A SURVEY ON SUPPLY PLANNING UNDER UNCERTAINTIES IN MRP ENVIRONMENTS

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Abstract: Inventory control in a Supply chain is crucial for companies desiring to satisfy their customers demands as well as controlling costs. This paper examines specifically supply planning under uncertainties in MRP environments. In literature, many models exist for a random demand, certain of them are described and commented in this paper, also presented are some results for lead time uncertainties. Lead time uncertainty has been ignored in the past, in spite of their significant importance. In particular, a promising research area concerns assembly systems with uncertain lead times, for which the main difficulty comes from the inter-dependence of components inventories. Another promising area, which is also presented, concerns the supply planning under simultaneously demand and lead-time uncertainties, which certainly is of great interest for both the academic and industrial communities.

Keywords: Production systems, Inventory control, Planning, Uncertainty.

1. INTRODUCTION

Inventory control is an important element for production systems. An improper policy of inventory control leads either to shortages, which generate expenses, or to needless stocks, which decrease capital assets. So, efficient supply planning methods to order the correct quantity of components at the right time should be developed.

Various causes of uncertainty exist: supply reliability; machine breakdown; random level of customers demand, etc. To minimize the influence of these uncertainties, enterprises implement safety stocks, but stock is expensive. So, the problem is to control stocks and to avoid stockout while maintaining a high level of service.

Efforts to reduce the random factors are necessary, but another aspect of possible progress should not be neglected, namely: improving methods for supply planning under uncertainties (Maloni and Belton, 1997).

Demand forecasts give information on the final needs; this information should be transmitted from the distribution centers to the production sites and to the raw material suppliers by means of the planning activities (Ballou, 1999).

In this supply chain the decisions are related to the following questions:

- What are optimal moments and optimal quantities to supply?
- Which product to manufacture, when and how much?
- Which demands to satisfy, with what products and at what quantities?

For this, the Material Requirement Planning (MRP) techniques are widely used. There exist a lot of inventory control software based on the MRP approach.

In a deterministic environment, the MRP logic give an optimal just-in-time schedule. But, for supply planning in a stochastic environment, this method needs some parameterisation. This paper is a survey on this topic, especially on supply planning under uncertainties in MRP systems.

In literature, a number of models exist for dealing with random demand. In addition, this survey analyses the lead time uncertainties, and shows new & promising research areas especially concerning assembly systems with uncertain lead times, for which the main difficulty is in the inter-dependence of components inventories.

At present, only few papers deal simultaneously with uncertainties caused by the demand and lead-time. Yet, considering both aspects in the same time is a more realistic approach, and should interest the academic as well as industrial community. This is highlighted in this survey.

This paper is organized as follows. Section 2, the MRP systems and its parameters are presented. More frequent types of uncertainties are discussed. Section 3 deals with an analysis of literature concerning MRP parameterisation in the case of demand uncertainties. Section 4 presents the literature of lead times uncertainties and both lead time and demand uncertainties. Finally, in Section 5 a conclusion and some perspectives are given.

2. MRP APPROACH

2.1 Basic principles of the MRP systems

The goal of MRP is to determine a replenishment schedule for a given time horizon. For example, lets consider the following bill of materials - BOM (see Fig. 1) for a finished product. The needs for the finished product are given by the Master Production Schedule – MPS (Fig. 2), and the ones for the components are deduced from pegging.

Lets introduce the following notation:
$S(i)$ inventory for the period i,
$N(i)$ net needs for the period i,
$G(i)$ gross needs for the period i,
$O(i)$ released orders for the period i,
Δt lead time.

