertation deals with subjects like the applicability of MRP, alternatives for MRP, and determination of stock norms and imbalance in divergent systems. Over the last three years he has worked part-time as a consultant on logistics management in the automotive industry, the food industry and the chemical industry.

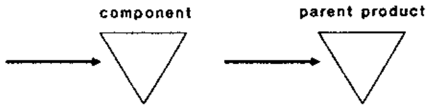

Figure 1 The bill-of-material for the component

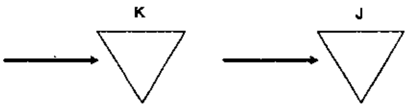

Figure 2 The product structure of J and K

the determination of the planned orders for the parent products, no information about the availability of components is used

In a deterministic environment this makes sense, since then it is possible to keep the availability of the components 'in line' with the requirements of the parent products

In a stochastic environment however, the MRP logic is less suitable Due to uncertainty the (expected) availability of components may no longer be 'in line' with the requirements In these situations it may be not optimal to apply the MRP logic The MRP logic always assumes that the requirements of the component are fixed and that the supply should be adapted ('rescheduled') to meet the requirements Sometimes however, it may be more efficient to adapt the requirements (i e to use the flexibility in the component's requirements by changing downstream lot-sizes) rather than to adapt the supply This is illustrated by the following example·

Example Imagine two products· J and K The product structure of J and K is illustrated in Figure 2 One unit of K is used to produce one unit of J The parameters for J and K are

	J	K
lead time (l)	1 period	1 period
lot-size (Q)	40 units	40 units
inventory	30 units	40 units
safety stock norm	10 units	0 units

Apparently, the lot-size for J is set equal to 40 units here This lot-size is meant as an *indication*. In practice, it often occurs that the *lot-sizes* are flexible This *flexibility* is called lot-size flexibility here. In the example above it is assumed, that the lot-size for J is flexible· any lot-size between 36 and 44 units is acceptable

The planning according to MRP logic is depicted in Table 1 The requirement for K in period 2 is covered by the inventory of K In period 6 the first planned order for K should be due

Now suppose that the inventory of K suddenly appears to be 39 instead of 40 units due to scrap How does MRP react to this? MRP will·

- advise release of the first planned order for 40 units K immediately,
- replan all other planned orders *four* periods earlier

Apparently MRP interprets the planned order quantity for J extremely strictly· *exactly* 40 units have to be available, no matter what the consequences are In other words, MRP does not take into account the available lot-size flexibility The result is that MRP considers the 39 units to be remnant stock when MRP determines the first planned order This is a serious problem

One might argue that this is highly exaggerated since the release of an extra order is only the advice of the MRP planning system; the planner may ignore this and will ultimately release an order for J equal to 39 units, and then the situation is such that the planned orders

Table 1 The planning for products J and K according to MRP

Product J, according to MRP Period	0	1	2	3	4	5	6	7
Requirements		10	10	10	10	10	10	10
Available balance	30	20	10	—	- 10	- 20	- 30	- 40
Planned order due				40				40
Planned order release			40				40	
Product K, according to MRP Period	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**
Requirements			40				40	
Available balance	40		0				- 40	
Planned order due							40	
Planned order release						40		

have to be planned only one period earlier (compared with the planning in Table 1)'. There are, however, a number of problems:

(a) With MRP the planned orders for K are replanned four periods earlier, which implies that requirements for its components (if there are any) get very nervous and the change has been amplified. Recall that for components the higher-level planned orders are seen as true requirements, on the basis of which orders are released. To avoid erroneous order releases for upstream stages, the planner would have to check the planned orders for all products at all downstream stages; usually this is impossible, especially in systems with many stages or many products. Besides, it is the purpose of the planning model to give sensible order release suggestions. The planner should not have to check all planned orders.

(b) Incorrect planned orders also imply a distorted capacity requirements planning.

(c) If the planner ultimately releases 39 products J, the planned orders are planned three periods *later* again (after they had been planned four weeks earlier)! Employees both in the planning department and on the shop floor may soon lose faith in such a nervous planning system.

(d) The planner gets a huge amount of exception messages like the one for product K and its components. Because of the huge amount of 'false' messages he is unable to determine the truly serious messages.

At first glance, it seems to make sense to introduce a quantity buffer norm for K to absorb the fluctuations due to random scrap. However, MRP is unable to deal efficiently with such buffer norms.

