Replenishment policies in static and dynamic spare parts inventory control: A survey

Nouha GHORBEL[1,2], Sid-Ali ADDOUCHE[1], Abderrahaman EL-MHAMEDI[1], Younes BOUJELBENE[2]
[1]LISMMA – University of Vincennes – Saint-Denis (Paris8),
IUT de Montreuil, 140 rue de la nouvelle France, 93100 Montreuil, France
[2]Laboratoire URECA, Université de Sfax, Tunisie

***Abstract* - In this paper we give a comparative overview on research works dealing with replenishment policies. Following recalls of the inventory control concepts, a recent literature review is given relating to spare parts. Cited works are classified into two categories, those who consider inventory control as statistic and the others, as dynamic. For each category, works about economic order quantity and lot sizing methods are given. The previously cited research works deal with replenishment policies for continuous and periodic review systems. We gave an importance to the works that consider the uncertainty on the parameters such as demand for spare parts, availability, lead-time, etc. For each section, a recapitulative table of the cited papers is given.**

***Keywords* - Replenishment, inventory control, uncertainty, economic order quantity, spare parts**

I.INTRODUCTION

The area of spare parts (SP) inventory control is quite large and the problems are particularly diverse (M.A. Driessen 2014). We can cite location problems (HUO Jia-zhen 2007), (D. C. Hartanto Wong 2005) and (Tongdan Jin 2009), allocation problems (Loo Hay Lee 2008), (D. V. Hartanto Wong 2007) and (Marzio Marseguerra 2005), size problems (Liu 2008) and others. To our knowledge, there is no recent overview in literature that summarizes all the work on procurement policies in inventory control.

To enable all to identify the current scientific challenges and position themselves, we conducted a literature review on recent work in spare parts inventory control field, by focusing on the problems of sizing stock, including uncertainty. The latter can affect demand for spare parts, availability, lead-time, etc.

Furthermore, the sizing problem is still current, that is to say, you still have to look how to supply parts and induce a lower cost. To compare the works of research, we make a systematic recall of the bases of inventory management referring particularly to the model of Wilson and the concept of "Economic Order Quantity" (EOQ).

To classify the work on the problems of determining the EOQ spare parts inventory management, we need to distinguish between static and dynamic inventory management. Determining the parameters of stock in the static management based on the assumption of constancy of all variables in period t (between two supplies). The reference model of static inventory management was formalized by (Wilson1934) from (Harris1913)'s work. Wilson is based on a simplistic model optimizing the cost of managing a stock during a fixed period of replenishment to be determined. It is assumed that consumption per unit time and k is certain and constant.

This paper presents in a first part, an overview on the main work in the field of spare parts inventory management, and then moves to classify the work dealing with the problems of determining the EOQ of spare parts inventory management in a static stock.

Although the economic reality is completely different, all the variables in the model vary over time. Hence the need to find a method that takes into account both the variation of parameters over time and the uncertain environment that reflects the industrial reality. For this, the second part of this paper will address the main methods that allow the transition from a traditional inventory management to manage stock dynamics in the presence of certain types of uncertainties that affect the determination of EOQ. These types of uncertainties will be presented as procurement policies.

In both parts, determining EOQ spare parts to supply is related to the procurement policy adopted.

We mention that all research conducted in this study have for database website Direct Sciences. So, it is a recent and comprehensive research in the sense that it covers the majority of international journals in the field. Indeed, we find among the papers present in this article: Computers & Operations Research, European Journal of Operational Research, Journal of Purchasing and Materials Management, International Journal of Hospitality Management, Economics International Journal of Production Economics, Inventory Management Journal Management Science, International Journal of Engineering Development and Research, Computer and Industrial Engineering, Applied Mathematics and Computation, Tourism Management , Computers and Mathematics with Applications, Operations Research Letters, Physica Verlag, Series on Production and Logistics, Mathematical and Computer Modelling, Expert Systems with Applications Reliability Engineering and System Safety, Decision Support Systems, Automatica, Journal of the Franklin Institute, Computer Communications, Production and Inventory Management Journal and Computers in Industrial Engineering.

In this research, we did not choose a very specific procedure to select treated articles but we based on the selection of the most recent articles and particularly which treat the problem of inventory management of spare parts. For this, our references are numerous and classified thereafter according to the procurement policy adopted and the way to manage their stock: static or dynamic.