The available inventory for the first period $S(1)$ is given. For each subsequent need, the value is calculated from the net needs of the previous period:

$$S(i) = \max\{0, -N(i-1)\}, \qquad (1)$$

The net needs of the period i are obtained as follow:

$$N(i) = G(i) - S(i), \qquad (2)$$

The released order quantity:

$$O(i) = \max\{0, N(i - \Delta t)\}, \qquad (3)$$

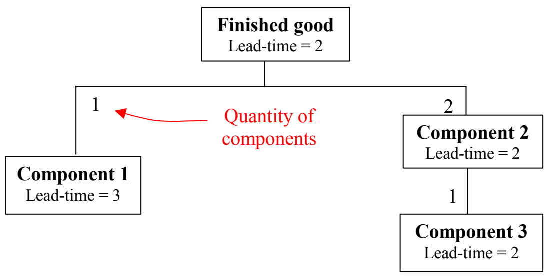

Fig. 1. Bill of materials

Level 0 Finished good Lead time = 2	Period	1	2	3	4	5	6	7	8	9	10
	Gross need (MPS)	0	0	0	50	10	40	20	30	50	60
	Available inventory	20	20	20	20	0	0	0	0	0	0
	Net need	-20	-20	-20	30	10	40	20	30	50	60
	Manufacturing/order	0	30	10	40	20	30	50	60	0	0

Quantity = 1

Level 1 Component1 Lead time = 3	Period	1	2	3	4	5	6	7	8		
	Gross need (MPS)	0	30	10	40	20	30	50	60		
	Available inventory	100	100	70	60	20	0	0	0		
	Net need	-100	-70	-60	-20	0	30	50	60		
	Manufacturing/order	0	0	30	50	60	0	0	0		

Quantity = 2

Level 1 Component 2 Lead time = 2	Period	1	2	3	4	5	6	7	8		
	Gross need (MPS)	0	60	20	80	40	60	100	120		
	Available inventory	140	140	80	60	0	0	0	0		
	Net need	-140	-80	-60	20	40	60	100	120		
	Manufacturing/order	0	20	40	60	100	120	0	0		

Quantity = 1

Fig. 2. Master Production Schedule

2.2 MRP under uncertainties

The main problem which often arises with the MRP systems is derived from the input data uncertainties, especially the time and the quantity uncertainties (see Fig.3).

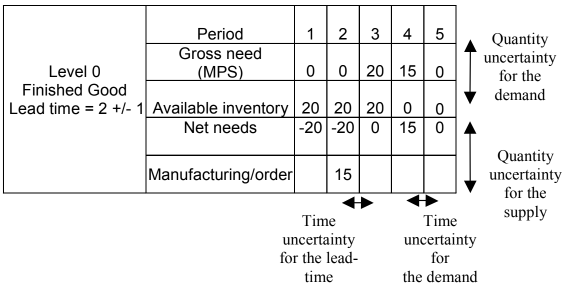

Fig. 3. Input data uncertainties

In literature often only lead time uncertainty (time) and demand level uncertainty (quantity) are considered (Nahmias, 1997; Vollmann *et al*., 1997). The former means that the demand isn't known exactly in advance and, so the planned quantities for a period may be different from the actual demand for this period. The later means that the actual lead time may be different from planned lead time, so the planned supply for a period may not arrive at the appropriate time.

Under uncertainties, MPS of each level needs to be updated quite frequently. Questions that have to be answered are:

- How often should the MPS updating be done? (what is the frequency?)
- Should all the data be updated at the same time?

Continual changes in requirements are likely to give rise to the need to make equivalent continual adjustments to the schedules of plans. The situation of constant plan changes is referred to as *nervousness* (Blackburn *et al*., 1986).

To update all the data as often as necessary is time consuming: the MRP system needs a lot of calculations and has the reputation being overloaded (Plenert, 1999). Also, recalculations cause MRP nervousness and should be done infrequently if possible.

So for small variations of data, one solution is to do only a net-change rescheduling. Otherwise, regenerative rescheduling (recalculation of all the data) has to be performed (Koh *et al*., 2002).

Yücesan and De Groote (2000) did a survey on supply planning under uncertainties, but they focused on the impact of the production management under uncertainty on the lead times by observing the service level. Process uncertainties are considered in (Koh *et al*., 2002; Koh and Saad, 2003).