The main cause of this is the fact that MRP interprets buffer norms as *local norms*. A buffer norm for a component is a local norm if the buffer norm can only be covered by inventory of this very same component. Sometimes it is allowed to cover the buffer norm for a component by this component's inventory or by the inventory of the corresponding final product. Such buffer norms are called *integral norms*.

Integral norms are more efficient than local norms: in situations with integral norms and no inventory for the component, but with excess inventory for the corresponding final product (e.g. due to lot-sizing), the excess inventory for the final product can be used to cover the component's buffer norm. In such situations no replenishment for the component is needed. However, if in such situations the component's buffer norm is interpreted as a local norm (like MRP does), a replenishment suggestion for the component will be given and excess inventory will result. A more extensive discussion on local and integral buffer norms is given in Van Donselaar (1989).

In the example above the lot-sizes were assumed to be flexible. This lot-size flexibility is very useful in many situations. It is particularly useful when the planned orders for the parent product are no longer exactly in line with the component's expected inventory. The component's inventory may slightly deviate from the planned orders of the parent product if:

- The planned orders change from period to period, e.g. due to dynamic order policies and changes in the expected requirements or dynamic order policies and deviations between actual and expected demand.
- The (expected) inventory of the component changes from period to period, e.g. due to scrap.

From the example above it can be concluded that MRP does not take into account the lot-size flexibility. It appears that, if due to uncertainty the available inventory for the component is slightly smaller than the planned orders for the parent product, the MRP logic will always make sure that the entire order quantity is satisfied. If in reality the lot-sizes are flexible, this leads to excess inventories and nervousness, even in situations with minor uncertainty.

Once the requirements for the component are determined, any flexibility in the requirements is ignored by the MRP logic (that is: this flexibility is not used by the MRP logic). The basic cause of this 'loss of flexibility' is a 'loss of information'. Due to the fact that MRP only explodes the planned orders of the parent products, the information which led to these planned orders is no longer available at the component level. The information which led to the planned orders for the parent products is needed to deal efficiently with minor variations at the component level. This observation leads to an alternative planning model for material co-ordination: LRP.

3. LRP

In this section an alternative planning model for material co-ordination will be introduced: LRP. LRP stands for line requirements planning. LRP is based on the base-stock concept of Magee (1958) and the echelon concept of Clark and Scarf (1960). To clarify LRP, first its ancestors are introduced. Then the logic of LRP is presented. An example is used to illustrate this logic. Thereafter it is shown how the planning model LRP deals with lot-size flexibility, imbalance in a divergent system, firm planned orders and the order release decision

3 1 *The ancestors of LRP*

The concept of LRP is primarily based on the echelon concept as introduced by Clark and Scarf (1960) which in turn is an extension of the base-stock concept of Magee (1958) For every product Clark and Scarf define an echelon, which starts with the release point of this product and contains all products in downstream stages having this product as a component For stationary linear systems without setup costs for the intermediate and final stages they prove the optimality of the following reorder policy· 'order up to a stock norm S, if the content of the echelon is below a norm' Note that this reorder policy takes into account the inventory in all the downstream stages Therefore this reorder policy will be referred to as an integral reorder policy The traditional reorder policies are local reorder policies· they are based on the inventory in one stage only

To clarify the echelon concept consider the following example· a toy car (C) has five wheels (W) The product structure of the car is depicted in Figure 3 Let I_C and I_W denote the inventories on hand plus on order for the car and the wheels The variables l_C and l_W indicate the lead times The review period is equal to one period The demand for the car equals μ_C cars per period

The echelon for the car C consists of the last part of the production process, starting from the release point for C The content of the echelon should cover at least a norm r_C In a deterministic environment r_C is equal to the average demand during the lead time plus review period· $r_C = (l_C + 1) \times \mu$ In a stationary stochastic environment a safety component should be added The reorder policy for C can be formulated as

$$\text{order if } I_C < r_C$$

This shows that for the final product stage the integral reorder policy is equivalent with a local reorder policy The echelon for the wheel W consists of the entire production process, starting from the release point for W and ending with the stock point for the car The inventory in this echelon, expressed in number of wheels, equals $I_W + 5 \times I_C$ (recall that one car contains five wheels) The echelon for the wheel should contain at least r_W wheels This leads to the following reorder policy·

$$\text{order if } I_W + 5 \times I_C < r_W$$

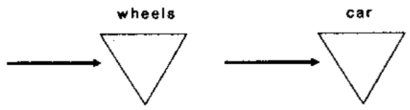

Figure 3 The product structure of the car

Earlier, Magee (1958) and Timmer *et al* (1984) had already suggested immediately passing on the historical demand information available at downstream stages to the upstream stages and reordering as soon as the echelon inventory drops below the so-called base-stock level Timmer *et al* suggest deriving the base-stock level from the probability distribution function of the demand during the echelon lead time plus review period