II. INVENTORY CONTROL

Spare parts inventory control is an important challenge when spare parts of many systems change over time (Vaisakh P. S. 2013). To maintain the performance of complex systems, spare parts inventory control must be a priority. When a manufacturer starts to market a new product, it is committed to providing the necessary spare parts for replacement of failed parts in the future. This commitment creates a real problem of spare parts inventory control, sizing and location. To meet the demand of spare parts from maintenance services, which have generally a stochastic nature, the manufacturer must set an effective strategy of inventory control. The object of this management is to provide in time and at the lowest cost the spare parts needed for clients. In this context, (Tongdan Jin 2009) provide a model for an application for global demand of spare parts generated by a single product with a growing number of parts in a homogeneous Poisson process. Their model is a special case where the time to failure of the product follows the exponential distribution; the results found by this method are means and variances of demand for spare parts. Using a multi-resolution based on their model, a policy of restocking dynamics (Q, R) has been formulated and solved. Finally, they illustrate the model by two numerical examples to demonstrate the relevance of their model in spare parts inventory control under a service level constraint. A study of effectiveness of this method was carried out through simulation.

Preventive maintenance or corrective maintenance is still behind the need for inventory management of spare parts. Determining the required amount of spare parts for maintenance service is always difficult through the predictions based on historical data. Therefore, obtaining an optimal policy of stock management is difficult. Jointly optimizing the management stock spare parts and preventive maintenance were presented by (W. Wang, 2012). In fact, in the presence of random nature of plant failures, they develop a cost model for stochastic spare parts inventory control and maintenance, and are based on a dynamic programming to find the joint optimal solutions on a finite time horizon.

To construct the probabilities of the number of failures and the number of the defective items identified at a preventive maintenance epoch, (W. Wang, 2012) use the delay-time concept developed for inspection modeling which has not been used in this type of problems before. They are in the case of a policy for periodic review of inventory management to meet the needs of a maintenance service. They demonstrate their models through a numerical example.

Many studies deal with the issue of spare parts, but there are few that take into account the uncertainty that has been on variables such as inventory management work (Tiwari 2002) and (Gupta 2005). (Godichaud 2008) proposes an original use of the Bayesian network tool for the evaluation of beneficial reuse of products to disassemble in the presence of uncertainty. This uncertainty mainly concerns the requirements for products from the processes of disassembly and arrivals of the products' end of life. (Alami 2009) addresses the problem of determining the economic lot of SP to be produced, taking into account the different phases of the life cycle of the product.

There are studies that treat the problem of spare parts supply chain but there are not many that reflect the uncertainty of variables such as inventory management work (Tiwari 2002) (Gupta 2005).

(Godichaud 2008) proposed an original use of Dynamic Bayesian Networks for the Evaluation of pathways reclamation of products to disassemble in the presence of uncertainties. This uncertainty is mainly in requirements from processes of disassembly and arrivals of end of life. (Alami 2009) addressed the problem of determining the economic quantity of SP over the different cycle phases of the products' life.

In recent years growing interest has been dedicated to supply chain management. Modeling complexity is added to the supply chain coordination problem by taking into account the reverse logistics activities. An increasing number of ecological constraints, together with economic incentives, allow that product recovery to become an interesting field in supply chain management research.

Limitations, enormous waste and product disposal costs, the manufacturers' obligations to take back the used products from customers and the fact that returned products might have a positive economic value are some of the characteristics that make this field challenging. Many studies treat the problem of supply policy such as (S. Minner 2001) that combines the problem of safety stock planning in a general supply chain with the integration of external and internal product return and reuse. The authors tried to integrate used SP in the supply chain to optimize the procurement policy by modifying the level of safety stock required and the optimum amount of spare parts to provide.

In the literature of inventory control problems, we find two types of hypothesis: Continuous review hypothesis where an order can be made at any time depending on inventory position and periodic review hypothesis where an order can be initiated only at discrete time interval. (Kadir Ertogral 2005) analyze a multi period inventory problem that does not belong to any of these two hypotheses. They consider that the replenishment intervals are in dependent and identically distributed random variables for the case where there are periodic replenishments. Also, they suppose that only a certain share of unmet demand is out of stock and the rest of it is lost.

In this context, they show the concavity of the function of expected profit and give the condition that must own for the optimal replenish-up-to-level and this is in the general distribution between replenishment periods. With numerical examples, authors present pertinent solutions and analysis in uniform and exponential distributions.

From our different readings in the field of stock management, we noticed that the majority of articles found in our database (remember that our source is the website direct Sciences) address the problematic of management of stock in the chain supply in general. We seek through this article to collect all the work that specifically addresses the issue of management of spare parts. It should be noted that all articles on inventory management of SP often respond to industrial needs which shows the importance of this problematic.

In this context, we have classified these works according to two main criteria: the calculation of the quantity of spare parts to supply using the standard Wilson "Economic Order Quantity" or its extension and this is in the context of static and dynamic management stock. We classify each time the works according to the different procurement policies. The continuation of our research will be distributed according to this classification.

