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Supply planning under uncertainties in MRP environments: A state of the art

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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. Models from literature that deal with random demand or lead time uncertainties are described and commented. Promising research areas emerge from this survey. It appears that lead time uncertainty has been ignored in the past, in spite of their significant importance. In particular, an interesting topic concerns assembly systems with uncertain lead times, for which the main difficulty comes from the inter-dependence of components inventories. Another promising issue, which is also presented, relates to supply planning under simultaneously demand and lead time uncertainties, which is certainly of great interest for both the academic and industrial communities.

Keywords: Production systems; Inventory control; Planning; Uncertainty

1. Introduction

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

This is especially true when uncertainties occur. Koh, Saad, and Jones (2002) classify them in two main categories: input (as external supply or demand reliability) and process (as machine breakdown, etc.). To minimize the influence of these uncertainties, enterprises implement safety stocks, but stock is expensive. So, the problem is to control inventories 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 & Benton, 1997).

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?

The choice of replenishment policies is important and depends on the type of product. Hautaniemi and Pirttilä (1999) propose a classification of the items to select an appropriate method.

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). 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 gives an optimal just-in-time schedule. But, for supply planning in a stochastic environment, this method needs some parameterisation.

The previous states of the art can be find in the following papers. Yeung, Wong, and Ma (1998) propose a review on

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parameters having an impact on the effectiveness of MRP systems under deterministic or stochastic environment. Yücesan and De Groote (2000) give a survey on supply planning under uncertainties, but they focus on the impact of the production management under uncertainty on the lead times by observing the service level. Process uncertainties are considered by Koh et al. (2002) and Koh and Saad (2003). Very recently, Mula, Poler, Garcia-Sabater, and Lario (2006b) present a review for production planning under uncertainty. They categorize papers into four modelling approaches (conceptual, analytical, artificial intelligence and simulation).

This is a new survey on supply planning under uncertainties in MRP systems (a first version of this paper has been presented at the 16th IFAC World Congress (Dolgui, Louly, & Prodhon, 2005)). In literature, a number of models exists for dealing with random demand. The principle results are analyzed in this paper. In addition, it analyses the lead time uncertainties, and shows new and promising research areas especially concerning assembly systems with uncertain lead times, for which the main difficulty is in the inter-dependence of components inventories. Finally, 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 nervousness of the system under uncertainties. Section 4 presents the literature concerning demand uncertainties. Lead times and both lead time and demand uncertainties are discussed in Sections 5 and 6, respectively. Finally, in Section 7 a conclusion and some perspectives are given.

2. MRP approach

2.1. The basic principles of 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. If the latter is a direct assembly of several components, the system is said to be one-level and *multi-item*. If there are other levels in the BOM, thus we have a *mutli-level* system.

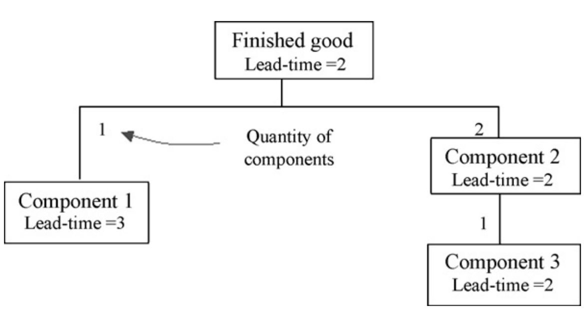

Fig. 1. Bill of materials.

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.

Finally, if the production of the finished product need several successive operations, the system is said *multi-stage*. 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.

Let 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:

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

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

$$N(i) = G(i) - S(i) \tag{2}$$

The released order quantity is

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

2.2. MRP under uncertainties

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

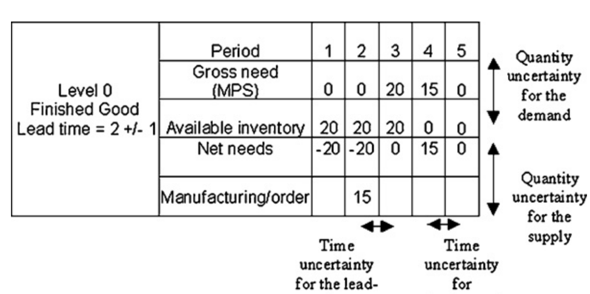

Fig. 3. Input data uncertainties.