In the previous example with the car and wheels, the lead time of the echelon for the wheels equals $l_C + l_W$ periods. The demand per period equals μ_C cars; this demand is equivalent to $5\mu_C$ wheels per period In a deterministic environment the safety component in the base-stock level equals zero Therefore in a deterministic environment Timmer *et al* suggest setting r_W as follows·

$$r_W = (l_C + l_W + 1)\, 5\mu_C$$

Finally Van Donselaar *et al* (1987) suggest using BSC as the basis for a time-phased planning They call this planning method LRP Their ideas are not exclusive, earlier Stommels (1979), Büchel (1982), Luyten (1987) and Kwikkers (1987) had proposed similar planning methods

3 2 *The logic of LRP*

To obtain LRP, BSC is adapted in two ways·

- The reorder point r_W is turned into a dynamic reorder point, based on the forecasts $\hat{D}_C(t+i)$, $i = 0, \ldots, CLT$ Here CLT is the mnemonic for the cumulative lead time that is the lead time of the echelon Consequently, in the previous example r_W is determined by

  $$r_W(t) = \sum_{i=0}^{l_C + l_W} \hat{D}_C(t+i) \times 5$$

  (In a stochastic environment this reorder point is increased with a safety norm to buffer against the variations during the cumulative lead time)
- Not only order release suggestions for the current period are generated Also a time-phased planning consisting of planned orders is made to facilitate, for example, capacity planning

Before the determination of these planned orders is described, the term integral inventory will be introduced The integral inventory for a particular production stage is defined as the inventory on hand in this production stage and the inventory on hand plus on order in all downstream stages The (integral) inventory is reviewed here at the beginning of the period, before the inventory has been replenished by scheduled receipts and decreased by the demand The replenishment takes place at the beginning of the period after the review moment and before demand takes place

Suppose that in the example with the car, the inventory on hand for the car and the wheels are equal to IOH_C and IOH_W, respectively In this example the integral inventory for the wheels is equal to $IOH_W + 5 \times I_C$

The planned orders determined by LRP are based on an available balance This available balance is defined as the integral inventory plus the cumulative scheduled receipts minus the cumulative integral requirements For the example with the car, the available balance and the cumulative integral requirements for the wheels equals (for $j \geqslant 0$)

$$\text{available balance}_W(t+j) = \text{integral inventory}_W(t) + \text{cum scheduled receipts}_W(t+j) - \text{cum integral requirements}_W(t+j)$$

where

$$\text{integral inventory}_W(t) = IOH_W(t) + 5 \times I_C(t)$$

$$\text{cum integral requirements}_W(t+j) = \sum_{i=0}^{l_C+j} \hat{D}_C(t+i) \times 5$$

$$\text{cum scheduled receipts}_W(t+j) = \sum_{i=0}^{j} \text{scheduled receipts}_W(t+i)$$

The 'planned orders due' in period $t+j$, with $j \geqslant l_W$, are given by

$$\text{planned order}_W(t+j) = \text{integral buffer norm}_W - \text{available balance}_W(t+j) - \sum_{i=0}^{j-1} \text{planned order}_W(t+i)$$

In the case that no lot-for-lot order policy is applied, the 'planned orders due' should be adapted in the same way as in the regular time-phased-order-point logic

3 3 *An example to illustrate LRP*

To clarify LRP, the example with products J and K from Section 2 will be used In this example planning tables rather than mathematical formulae will be used The logic behind these tables is equivalent to the logic expressed by the previous mathematical formulae, which apply to linear systems Planning according to LRP for products J and K is presented in Table 2.