III. DETERMINATION OF ORDER QUANTITY IN STATIC INVENTORY CONTROL

1.1 Economic order quantity

The economic order quantity (EOQ) is the optimal quantity to order to replenish inventory, based on a trade-off between inventories and ordering costs. The optimal quantity Q* to order (i.e., the order quantity that minimizes total cost) is given by:

$$Q^* = \sqrt{\frac{2AD}{H}} \quad (1)$$

When:

D: Average demand (number of items per time unit)
A: ordering cost ($ per order)
H: holding cost of an item ($ per item per unit time)

Equation 1 for Q* is known as the EOQ formula.

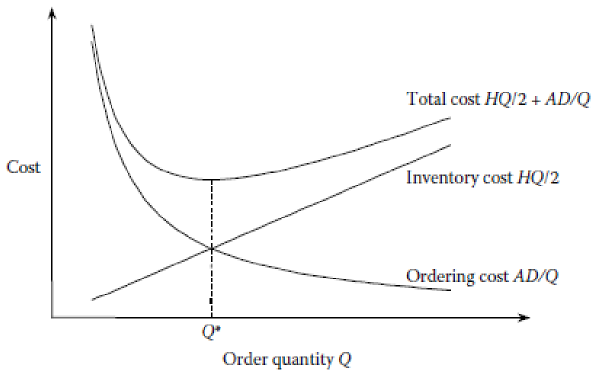

Figure 1 : Trade-off between inventory and ordering costs in an EOQ model

Wilson has developed for a very long time EOQ model, and despite that, more research is based on this model or alternative approaches to manage and solve the problems of inventory management in our days. Many works in inventory control are based on the basic model of Wilson: the EOQ. Among the famous work, we find (Jung Hoon 2006) who establish and analyze three EOQ based inventory models under profit maximization via geometric programming techniques. Using these techniques, they obtain the optimal order quantity and price for each of these models considering production as well as pricing decisions. Equally, they studied the effects of changes in optimal solutions in case of change of different parameters. A comparison analysis between models of profit maximization was performed. Finally, several interesting economic implications were observed by investigating the error in the optimal price, order quantity, and the benefit of these models.

(Oded Berman 2006) focus his work on two types of demand functions: a piecewise constant function and a family of exponential functions. Indeed, it develops EOQ-type model with a rate of demand like a function of inventory levels.

Demand functions and cost functions are fairly general considering. (Oded Berman 2006) process and analyze the problem to reach the optimization and analysis of particular sensitivity. The model was extended by adding to the size random order. Parallel to the EOQ model, Wilson has also developed the EPQ model. These two models were developed using different optimization methods. But in many works which deal with the EOQ / EPQ with linear cost only back orders are seen. (Leopoldo Eduardo 2011) use the basic concepts of geometry and algebra to develop a new simpler method. Through this method, it finds the optimal lot size and level of backorders considering both linear and fixed costs backorders. Finally, a review of different optimization methods used in the theory of stock was introduced.

In the same field, a new method was presented by (L. A.-J.-B. Juan García-Laguna 2010) for EOQ and EPQ where the lot size must be a full quantity. Operationally, this method is very simple and allows a rule to discriminate between cases where there is a single optimal solution or two optimal solutions. Their new approach allows the resolution of other production-inventory models. Finally and with numerical examples, the authors show the pertinence of their method.

In inventory control, most of works done use methods and calculation equations that are relatively difficult in operational. (David W., 2009) modeled differently the problem of determining the EOQ with partial backordering through different equations as the equation for classical EOQ model and realized many extensions of the model.

Despite the success of the method of Wilson "EOQ", it shows limited results in the industry. Then, several manufacturers have thought of replacing it with a new purchasing policy called the policy just in time showed best results. Decision to be taken by contractors is always difficult when taking into account the cost generated by each policy. In fact, despite the advantage of reducing the number of warehouses with supply policy just in time, it is still worrying for manufacturers. To distinguish between these two policies, (Wu Mina 2006) extend a classical EOQ with a price discount model to calculate the EOQ-just-in-time cost point indifference. A case study was mounted in the concrete industry in Singapore to test the model.

In this section, we have shown how to calculate the EOQ order with the Wilson model. We have cited the more recent work that used the EOQ as basic model. According to these work, we can notice that this model allows calculating the optimum amount to be ordered in several different areas. We will now see how to determine the optimal spare parts amount to order for the different procurement policies.

According to our reading, we note that despite the age of "EOQ model", it remains the basic model for all calculations order quantities in the supply management of stock and the majority of articles found are based on this model or its extensions to determine the optimal supply quantity. This comment will be proved later in this research.