In literature often only demand level uncertainty (quantity) and lead time uncertainty (time) are considered (Nahmias, 1997; Vollmann, Berry, & Whybark, 1997). The former means that the demand is not 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 scheduled plans. Updating all the data as often as necessary provoke the situation of constant plan changes, referred to as nervousness (Blackburn, Kropp, & Millen, 1986). Furthermore, recalculations are time consuming: the MRP system needs a lot of calculations and has the reputation being overloaded (Plenert, 1999). An other consequence of changes is the cost related to scheduled orders adjustment (personnel scheduling, machine loading, . . .). This one is more or less important depending on the flexibility of the production system. For these reasons, modifications should be done infrequently if possible.

Thus 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).

2.3. MRP parameters

The basic MRP rules work well for a 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 ones:

- safety stock;
- safety lead time/planned lead time;
- lot-sizing rules;
- freezing the MPS;
- planning horizon.

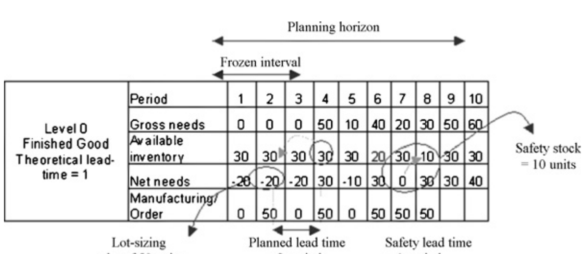

Fig. 4. MRP parameters.

2.4. Safety stock and safety lead time

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 & 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 of 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 & 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–Whitin algorithm (Wagner & Whitin, 1958) (WW) is a procedure that determines the minimal order cost for a dynamic deterministic demand without capacity constraint.

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

- Silver–Meal heuristic (Silver & Meal, 1973) (SM) 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 & 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.

Lambrecht et al. (1983) compare some heuristic procedures for multi-stage assembly systems under deterministic environment. 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 on 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 (Dolgui, Pashkevich, & Pashkevich, 2004; Nahmias, 1997; Pashkevich & 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 when 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 eight periods, a frozen horizon (FH) of three periods, and a replanning frequency (RF) of two 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.

3. Nervousness

Nervousness is relative to the continual adjustments in the schedules. Yet, infrequent MPS changes lead to a poor service

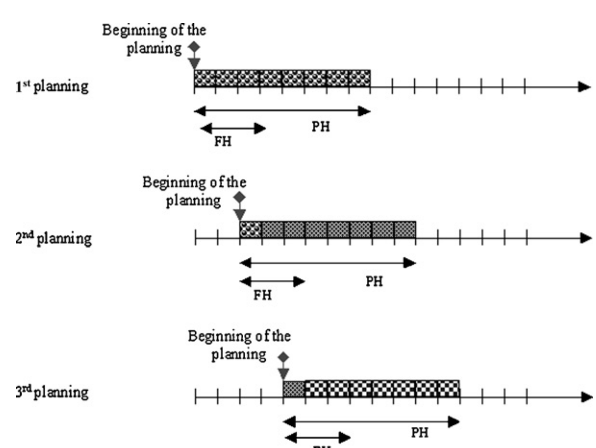

Fig. 5. Rolling time horizon.

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 & 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.

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 variations on the demand level, due date, order quantity, and lead time. This phenomenon is particularly visible with the POQ rule.

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

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 POQ uses only the order release date (and not the order quantity), the nervousness can be reduced.

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.

Lots of papers deal with instability under MRP environment. For example, with deterministic demand, on a multi-level assembly system, Simpson (1999) proposes some heuristics dealing with the weighted order cycle, and a lower bound, to minimize the total costs. He suggests the use of modified costs to reduce nervousness. However, most of the time, nervousness is studied under demand uncertainty, as shown in Table 1. The column entitled *Paper* gives the reference paper, *Criteria* refers to the objective targeted by the authors, the column *Parameters* gives the parameters used in the paper, *Type of system* provides the kind of system handled and the *Comments* notify the specificity of the method and the advises or noticeable remarks.