2.3 MRP parameters

The basic MRP rules work well for an deterministic environment. To adapt the method for an uncertain environment, some parameters should be adjusted (see Fig. 4). Parameters that might soften the effects of these uncertainties are the following:

- safety stocks
- safety lead-time / planned lead time
- lot-sizing rules
- freezing the MPS
- planning horizon

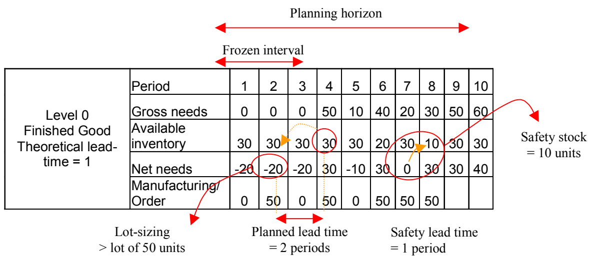

Fig. 4. MRP parameters

2.4 Safety stocks and lead-times

Safety stocks are exceptionally important for production, since they aim circumvent the random factors. Their impact is twofold: reducing the risk of shortages and increasing the holding cost. Hence, they have to be adjusted according to the following objectives:

- to minimize the shortage and holding costs;
- to guarantee a given service level.

Often, the safety stock is calculated for a service level and is equal to n times the standard deviation of the demand. But, according to (Plenert, 1999), it is possible to reduce, or even to remove most of the safety stocks by creating safety capacity in production.

Concerning the *safety lead-time*, this notion it based on the same principle that the safety stock, but, instead of acting on quantities, it works on the time. Usually, the safety lead-time is equal to k times the standard deviation of the lead-time (Melnyk and

Piper, 1981). The *planned lead-time* is equal to the theoretical lead-time plus the safety lead-time.

According to Whybark and Williams (1976), safety stocks should be used when there are uncertainties in quantities, and safety lead-time when the problem is dealing with the estimating the theoretical lead-time. Thus, it seems that the cost of the inventory is minimized and the service level is satisfactory in a MRP system using this principle. Furthermore, these results are valid for any source of uncertainty, lot-sizing rule, level of demand, lead-time, and level of uncertainty (Vollmann *et al.*, 1997). Nevertheless, Grasso and Taylor (1984) have reached another conclusion and prefer safety stocks for both quantity and lead-time uncertainties.

De Bodt and Van Wassenhove (1983) report that the use of safety stocks is not appropriate when the variability of the demand is low, and the time between the orders is small. Lowerre (1985) suggests an order requirement scheduling for MRP systems, to plan for changes. This provides a proportional safety stock to combat errors of forecasting for both time and quantity uncertainties.

2.5 Lot-sizing rules

It is often better to group orders together, instead of ordering by lot-for-lot rule (LFL), *i.e.* to order only the net needs for a single period. The LFL permits reducing inventory but does not take into consideration economical aspects and organizational constraints. Sometimes, the ordering cost is very expensive in relation to the holding cost, so lot-sizing is needed.

There exist many lot-sizing rules. The principal ones are:

- the Economic Order Quantity (EOQ);
- the Periodic Order Quantity (POQ);
- the Wagner-Within algorithm (WW).

The *Economic Order Quantity* (EOQ) was introduced by Harris in 1913. It is the easiest technique. It calculates a fixed quantity to order by the Wilson formula (Lee and Nahmias, 1993), but the time between the orders may vary. De Bodt *et al.* (1982) reported that, with large errors in forecasting, the EOQ rule may be preferable. From the EOQ, it can be deduced the *Periodic Order Quantity* (POQ): an optimal constant time between orders is calculated, and from the optimal constant time, the necessary quantity to order for each period is obtained.

The *Wagner-Within* algorithm – WW (1958) is a procedure that determines the minimal order cost for a dynamic deterministic demand without capacity constraint.

Since Wagner-Within algorithm is time-consuming for real size problems (Jeunet and Jonard, 2000), many heuristics have been developed, including the three following:

- *Silver-Meal* heuristic– SM (1973), permits to cover *p* periods with only one order. The aim is to find *p* that minimizes the average inventory cost by period. This heuristic is often more powerful than WW in case of uncertainties;
- *Least Unit Cost* (LUC) is a procedure that estimates different order quantities by accumulating the needs of the periods until the cost begins increasing (Backer, 1993);
- *Part Period Balancing* – PPB (De Matteis and Mendoza, 1968) permits to find the number of periods to cover in order to equilibrate the set up cost (or ordering cost) and the holding cost.