1.2 The EOQ in replenishment policies

New spare parts used in the replenishing industry are expensive, they have a high demand rate in the maintenance sector and the consumed quantity is variable. In literature there are four inventory basic policies for replenishing inventory (Murphy 2002), (Blumenfeld, 2009).We distinguishes in these replenishment policies, the policy for a continuous review system and the policy for a periodic review system. For the policies with continuous review system, we find two different policies: the policy (s,Q) which is characterized by a fixed quantity of supply and varying periodicity, and the policy (s,S) which is characterized by varying quantity of supply and at a varying periodicity. For the policies with a review periodic system, we also find two policies: (T,S) and (T,s, S) policies, which are characterized both by a fixed periodicity and a variable quantity of supply. Both policies are summarized in the table above:

Tableau 1: Replenishment policies in inventory control

T :Periodicity / Q :Quantity	Fixe	Variable
Fixe	-	(s,Q)
Variable	(T,S) ; (T,s,S)	(s,S)

For continuous review systems:

- The (s, Q) Policy: Whenever the inventory position (items on hand plus items on order) drops to the reorder point s or below, an order is placed for a fixed quantity Q.

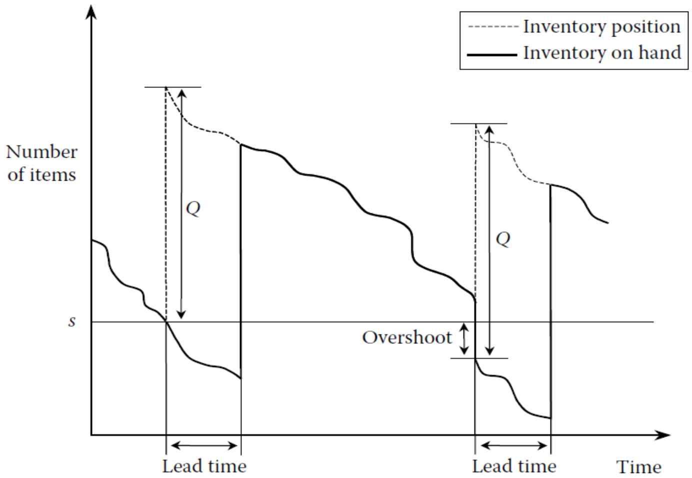

Figure 2: Inventory pattern over time in an (s, Q) policy

The reorder point, s, and order quantity, Q, in the (s, Q) policy are given approximately by

$$s= DL+k\sqrt{L\sigma_D^2+D^2\sigma_L^2} \quad (2)$$

$$Q=\sqrt{\frac{2AD}{H}} \quad (3)$$

When:

s = reorder point (number of items)

S = order-up-to level (number of items)

σ_D^2 = variance of demand (items^2 per unit time)

L = average lead time (units of time)

σ_L^2= variance of lead time (units of time^2)

k = service level factor

- The (s, S) Policy: Whenever the inventory position (items on hand plus items on order) drops to a given level s, or below, an order is placed for a sufficient quantity to bring the inventory position up to a given level, S.

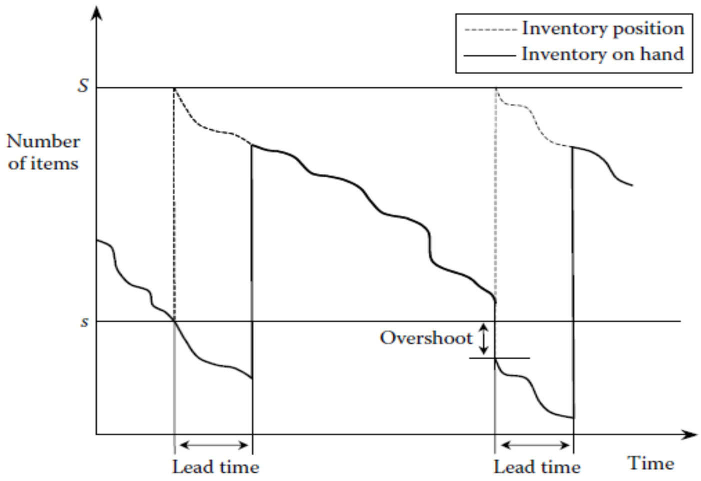

Figure 3: Inventory pattern over time in an (s, S) policy

Assumptions adopted for this policy are the same as those of the policy (s, Q).

The demand variance, σ_D^2, is defined for a demand in one time unit. Since the demands in each time unit are assumed to be independent, the variance of demand in a fixed time of t units is $\sigma_D^2 t$.