4. Demand uncertainties

In this section, random demand is more specifically 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

Table 1
Dealing with nervousness (simulation)

Paper	Criteria	Parameters	Type of system	Comments
Blackburn et al. (1986)	System inventory and ordering costs	Five strategies (**freezing**, forecast, . . .)	Multi-level, uncertain demand	
Sridharan and Berry (1990)	Change and inventory costs, service level	**Freezing**, replannification	One-level, uncertain demand	No backorders
Zhao and Lee (1993)	Holding, set up and shortage costs, service level	**Freezing**, replannification, planning horizon	Multi-level, uncertain demand	No backorders, increase the cost, decrease the service level
Ho and Lau (1994)	Carrying, set up, extra inventory and rescheduling costs	**Lot-sizing**	Multi-level, uncertain lead time	Five lot-sizing rules: PPB/SM better against nervousness
Sridharan and Laforge (1994)	Service level	**Freezing**	Single-item, uncertain demand	Decrease of the service level
Ho and Ireland (1998)	Set up and inventory carrying costs	**Lot-sizing**	Multi-level, uncertain demand and lead time	Four lot-sizing rules: PPM/SM better than EOQ/LFL with big forecast errors
Gomaa, Hussien, and Zahran (1999)	Set up, holding and shortage costs	**Lot-sizing**	Multi-level, uncertain demand or lead time	Nine lot-sizing rules among 10 factors: PPB advised
Jeunet and Jonard (2000)	Set up and carrying costs	**Lot-sizing**	One-level, uncertain demand	Nine lot-sizing rules: use POQ/LUC/PPB with not flexible systems and exact method (WW) with flexible systems
Kazan, Nagi, and Rump (2000)	Change, set up and holding costs	**Lot-sizing**	One-level, uncertain demand	Three lot-sizing rules: use SM with modified costs
Bai, Davis, Kanet, Cantrell, and Patterson (2002)	Change, holding set up costs, service level	**Freezing**, lot-sizing, safety stock, replannification	Multi-level, uncertain demand	

Parameters in bold are the recommended ones.

pegging. As we have just seen, this variation may provoke nervousness. Another problem that is inherent with this kind of uncertainty is about inventories. It may appear either some shortages or some surplus, and this increases costs. Thus, it is necessary to parameterize MRP systems in order to soften these phenomenons.

Under 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 & Nahmias, 1993).

Another approach is the determination of MPS parameters using freezing or rescheduling. Yeung et al. (1998) remind in their review 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 as shown by Lin and Krajewski (1992) with a multi-level product, but they did not take into account the backlogging cost on the finished good.

From Table 2, it is possible to conclude that a lot of approaches and cases are treated. The method mainly used is simulation, except the works from Grubbström in which a model based on Laplace transform is used. The columns used are the same as in Table 1. We can see that the main parameters, i.e. lot-sizing rules, actions on MPS and safety stocks, have been studied to try to reduce the effects due to uncertain demands.

Nevertheless, some authors believe that these 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.

Another recent approach to manage demand uncertainties is to use a fuzzy model. This is what is done by Grabot, Geneste, Reynoso-Castillo, and Verot (2005) for a system with multi-product and multi-level. They find that this formulation is reacher semantically than in a traditional MRP.

5. Lead time uncertainties

This section deals with random lead times studies. That means the time needed to receive a component may vary from forecasted. As with random demand, lead time uncertainties may 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

Table 2
Demand uncertainty

Paper	Criteria	Parameters	Type of system	Comments
De Bodt and Van Wassenhove (1983)	Inventory holding and ordering costs	Lot-sizing, **Safety stocks**	One-level	Recommended with low setup cost, low demand variability, low TBO
Sridharan and Berry (1990)	Change and inventory costs, service level	**Freezing**, replannification	One-level	No backorders, too long freezing increases costs due to forecast errors
Zhao and Lee (1993)	Holding, set up a shortage costs, service level	Freezing, replannification, **planning horizon**	Multi-level	
Sridharan and Laforge (1994)	Service level	**Freezing**	Single-item	Extention of the frozen period leads to more inventory
Grubbström and Molinder (1996)	Sep up, inventory holding and backlogging costs	**Safety MPS**	One and two-level	Model, Poisson-distributed demand
Grubbström (1998)	Annuity stream criterion	**Safety stocks**	One-level	Model, Poisson-distributed demand
Grubbström and Tang (1999)	Net present value	**Safety stocks**	Multi-level	Model, Gamma-distributed demand
Gomaa et al. (1999)	Nervousness, set up, holding and shortage costs	Nine **lot-sizing** rules among 10 factors	Multi-level	Math. program, PPB advised
Kazan et al. (2000)	Change, set up and holding costs	**Lot-sizing**	One-level	SM advised with high setup/holding cost ratio
Jeunet and Jonard (2000)	Set up and inventory carrying costs	**Lot-sizing**	One-level	Depending on system: SM (average flexibility), POQ/LUC (low flexibility) WW (high flexibility)
Tang and Grubbström (2002)	Holding, stockout, rescheduling costs	**Freezing, replannification**	One-level	Optimisation
Bai et al. (2002)	Change, holding set up costs, service level	Freezing, lot-sizing, **safety stock**, replannification	Multi-level	Safety stocks are good to have a certain service level
Grubbström and Wang (2003)	Net present value	**Safety stocks**	Multi-level, multi-stage, capacity	Model, Poisson-distributed demand