Lot-sizing models with capacity constraints can be found in (Lee and Nahmias, 1993), and models with variation of the supply cost in (Martel and Gascon, 1998). A ranking of the most known lot-sizing rules with their parameters appeared in (Kuik *et al*., 1994). In addition they offer a discussion about the main criticisms associated with lot-sizing.

It should be noted that available software tools for production planning usually implement only few rules, such as LFL, EOQ, POQ, and, only in some cases, WW and SM. As the computing times for the latter rules are higher than for the three former, it could be useful, before the application of WW or SM, to group products into families which use the same components and pieces of equipment, and follow the same tendency (Giard, 1981). Nevertheless, if the needs of the higher BOM level are grouped together, it might not be the best solution for the total cost when including all lower levels (a decision taken at one level of the BOM is thrown back to the lower levels). Moreover, if the holding cost is high in relation to the ordering cost, the LFL rule is quite acceptable.

So, it is difficult to find a lot-sizing rule that is optimal in general and at all levels. Plenert (1999) suggested to apply the LFL rule to A-class, and most of B-class parts, according to the Pareto classification, except some specific cases. For example, Ho and Lau (1994) demonstrated that, with uncertain lead times, SM rule provides better results.

In general, with demand and lead time uncertainties, the relative efficiency of lot-sizing rules performances is not stable. For example, Fildes and Kingsman (1997), cited by Koh *et al*. (2002), made a relevant study with uncertainties on the demand level and have seen this effect. Therefore, in the case of uncertainties, one should first try to improve the forecast performances (Nahmias, 1997; Dolgui *et al.*, 2004; Pashkevich and Dolgui, 2005).

2.6 Master Production Schedule (*MPS*)

The MPS gives the production plan (*i.e.* quantities to produce in a given future period), and is obtained by analysis on demand level, inventories, lead times, production capacities, and costs. The MPS is also a mean of communication between the departments of a company in order to coordinate their actions in space and time.

The aim of the MPS is to anticipate the future needs and be able to implement actions with an acceptable lead-time (supplying of components, for example), in order to minimize the total cost. The time periods at which the MPS is done, is called planning horizon. To be adapted to the production system's dynamic nature, the time horizon can be limited instead of a theoretically infinite one. Then, the time must be rolled at a certain frequency. So, there are a rolling time horizon and a replanning frequency. Thus, data is periodically updated and new information can be integrated, giving a more accurate view of the production system.

Fig. 5 gives an example with a planning horizon (PH) consisting of 8 periods, a frozen horizon (FH) of 3 periods, and a replanning frequency (RF) of 2 periods.

The choice of the replanning frequency is an important and complex problem. One has to compromise between the need of information updating and the nervousness produced by too many changes of the MRP data. It is possible to reduce the phenomena by freezing the MPS. Therefore, any modification is forbidden during the frozen periods, even if a rescheduling occurs.

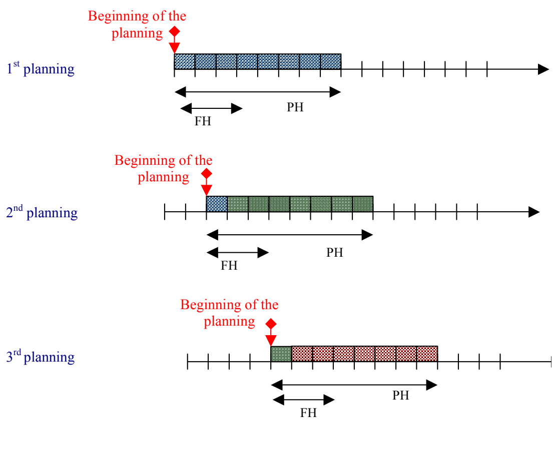

Fig. 5. Rolling time horizon

3. DEMAND UNCERTAINTIES

In this Section, demand uncertainty is discussed. This kind of uncertainty occurs when the needs for finished products vary from earlier forecasts. That also induces some changes in the components needs calculated by pegging. This variation may provoke either some shortages or some surplus in inventories, and this increases costs. Another problem is inherent with this kind of uncertainty is nervousness. Thus, it is necessary to parameterise MRP systems in order to soften this phenomenon.