The reorder point, s, and order-up-to level, S, in the (s, S) policy are given approximately by

$$s = DL + k\sqrt{L\sigma_D^2 + D^2\sigma_L^2} \quad (4)$$

$$S = s + Q \quad (6)$$

Where: $$Q = \sqrt{\frac{2AD}{H}} \quad (3)$$

Uncertain situations are a major problem in the system of management and production. These situations can be caused by unexpected failures, unexpected repairs, etc. (Yunzeng Wang 1996) analyze the effects of these uncertain situations on the calculation of optimal lot sizing in continuous review environment. They consider in their study two models: the classical EOQ model and the order-quantity reorder point model with backlogging. After getting the optimal distributed variable capacity requirements for both models, they show that the optimal order quantity and optimal reorder point for the second model are greater than those without variable capacity. They develop effective procedures to find the best solutions when the distribution has an exponential variable capacity.

(Xin Chena 2006) consider a continuous review system model for a single product and in an infinite time horizon. Pricing and inventory decisions in their model are carried out simultaneously on the assumption that ordering cost includes a fixed cost. They concluded that there is a stationary procurement policy (S, s) allowing the maximization of present value or the expected discounted or expected average profit on general terms conditions.

In the same area, (Seyed Hamid Reza Pasandideh 2011) develop a model in inventory continuous review (R,Q) ordering policy. It is a model with two-echelon system for a non-repairable item where the system consists of one warehouse and m identical retailers. In order to minimize the total annual cost of investment in stock, the authors develop a mathematical model, constrained on the frequency of orders average annual expected number of back orders, and express the budget. The aim of their work is to get the optimal stocking policy for their system. In order to resolve the problem effectively, the authors propose a parameter-tuned genetic algorithm to deal with the nonlinear integer-programming. Finally, they test their model with a numerical example to demonstrate its effectiveness.

For periodic review systems

The (T, S) Policy: Inventory position (items on hand plus items on order) is reviewed at regular instants spaced at time intervals of length T. At each review, an order is placed for a sufficient quantity to bring the inventory position up to a given level, S.

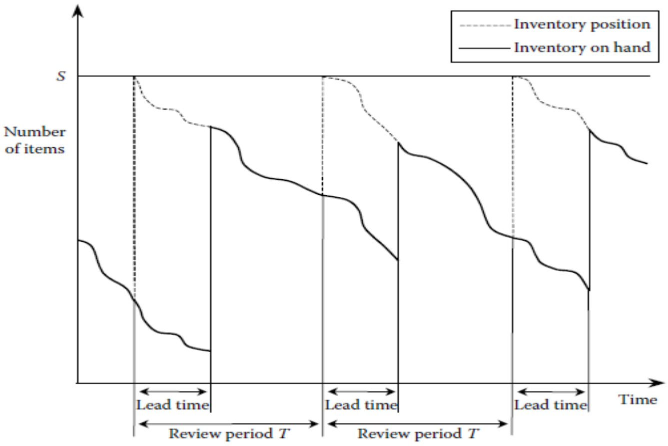

Figure 4: Inventory pattern over time in a (T, S) policy

Assumptions adopted for this policy are the same as those of the policy (s,Q) and (s,S), but with a constant review period (i.e., time interval between reviews).

With: T = review period (units of time)
The ordering cost, A, in this policy includes the cost, if any, of reviewing of the inventory position in each review period. The demand variance, σ_D^2, is defined for a demand in one time unit. Since the demands in each time unit are assumed to be independent, the variance of demand in a fixed time of t units is $\sigma_D^2 t$.

The review period, T, and order-up-to level, S, in the (T, S) policy are given approximately by:

$$T=\sqrt{\frac{2A}{DH}} \tag{7}$$

$$S= D\,(L+T)+k\sqrt{(L+T)\sigma_D^2+D^2\sigma_L^2} \tag{8}$$

The (T, s, S) Policy: Inventory position (items on hand plus items on order) is reviewed at regular instants spaced at time intervals of length T. At each review, if the inventory position is at level s or below, an order is placed for a sufficient quantity to bring the inventory position up to a given level S. If the inventory position is above s, no order is placed (fig 7).

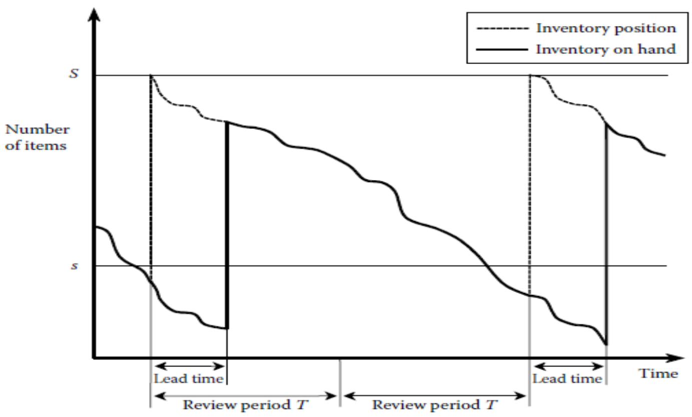

Figure 5: Inventory pattern over time in a (T, s, S) policy

Assumptions adopted for this policy are the same as those of the policy (T,S).