Parameters in bold are the recommended ones.

Table 3
Lead time uncertainty

Paper	Criteria	Type of system	Comments
Safety lead time			
Hegedus and Hopp (2001)	Inventory cost, service level	Multi-component	Optimization, minimize inventory costs while ensuring a service level
Dolgui and Louly (2002)	Holding and backlogging costs	Multi-component	Markovian model for a dynamical multi-period planning
Louly and Dolgui (2002a, b, 2003)	Holding and backlogging costs	Multi-component	Optimization
Lot-sizing rules			
Ho and Lau (1994)	Carrying, set up, extra inventory and rescheduling costs	Multi-level	PPB/SM advised
Gupta and Brennan (1994, 1995)	Set up, inventory, shortage costs, service level	Multi-level	LUC/EOQ advised
Gomaa et al. (1999)	Nervousness total cost	Multi-level	Math. program, simulation, WW advised

still the safety lead time, but one can choose an effective lot-sizing rule.

Summary of the more essential papers on the lead time uncertainties is presented in Table 3, in which the columns provide the same information as in Table 1. The works are mainly done by simulation except when it is specified in column *Comments*. It clearly appears that the exploration of this kind of uncertainty is still sporadic. Particularly, 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 explored 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.

A recent paper dealing with a variant of random lead time is from Gurnani and Gerchak (2007). They study the problem of coordination in assembly systems where a single component can be provided by several suppliers, each one choosing their production quantities. Furthermore, the suppliers' output exhibit random yields.

Dellaert and Jeunet (2005) study the impact of a positive lead time on multi-level lot-sizing rules. They find that it can be seen as an alternative to the use of safety stocks.

Finally, some other papers deal with the lead-time uncertainties, but not in a MRP environment (Arda & Hennet, 2004; Ben-Daya & Hariga, 2003; Bookbinder & Çakanyildirim, 1999; Çakanyildirim, Bookbinder, & Gerchak, 2000; Fujiwara & Sedarage, 1997; Parlar & Perry, 1995; Weiss & Rosenthal, 1992). These results can be useful to find new ideas to develop for example the supplier availability, studied for (S,s) systems.

6. Both demand and lead time uncertainties

Finally, this section is about simultaneous random demand and random lead times. As evident from Table 4, there still a lot of work left in this domain. The information given in the columns are of same type as in Table 1. In most cases, the parameters used are the lot-sizing rules, safety lead time and safety stocks.

A great part of the specificities of these systems has already been tackled in the publications. Note that few parameters have been studied and actions on the MPS have been neglected. However, these could be promising especially for simultaneous lead time and demand uncertainties.

Nevertheless, there is a tendency to explore such complex systems nowadays. Morel, Panetto, Zaremba and Mayer (2003) propose a modelization using the principle of Holonic Manufacturing System. Vandaele and De Boeck (2003) develop a software dedicated to high level tuning under input and output uncertainties. The aim is to find a reduced lead time, optimal lot-sizing and the utilisation levels of the system in order to guarantee a high customer service level. Koh and Saad (2006) present a business model to diagnose the underlying causes of uncertainties.