For product J the planning according to LRP is exactly the same as the planning according to MRP Recall that for the final stage the integral planning is always equivalent to the local planning For product K the planning according to LRP is based on the requirements of product J The requirements of J are modified by offsetting with the lead time of J· if 10 units J are needed in period 1, and if it takes one period to make those products, then 10 products K should be available in period 0 The requirements for J are not netted with the inventory of J, which would have resulted in the local requirements for K Instead, the integral requirements for K are compared with the integral inventory of K The integral inventory of K is equal to the number of products K in all downstream manufacturing stages. This includes both the 40 units K on hand as well as the 30 units K which have been used to make the on-hand inventory of J As a result the integral inventory of K equals 70 units As soon as the available balance becomes less than the integral buffer norm (equal to 10 + 0 = 10), a new order is planned In this example LRP and MRP yield the same planned order

Table 2 Planning for products J and K according to LRP

Product J period	0	1	2	3	4	5	6	7
Integral requirements		10	10	10	10	10	10	10 →
Integral inventory	30							
Available balance	30	20	10	—	−10	−20	−30	−40
Planned order due				40				40
Planned order release			40				40	
Product K period	0	1	2	3	4	5	6	
Integral requirements	10	10	10	10	10	10	10 ←	
Integral inventory	70							
Available balance	60	50	40	30	20	10	—	
Planned order due							40	
Planned order release						40		

3 4 *LRP and lot-size flexibility*

Just like in Section 2, it is assumed now, that the inventory of K suddenly turns out to be 39 instead of 40 units How does LRP react? LRP will

- replan all planned orders *one* period earlier

LRP notes that the available balance for K is 39 instead of 40 in period 2 and recognizes that this is still sufficient to meet three periods of requirements for J Clearly the LRP advice is very different from the advice given by MRP The planning according to LRP is less nervous, since LRP assumes that the lot-size for J is completely flexible

3 5 *LRP in divergent systems*

Up to now the LRP logic has been described for linear systems only Similar logic can be applied in divergent systems as well

A divergent system is a system which consists of a common component and two or more final products These final products are made out of the common component.

The LRP logic for divergent systems is as follows· in a divergent system the integral requirements of the common component are equal to the sum of the off-set integral requirements of all final products Likewise the integral inventory of the common component is equal to the inventory (on hand) of the common component plus the sum of the inventories (on hand plus on order) in all downstream stages Just like in linear systems LRP determines the available balance for the common component by subtracting the integral requirements from the integral inventory This available balance is used then to calculate the planned orders

Since LRP only considers integral inventories, it ignores the way the inventories are assigned to the different products in the divergent system As a result it ignores imbalance too Roughly speaking, imbalance is the phenomenon which occurs in divergent systems if the run-out-times of the final products' inventories are unequal Unlike MRP, LRP assumes that the imbalance does not affect the planning of the component

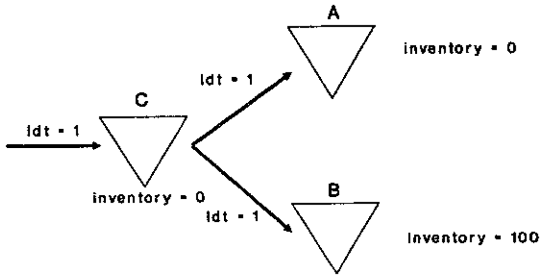

Figure 4 Imbalance in a divergent system

Table 3 Planning for product C according to LRP

Product C period	0	1	2	3	4	5	6
Integral requirements	20	20	20	20	20	20	20
Integral inventory	100						
Available balance	80	60	40	20	0	− 20	− 40
Planned order due						20	20
Planned order release					20	20	

To illustrate this, consider the example depicted in Figure 4 The products A, B and C all have a lead time equal to 1 period and no safety stock norm One product of C is needed to make either one product of A or one product of B The demand for A and B is equal to 10 units per period Since the inventory of A and B is equal to 0 and 100 units, respectively, the run-out-time of A and B is O and 10 periods, respectively Clearly the system is out of balance Table 3 contains the planning for product C according to LRP

In this example LRP will give a wrong order suggestion, due to the imbalance LRP implicitly assumes a kind of flexibility which is not available in the system; LRP assumes that the integral inventory for C, which is equal to (0 + 100 + 0 = 100) units, is (or can be) distributed equally over the two final products Therefore LRP suggests planning the next order for C due in period 5 However the integral inventory is distributed already over A and B and cannot be redistributed According to the MRP logic, the first planned order for C should be due in period 1

In general, the more deterministic the environment and the larger the final products' lot-sizes, the more important the role of imbalance may be In Van Donselaar (1990) a theoretical analysis on the consequences of imbalance in divergent LRP-controlled systems is presented This analysis shows that lot-sizing is a major source of imbalance Yet the analysis also shows that the impact of imbalance is small if the environment is very uncertain The latter is explained by the fact that the safety stock, which is available in order to protect the system against uncertainty, also helps to protect the system in cases of system out-of-balance