With: s = reorder point
When the supplier puts the restriction on minimum order quantity, the variable order quantity is decided based on the (S, s) policy, where maximum level of inventory is S and minimum safety stock is s. The replenishment level is in between S and s value. The (T, S) policy represents a special case of the (T, s, S) policy in which s = S.

The review period, T, reorder point s, and order-up-to level, S, in the (T, s, S) policy is given approximately by:

$$T= \sqrt{\frac{2A}{DH}} \quad (7)$$

$$s= DL+k\sqrt{L\sigma_D^2+D^2\sigma_L^2} \quad (4)$$

$$S= s+Q \quad (6)$$

Where:

$$Q = \sqrt{\frac{2AD}{H}} \quad (3)$$

Due to its performance, the system of review provides multiple solutions to the stock manager. For this, it was often used in the literature. Despite this, the selection of the optimal review period based on the basic parameters of inventory management such as availability and demand is still difficult. (Edward A. Silver 2008) treat the normal and gamma distributions in a system of periodic review. According to the literature, these two distributions are the most commonly used over the key demand of time interval. They show that the total cost function can be no convex and therefore it is not necessarily performed well according to the review period. This result complicates the determination of the optimal review period. Finally, they explain how the best review period changes in function of various parameters.

Most works using the order splitting for continuous review inventory system are concentrated on the reduction of safety stock in different sourcing contexts. (Chi 2001) studied the possibility of the multiple-delivery arrangement in the sole sourcing environment. For a periodic review system, they focused on the reduction of stock cycle. In addition they demonstrate that, if the cost of dispatching an order for an item is high, splitting an order into multiple deliveries can substantially reduce the total cost. The ordering cost can be decreased by using information technology like electronic data interchange and therefore shortens the period length.

Moreover, (Soren Glud J., 2000) develop a model with lost sales in a periodic review system during a stock out and under constraint that at any time, a maximum one replenishment order can be outstanding. The used (r,Q) replenishment policy that whenever the inventory position (items on hand plus items on order) drops to the reorder point r or below, an order is placed for a fixed quantity Q. Authors consider that, in a succession review period, the demands are independent and identically distributed variables. To estimate the reorder level r and the cycle stockholding cost, they used asymptotic results of renewal theory. They illustrate their methodology with numerical examples based on Wilson model “EOQ”.

In literature, the fill rate is defined as the fraction of demand that is satisfied directly from shelf. It is calculated generally by the traditional approximation which calculates the fill rate as the complement of the quotient between the expected unfulfilled demand and the expected demand per replenishment cycle. In this context and to compute the fill rate for any discrete demand distribution in periodic review system, (Ester Guijarro 2012) develop an original generalized method. They propose a revised definition of the fill rate in a discrete demand context to avoid the distortion caused by the cycles with no demand.

They demonstrate the systematic underestimation of the fill rate and prove that the new generalized method is: leads to the exact fill rate value, suitable even when the probability of zero demand cannot be neglected and can be applied to any discrete demand distribution. For those who want to extend this work, the authors propose some road extensions such as: analyzing risks of using different fill rate approximations to set the parameters of the stock policy, deriving a new expression for the backordering scenario that follows the approach suggested in this work, assessing the exact method when using other discrete distribution functions of demand able to model significant variability on demand sizes with a high probability of zero demand and characterizing the cases where approximations (including some possible new ones) have the most important deviations.

Furthermore, (Jiang Zhang 2007) develop an exact formula for the fill rate of a single-stage inventory system supplying external demands and receiving stocks from an ample supply. Time is divided into fixed period. In each period, demands arrive and are either filled or backlogged. The system operates under a general periodic review stock based policy.

In order to minimize costs, researchers try to calculate the optimal parameters of stock policies. In this setting and in a periodic review policy, (Manuel Cardos 2011) develop a model based on two approximations: The first approximation PI based on the assumption that there is no stock out during the lead time. The second approximation PII based on the same assumption as PI, but applying it to simplify the CLS (Cycle Stock Level) estimation. These approximations used to compute the cycle service level for a periodic review policy are subject to two conditions: the first is easy to compute so it could be applicable in operations management in practice, and the second, more accurate than the classic approximation since the latter presents a substantial bias as pointed out in their work. In addition, they point out the risks of using the classic approximation since, unlike PI and PII, it may overestimate the CSL, which implies that when using the classic approximation to design the (R, S) policy given a target cycle service level, the system may not achieve the target, thereby being less protected than expected. Moreover, a heuristic approach based on PII has been suggested to accept or reject an inventory policy in terms of fulfilling a given target CSL.