3.1 Nervousness

Nervousness is generated from demand or lead-time uncertainties, but the former is the most studied.

To limit the nervousness caused by demand, there exist various means such as acting on the MPS or choosing a good lot-sizing rule.

Most of the nervousness comes from modifications of the MPS. Yet, infrequent MPS changes lead to a poor service level and an increase in inventory. So, the goal is to find an adequate compromise. Common methods are based on the frozen horizon, or on application of specific rules (time fences) concerning possibilities of modification of the MPS depending on the considered period. They permit steady objective for the production system.

To obtain better results, rescheduling should be done at the end of the frozen period (Zhao and Lam, 1997). Furthermore, a good forecast on the planned horizon plus freezing the MPS act against the internal supply uncertainties caused by the lot-sizing rules. As freezing the MPS alone is sometimes not sufficient, it is necessary complement this by utilizing an adequate *lot-sizing rule* .

The main results on the nervousness due to demand uncertainty are presented in Table 1, where "applications" is the kind of system studied and "results" is the conclusion or some advices.

Some lot-sizing rules can generate more nervousness than others (Vollmann *et al.*, 1997). This means that they can provoke great changes in scheduling even if the originally modifications are small. This can be observed as well for the demand level, due date, order quantity, and lead time. These phenomena are particularly visible with the POQ rule.

Also if planned orders are made too early, or if MRP parameters are not properly chosen again they become apparent. The higher the number of BOM levels there are, the larger the amplitude of the effects.

Table 1 Nervousness caused by demand uncertainty

Action	Parameter	Paper	Applications	Results
Lot-sizing rules	**Modified Costs** (Blackburn and Millen, 1982ab)	Zhao and Lam, 1997	Rolling horizon Known demand	Methods the more effective under most conditions
	PPB / SM	Ho and Ireland, 1998	Forecast errors Deterministic lead-times Multi-level products Rolling horizon	Methods creating less nervousness, particularly when forecast errors are large
	EOQ / LFL	Ho and Ireland, 1998	Uncertain demand Deterministic lead-times Multi-level products Rolling horizon	Methods creating more nervousness in relation to PPB and SM
MPS	**Rescheduling**	Zhao and Lam, 1997	Rolling horizon Known demand	Replanning after the frozen period
	Freezing the MPS	Zhao and Lee, 1993, 1996	Multi-level products	Strategy the more advantageous
		Blackburn et al., 1986	Rolling horizon Multi-level products	Dominating strategy with a change cost procedure (among 5 tested strategies)
		Sridharan and LaForge, 1994	One finished good having a demand with normal distribution	Utilization against demand uncertainties = small decrease of the service level

One method could be to choose the EOQ or the LFL for the higher level and those levels immediately inferior, then to use the POQ for all the other levels. As the EOQ use only the order release date (and not the order quantity), the nervousness can be reduced.

3.2 General approaches

For MRP parametrization with demand uncertainties, a basic model, at least in discrete cases, is the Newsboy one. In fact, the *Newsboy model* is more interesting by its structure (generalizable) than by its initial (particular) field of utilisation for products with low life cycle (Lee and Nahmias, 1993).

Another approach is the determination of MPS parameters using freezing or rescheduling. Yeung *et al.* (1998) show that the *freezing* can be calculated either by number of orders (order-based), or by number of periods (period-based). The former better decreases the total cost; a similar conclusion is also obtained by Lin and Krajewski (1992) with a multi-level product, but they did not take into account the backlogging cost on the finished good.

Nevertheless, some authors believe that demand uncertainties are not always a bad thing: they provoke forecast errors true, but if the bias is positive, then this creates extra inventory that could work as a safety net in case of unplanned demands.

Lee and Adam (1986), and Biggs and Campion (1982) (cited by Yeung *et al.*, 1998) develop this idea. But Zhao and Lee (1993) disagree. Following their simulation for a product with a multi-level BOM, an increase of the costs and a fall of the service level are observed when forecast errors occur.

Jeunet and Jonard (2000) measure the degree of stability (robustness) in planned orders provided by lot-sizing models in response of changes in demand estimate. The authors show that the cost of frequently adjusted planning orders and performances of the lot-sizing methods depend on flexibility of the production system.