3 6 *Firm planned orders*

LRP does not take into account firm planned orders of downstream stages Firm planned orders are planned orders, of which the quantity and timing are made firm by the planner That is, the planner has decided that those orders should be planned in a specific (detailed) way The planning system is no longer allowed to automatically overrule these planned orders if a new planning is made

In this way planning logic which deviates from the normal planning logic can be incorporated in the planning system Firm planned orders can be helpful if, for example, the lot-size which is required for a particular planned order is larger than the normal lot-size Firm planned orders provide the flexibility to deviate from the standard planning logic Once the planned orders are firmed however, they are inflexible. The planning system does not automatically adjust them, even though the situation may change drastically

LRP explodes the requirements instead of the planned orders. As a result LRP does not take into account the firm planned order information from downstream stages when the planned orders for a component are determined The more these firm planned orders deviate from the normal planned orders, the more serious this problem is

In MRP the master production schedule (see Orlicky 1975) should be a set of firm planned orders. This might argue against LRP However, the arguments in Van Donselaar (1989) indicate that it is questionable whether firm planned orders are the most appropriate means to formalize agreements between the production department and the sales department An alternative could be to make agreements on the number of weeks the production department will work in advance This number of weeks is time-dependent and can be added to the lead-time, when off-setting the requirements

3 7 *The order release*

The planner, who wants to release an order in a deterministic environment in which LRP is applied, is faced with two problems·

- There is no guarantee that sufficient components are available to release the appropriate order quantity As a result the component availability has to be checked before an order is released
- In case insufficient components are available in a divergent system, an allocation rule is needed

In the case that MRP is applied in a deterministic environment in which both the normative and the actual lead time are constant there will always be sufficient components available In a stochastic environment neither MRP nor LRP is able to guarantee that sufficient components are available, and with both planning models a component availability check as well as an allocation rule are needed

4. A comparison between MRP and LRP

MRP explodes planned orders derived from several types of information like requirements, inventory, lead time, lot-size and buffer norms. After the explosion, the only information directly available for the product, which uses the exploded requirements, is planned order release dates and quantities, not the information which led to these dates and quantities This is also the main difference with LRP· LRP explodes information on inventories, expected requirements and buffer norms separately to upstream stages (see Figure 5)

The main disadvantage of LRP is the fact that LRP structurally ignores restrictions like firm planned orders at downstream stages and imbalance. As mentioned before, a theoretical analysis has shown that the influence of imbalance is negligible in many situations

The main advantage of LRP as compared with MRP, is the fact that the distortion of information with respect to requirements, buffers and inventories is minimal LRP explodes inventory and requirements separately and in their basic form; the requirements are not, for example, transformed by lot-sizing This contributes to·

(1) a higher transparency;
(2) less nervousness;
(3) an integral planning

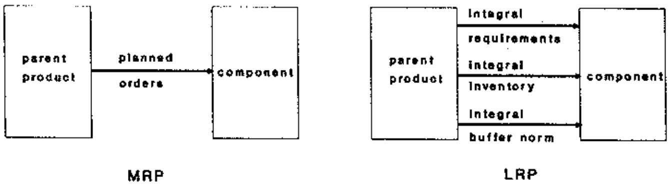

Figure 5 The information explosion in MRP and LRP

Advantages of LRP may be summarized as below·

- Requirements for the component are directly derived from the requirements for the final products Therefore it is easier to see how the requirements are built up. Moreover, changes (e.g. due to a simulation) in the final products' requirements are clearly recognizable at the component level Note that on the other hand this way of explosion also causes the loss of lot-sizing and scheduling information
- The fact that LRP leads to more stable plans is illustrated in this article with one example only This example has been used to demonstrate that MRP does not use the lot-size flexibility in the system This inability of MRP leads to nervousness
- Thanks to LRP, an integral insight is given to production planners The planners of components see the amount of inventory and slack, which is available in the *entire* system. This prevents local optimization and supports the use of integral buffer norms, resulting in a more efficient use of inventories

5. Conclusions

The comparison of MRP and LRP shows that both planning concepts have strong features In deterministic environments with rigid order-restrictions the MRP-algorithm will be the best solution In stochastic environments LRP is able to use the inventories more efficiently, resulting in lower inventory levels

In stochastic environments with rigid order-restrictions a new planning concept should be developed, which combines the strong features of MRP and LRP In Van Donselaar (1989) a first attempt to develop such a planning concept is presented

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