Further, (Urban 2005) develop a periodic-review model taking into account that the demand rates of many consumer products are serially correlated and are dependent on the quantity of inventory displayed to the customer. Authors demonstrate the effect of demand patterns on the safety stock requirement. Then, they present an adaptive, based stock policy based on the critical fractal and finally, they develop a methodological solution.

In the previous section we have seen the methods of calculating the EOQ in a certain future for a continuous review system and a periodic review system. Indeed, a calculation of stock parameters on the basis of Wilson's formula has been developed. We have also mentioned the main recent work that has addressed the perimeters of the problem of calculating the quantity to order in inventory management.

In the second part, we will see in the literature, the main calculation methods of stock parameters in different periods and an uncertain future.

IV. DETERMINATION OF ORDER QUANTITY IN DYNAMIC INVENTORY CONTROL

In the previous section, we used the Wilson model to calculate the optimum quantity to order in stock management policies. In addition, many studies have been conducted on methods for calculating order quantities in the presence of a time-varying demand. These methods, called Lot sizing methods, are widely used in MRP systems to determine the optimal size of lots to launch when orders are grouped.

In the first paragraph of this section, we first give an overview of the most widely used methods in literature to calculate the lot size. We focus on some important references that have addressed this problem in the case of stochastic demand.

Lot sizing methods

Lot sizing methods are inventory control methods often used in MRP systems to run grouped commands in order to minimize costs.

In recent decades, several methods for calculating the lot sizing whose performance varies depending on the type of problem have been developed. The method performance is obtained after comparing the total costs they generate and the time resolution they require to solve the problem.

Generally, the total cost is defined as the sum of control costs (start-up costs), costs of remaining stocks from one period to another (holding costs) and costs resulting from constraints to the system.

As mentioned by (Solomon 1991),lot sizing calculation methods that use only the start-up costs and holding costs, are called Uncapacitated lot-sizing techniques as they do any kind of constraint on the available resource(these methods assume, for example, that production capacity is unlimited).

In addition, methods that consider a cost structure taking into account various constraints on available resources (such as boundary constraint of capacity), are called capacitated lot-sizing techniques.

In literature, two basic methods for calculating the lot sizing have been developed since 1930. The first method, proposed by Wilson (1934), is the method of Economic Order Quantity (EOQ), in which the lot size is given by Wilson's formula. The second method is the Periodic Order Quantity method (T. Vollmann 1988) which is based on the notion of orders economic period and calculated with Wilson's formula. However, it has been demonstrated by (H. M. Wagner 1958) (H. Wagner 1975) and (E. A. Silver 1973) that these methods are inadequate in the case of varying demand over time.

Therefore, several methods for lot sizing calculation for the case of varying demand have been developed since the 1950. Among these methods, we cite the Wagner-Whitin algorithm based on dynamic programming, which gives an optimal solution to the lot sizing calculation problem. It has, however, the disadvantage of a complex practical implementation. There are also other methods that provide solutions close to the optimal solution and are simpler to implement. These methods include the Silver-Meal heuristic, Least Unit Cost heuristic, the Part-Period heuristic (Matteis 1968) and the Incremental Part-Period heuristic (La Forge 1982) (J.W. Patterson 1985).

These heuristics, which are extensions of the EOQ method, are to calculate the lot size balancing between inventory costs and start-up costs. There are other more sophisticated techniques such as Minimum Demand Technology methods (Z. Zhu 1994) and Technique for Order Placement and Sizing. A review of the literature on these methods is given by (Jeunet 2000).

Note that the study of methods for lot sizing calculation for a time-varying demand started with (H. M. Wagner 1958).There is currently, in this area, a considerable literature that extends the basic models to consider the capacity constraints, the case of multi-product, the case of multi-storey, etc.

However, the majority of these studies consider the case of deterministic demands. More details on these lot sizing calculation methods, are presented by (Berry 1972), (E. A. Silver 1973), (DeBodt 1984), (Potts 1992), (Kimms 1997), (Jeunet 2000) and (Sanchez 2001).The practical problem resides in the stochastic aspect of demand in most real cases. Under these conditions, no estimate of future demand is certain and, therefore, the demand deterministic model is just an approximation of reality whose pertinence depends on the case study.