From Tables 2 to 4, it is possible to conclude that a lot of approaches and cases treated, where "applications" means the particularity of the system on which the parameter is tested. Table 2 shows papers dealing with the use of lot-sizing rules to reduce the effects of demand uncertainties. Table 3 presents actions on MPS. Then, Table 4 gives some advice concerning safety stocks calculation.

Table 2 Lot-sizing rules

Lot-sizing rules	Paper	Applications	Results
PPB	Gomaa et al., 1999	Multi-level system considering a cost structure, a demand distribution, nervousness and inventory level	Mathematical program giving the best results with PPB rule (among 9 others rules under consideration)
SM	Kazan et al., 2000	One-level system Rolling horizon	Best method for high setup cost/holding cost ratio Nervousness due to rolling horizon (use of a modified SM rule)
	Jeunet and Jonard, 2000	One-level system	A good compromise for systems with an average flexibility (cost, computational time, robustness)
POQ / LUC	Jeunet and Jonard, 2000	One-level system	For systems with a little flexibility
Optimal methods (WW)	Jeunet and Jonard, 2000	One-level system	For flexible systems

Table 3 Actions on MPS

Action	Papers	Applications	Results
Safety MPS	Grubbström and Molinder, 1996	Multi-level product	Reduce order, holding and backlogging costs (To cumulate the uncertainties on the higher level before rescheduling)
Size of horizon	Zhao and Lee, 1993	Multi-level product	Horizon extension can debase MRP performances
Rescheduling	Yano and Carlson, 1985	One two-level product	Safety stocks and reduction of rescheduling frequency economically more efficient
Freezing the MPS	Sridharan and LaForge, 1994	One product	Extension of the frozen period leads to more inventory
	Lin and Krajewski, 1992 Yeung et al., 1998	Multi-level product without shortage cost	Order-based method better than period-based one in term of total cost
	Sridharan and Berry, 1990	One product Rolling horizon	Too long freezing provokes an increase of costs due to forecast errors

4. LEAD-TIME UNCERTAINTIES

This section deals with random lead-times studies. That means that the time needed to receive a component may vary from forecasted. As with random demand, lead-time uncertainties provoke either some shortages or surplus in inventories. These uncertainties have been neglected for a long time in favour of studying demand uncertainties. However, in industrial world, it is often concluded that problems of uncertainties are not limited to variations of the demand level, but also to fluctuations on the lead-times. That is why, nowadays, this gap in research activity begins to be filled in order to respond to companies having non-deterministic lead-times constraints.

An uncertain lead-time can also generate nervousness. In this case, the only mean to reduce it, is to find an appropriate MRP parameterisation. In more general cases, a good parameter is still the safety lead-time, but one can choose an effective lot-sizing rule.

Finally, for simultaneous random demand and random lead-times, in most cases, the parameters used are the lot-sizing rules, safety lead-time and safety stocks.

Table 4 Safety stocks calculation

Paper	Applications	Results
Bai et al., 2002	Multi-level product	Good to have a certain service level
Zhao and Lee, 1993	Multi-level product	Increase of costs and decrease of service level when forecast errors raise
De Bodt and Van Wassenhove, 1983	One product in rolling horizon	Safety stocks profitable: - a low setup cost and time between orders, - a low demand variability
Grubbström and Tang, 1999	Demand following a Gamma law Multi-level product	Optimal value of safety stocks reduced when variance on the demand decreases, and easily found when the LFL is used on the low levels
Grubbström, 1998	One level Finite horizon	Determine a level of safety stock for the MPS calculation before knowing the demand (use of the Laplace transforms)

Summary of the more essential papers on the lead-time uncertainties and simultaneous demand and lead-time uncertainties is presented in Tables 5 and 6, with comments on the solutions used and the results obtained.

A great part of the specificities of these systems has already been tackled in the publications. Note that few parameters have been studied.

As evident from Tables 5 and 6, there still a lot of work left in this domain. Safety stocks have not been studied adequately, certainly because of Whybark and Williams (1976), who proposed to use safety lead-times when uncertainties occur on lead-times.