In fact, the research tends to consider more realistic system by integrating capacity constraints for example. Koh, Saad, and Padmore (2004) propose a generic method that leads to an accurate simulation of MRP-controlled finite-capacitated manufacturing environment. Bollapragada and Rao (2006)

Table 4
Demand and lead time uncertainty (simulation)

Paper	Criteria	Parameters	Comments
Brennan and Gupta (1996)	Set up, inventory, shortage costs, service level	Lot-sizing	EOQ and backorders integrated in lot-sizing rules
Molinder (1997)	Set up, stockout, inventory costs, service level	Safety stocks, safety lead time, lot-sizing	Safety stocks for high variability of demand and low variability of lead time, safety lead time for high variability of demand and lead time
Ho and Ireland (1998)	Nervousness	Lot-sizing	PPB/SM advised
Koh and Saad (2003)	Delivery late	Eight parameters	Planned lead time advised

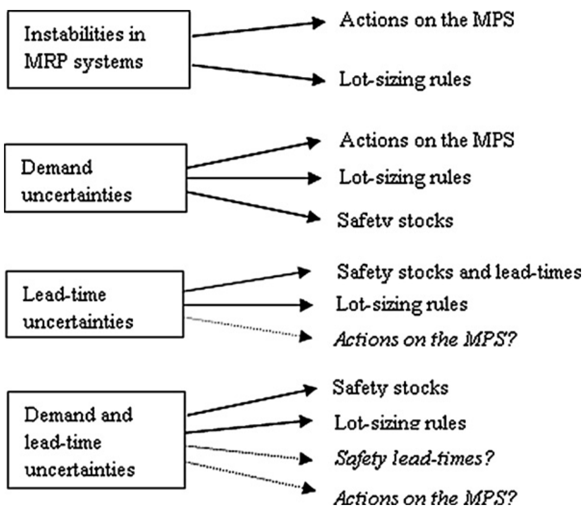

Fig. 6. Techniques commonly used.

study the replenishment planning under supply and demand uncertainties for a single product within a finite horizon with discrete time, and with capacity limits and service level requirements.

Another approach that appears is the use of fuzzy model to deal with uncertainties. That is what Chen and Huang (2006) and Mula, Poler, and Garcia (2006a) work on.

Finally, one can find some other papers dealing with demand and lead time uncertainties, but not in a MRP environment (Arda & Hennet, 2006; Kim, Chatfield, Harrison, & Hayya, 2006).

However, very few papers explore more precisely the impact of each MRP parameter under both demand and lead time uncertainties, even if it could be useful to better understand their impact on the behavior of the system in term of cost, service level and stability.

7. 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

Table 5
Papers on lot-sizing

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

Table 6
Papers on safety stock and safety lead-time

Parameters	Papers	Comments
Safety lead-times/ planned lead-times	Whybark and Williams (1976), Dolgui et al. (1995), Molinder (1997), Hegedus and Hopp (2001), Dolgui (2001), Dolgui and Louly (2002), Louly and Dolgui (2002a, b, 2003, 2004), Chauhan et al. (2003), Koh and Saad (2003), Dellaert and Jeunet (2005), and Gurnani and Gerchak (2007)	Uncertain lead-times
Safety stocks	Whybark and Williams (1976), De Bodt et al. (1982), De Bodt and Van Wassenhove (1983), Grasso and Taylor (1984), Yano and Carlson (1985), Blackburn et al. (1986), Lee and Adam (1986), Zhao and Lee (1993), Grubbström and Molinder (1996), Molinder (1997), Grubbström (1998), Grubbström and Tang (1999), Bai et al. (2002), Gudum and Kok (2002), and Grubbström and Wang (2003)	Service level under an uncertain demand and a low setup cost

Table 7
Papers on action on MPS

Parameters	Papers	Comments
Replannification/ horizon size	Yano and Carlson (1985), Sridharan and Berry (1990), Zhao and Lee (1993), Grubbström and Molinder (1996), and Bai et al. (2002)	Try to reduce the number of rescheduling in the case of demand errors, but to not degrade performances of MRP system, do not increase too much the length of the horizon
Freezing the MPS	Blackburn et al. (1986), Sridharan and Berry (1990), Lin and Krajewski (1992), Sridharan and Laforge (1994), Zhao and Lee (1993), Bai et al. (2002), and Tang and Grubbström (2002)	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

method which take into account all these uncertainties. This problem appears much too complex. In Dolgui and Louly (2001) and Louly and Dolgui (2002b), the optimisation of the replenishment planning in an globally uncertain environment has been proposed with the use of a toll box, grouping together some partial models and simulations.

Fig. 6 resumes techniques commonly used for the encountered problems. Tables 5–7 show the main influences of the parameters and the authors having dealt with them. Table 5 sums up the papers on lot-sizing rules, while Table 6 deals with safety stocks and lead time. Finally, Table 7 focuses on the MPS.

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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