Lot-sizing rules have not been studied in depth, especially concerning assembly systems that have an additional complexity due to the interdependence of inventories for the components for assembly (components used for several products).

Concerning actions on the MPS, they have not been studied for lead-time uncertainties. However, these could be promising especially for simultaneous lead-time and demand uncertainties.

Finally, some other papers deal with the lead-time uncertainties, but not in a MRP environment (Weiss and Rosenthal, 1992; Parlar and Perry, 1995; Bookbinder and Çakanyildirim, 1999; Çakanyildirim *et al.*, 2000; Ben-Daya and Hariga, 2003; Arda and Hennet, 2004). These results can be useful to find new ideas to develop for example the supplier availability, studied for (S,s) systems.

Table 5 Lot-sizing under lead-time uncertainties

Lotsizing rule	Paper	Applications	Results
PPB	Ho and Lau, 1994	Multi-level products, Rolling horizon, Variation on product structure, length of lead-times and cost structures that could make results of lot-sizing change	Mean total related cost is more reliable and more stable
LUC	Gupta and Brennan, 1994,1995	Multi-level products, Rolling horizon.	The results depend on the product structure, but the LUC is the more reliable method, it obtains low costs in most cases
EOQ	Gupta and Brennan, 1995,1996	Multi-level products, Rolling horizon.	Best method when uncertainties are on every level of the BOM or for the case of both demand and lead-time uncertainties
WW	Gomaa et al., 1999	Multi-level product	Mathematical program working the best with WW

Table 6 Safety stocks and lead time

Action	Papers	Applications	Results
Safety stocks	Gudum and Kok, 2002	Ensure a target service level under demand and lead-time uncertainties for multi-level products	Safety stock adjustment procedure
	Molinder, 1997	Uncertain demand and lead-times	Variability : - high for the demand and low for the lead-times >Safety stocks - high for both > Safety lead-time
Safety lead-times	Hegedus and Hopp, 2001	Assembly of a multi-component product under limited production capacities	Method minimizing inventory costs while ensuring a service level
Planned lead-times	Dolgui and Louly, 2002	Assembly of a multi-component product Infinite supply capacities and lead-time independent from size lot	Markovian model for a dynamical multi-period planning
	Louly and Dolgui, 2002b,c, 2003	Assembly a multi-component product	Optimal method minimizing average holding costs and backlogging on finished products

Table 7 Reference papers on MPS

Action	Comments	Reference papers	Other papers
Rescheduling / horizon	Try to reduce the number of rescheduling in the case of demand errors, but to not degrade performances of MRP system, do not increase to much the length of the horizon	Yano and Carlson, 1985 Zhao and Lee, 1993	Sridharan and Berry, 1987, 1990 Grubbström and Molinder, 1996 Yeung et al., 1998 Bai et al., 2002
Freezing the MPS	Permit to decrease the costs due to instabilities in the case of forecast errors, but also decrease a bit the service level and raise the stocks	Sridharan and Berry, 1990 Sridharan and LaForge, 1994 Zhao and Lee, 1993, 1996	Sridharan et al., 1987 Blackburn et al., 1986 Zhao and Lam, 1997 Yeung et al., 1998 Bai et al., 2002

Table 8 Best papers on safety stocks and lead-times

Action	Comments	Reference papers	Other papers
Safety lead-times / planned lead-times	Uncertain lead-times	Whybark and Williams, 1976	Molinder, 1997 Hegedus and Hopp, 2001 Dolgui et al., 1995 Dolgui, 2001 Dolgui and Louly, 2002 Louly and Dolgui, 2002b,c Louly and Dolgui, 2004 Chauhan et al., 2003
Safety stocks	Service level under an uncertain demand and a low setup cost	Whybark and Williams, 1976 De Bodt and Van Wassenhove, 1983	Blackburn et al., 1986 Lee and Adam, 1986 Zhao and Lee, 1993 Grubbström, 1998 Grubbström and Molinder, 1996 Molinder, 1997 Grubbström and Tang, 1999 Bai et al., 2002 Gudum and Kok, 2002

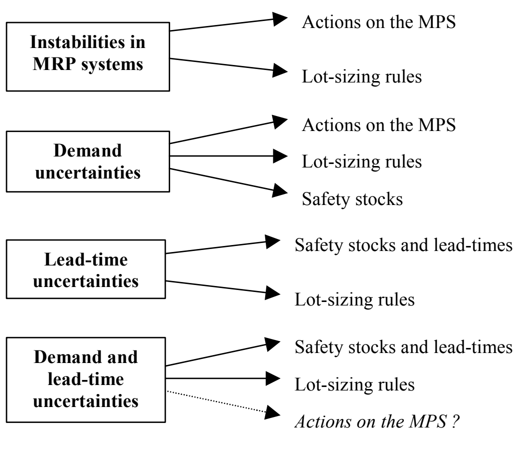

Fig. 6. Techniques commonly used

Table 9 Reference papers on lot-sizing rules

Rule	Comments	Reference papers	Other papers
PPB	Permit to have less instability especially when a high forecast errors occur on the demand	Ho and Lau, 1994	Ho and Ireland, 1998 Gomaa et al., 1999
LUC	Method the most robust in case of lead-time uncertainties and the best for one-level system with uncertain demand and a little system flexibility	Gupta and Brennen, 1994, 1995 Jeunet and Jonard, 2000	De Bodt and Van Wassenhove, 1983
SM	To have less instability in case of forecast errors on the demand	Ho and Ireland, 1998 Kazan et al., 2000	Blackburn and Millen, 1982a,b De Bodt and Van Wassenhove, 1983 Ho and Lau, 1994 Zhao and Lee, 1993, 1996 Zhao and Lam, 1997 Jeunet and Jonard, 2000
WW	When uncertainties on demand or lead-times are low and the system is flexible	De Bodt and Van Wassenhove, 1983 Jeunet and Jonard, 2000	Blackburn and Millen, 1982a,b Ho and Lau, 1994 Zhao and Lam, 1997 Kazan et al., 2000
POQ	For little flexible systems in case of demand uncertainties	Jeunet and Jonard, 2000	Gupta and Brennan, 1994
EOQ	When uncertainties occur on lead-time on every level or simultaneously on demand and lead-times	Gupta and Brennen, 1995 Brennen and Gupta, 1996	De Bodt et al., 1982 De Bodt and Van Wassenhove, 1983 Ho and Lau, 1994 Ho and Ireland, 1998 Jeunet and Jonard, 2000
LFL	Finished goods or items from A-class (Pareto)	Plenert, 1999	Blackburn et al., 1986 Ho and Lau, 1994 Ho and Ireland, 1998

5. CONCLUSIONS

This survey focused on the parameterisation of MRP systems under demand and lead-time uncertainties. With the expansion of the supply-chain paradigms, replenishment planning becomes more and more important. That is why studies on this topic have great interest (Prodhon, 2003).

The use of the safety stocks is very common to limit the risks of shortages due to random factors. However, this is a method that could sometimes be rather expensive. The search for efficient solutions which limit costs while satisfying customers is essential.

A number of studies have been done on demand uncertainty. Yet, concerning the lead-times, the number of publications is modest, particularly concerning multi-level products or assembly systems. These have an additional difficulty in having interdependent inventories of components used for the assembly of multiple products. Unfortunately, there are no methods which take into account all these uncertainties. This problem appears much too complex. In (Dolgui and Louly, 2001b; Louly and Dolgui, 2002a) the optimisation of the replenishment planning in an globally uncertain environment has been proposed the use of a toll box, grouping together some partial models and simulations.

Fig. 6 resumes techniques commonly used for the encountered problems. Tables 7-9 show the main influences of the parameters and the authors having dealt with this problem. Table 7 focuses on the MPS, while Table 8 deals with safety stocks and lead-time. Finally, Table 9 sums up the papers on lot-sizing rules.

In fact, this field still has a great deal of useful work ahead of it with considerable interest to the industrial sector. Taking into account simultaneously uncertain demand and lead-time is the most complex problem at present and the least studied. If satisfactorily, solved this will permit a more realistic evaluation of industrial systems and be of a great practical value.

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