In the work mentioned above, the forecasts are typically treated as in the case of deterministic demand, i.e. if they were firm orders. However, the existence of errors in the forecasts radically affects the behavior of procedures for calculating the lots size that are based on deterministic assumptions. The forecast errors involve unsatisfied demands (because of stock-outs) or excessive inventory costs (due to residual stocks of very large sizes). Although the problems of inventory management with a stationary demand are well known and well-studied for several decades, few work that deal with the case of non-stationary stochastic demands. There was, subsequently, a growing recognition, as shown by (Wemmerlov 1989), the need to introduce the stochastic and dynamic aspects in the lots sizing calculation methods to approach more the industrial reality. Therefore, several studies developed have tried to taking into account the forecast errors in the lots sizing calculation methods.

(E. A. Silver 1978) Suggested a method for lots size calculation in the presence of stochastic demand and forecast errors distributed according to a normal distribution. This method is an extension of the Silver-Meal heuristic developed by (E. A. Silver 1973). (Bookbinder 1988) proposed another heuristic in which periods of supply are fixed at the beginning of the horizon and orders launched are determined only to those specific periods of supply to minimize the average cost at a constraint service level.

Tableau 2: Summary of Lot sizing calculation methods

Type of inventory control	**Methods**	**Founders**	**References**
Static inventory control	Economic Order Quantity	(Wilson, 1934)	-
	Periodic Order Quantity	(T. Vollmann, 1988)	-
	Uncapacitated lot sizing techniques	(Solomon 1991),	(Yi Han 2009), (I. K. Yiyong Xiao 2012), (I. K. Yiyong Xiao 2011), (Horst Tempelmeier 2011), (Aksen 2007)
	Capacitated lot sizing techniques	(Solomon 1991),	(Irena Okhrin 2011), (Tao Wu 2011), (M. Caserta 2009), (M. Casertaa 2009), (Charles Sung 2008), (Wilco van den Heuvel 2006), (JINXING XIE 2002), (GuK lay Barbarosogylu 2000),
Dynamic inventory control	Wagner-Whithin algorithm	(H. M. Wagner 1958) (H. Wagner 1975)	(Hossein Jamshidi 1993), (Harish C. Bahl 1991), (Cem Saydam 1990), (Evans 1985)
	Silver-Meal heuristic	(E. A. Silver 1973) (E. A. Silver 1978)	(Schulz 2009), (J. Hu 2004), (Mohd Omar 2001)
	Least Unit Cost heuristic	(T. Vollmann, 1988)	(Supachai Pathumnakul 2011), (Yong-Jin Lee 2005), (R. Sriram 1998), (AZ SZENDROVITS 1997)
	Part-period method	(Matteis 1968)	(Wemmerlöv 1983)
	Incremental Part Period method	(La Forge 1982), (J.W. Patterson 1985)	-
	Minimum Demand Technique method	(Z. Zhu 1994)	-
	Technique of order Placement and Sizing	(B.J. Coleman 1990)	-

This table lists the set of methods used to calculate the economic quantities outside the traditional procurement policies.

Replenishment policies in dynamic inventory control

Various alternative methods have been proposed for modeling supply chains. According to (Beamon 1998), they can be grouped into four categories: deterministic models where all the parameters are known, stochastic models where at least one parameter is unknown but follows a probabilistic distribution, economic game-theoretic models and models based on simulation, which evaluate the performance of various supply chain strategies. The majority of these models are steady-state models based on average performance or steady-state conditions. However, static models are insufficient

When dealing with the dynamic characteristics of the supply chain system, which are due to demand fluctuations, lead-time delays, sales forecasting, etc. In particular, they are not able to describe, analyze and find remedies for a major problem in supply chains, which recently became known as “the bullwhip effect”. The “bullwhip” phenomenon is the amplification of demand variability as we move from a downstream level to an upstream level in a supply chain. In this context, (Haralambos Sarimveis 2008) present an overview of an alternative control methods that have been applied to the dynamic supply chain management problem.

- **For continuous review systems**

In industries, inventory managers consider to lose sales initially and begin to backorder demand later as they approach the replenishment time. (Chu C.W., 2001) model shortages in inventory management. They provide a unique context for studying different policies that deal with shortage. Indeed, they formulated and solved the model as a discrete time, stochastic constrained control problem. After, they compare numerically the performance of their model with the simpler other policies. A closed form solution is provided for the order quantity, in regards to any given values of the remaining control variables. Finally, they conjectured that the optimal backorder limit during the first time segment should be zero. They illustrate their model with experience in the chemical industry in which, the cost of backordering is highly time related.

One of the outstanding issues in operations research and industrial engineering is the analysis of inventory control in the early system (Azizah Aisyati 2013). In literature, costs are represented as real numbers in most models of the inventory that was proposed related, although the inventory of real world costs is usually with precision components. When uncertainty becomes a subject of debate, traditional approaches to treatment of uncertainty in the inventory control concentrates on probability theory.

propose two inventory models for the continuous review inventory problems using complementary probability theory and fuzzy set theory. They extend the classical continuous review inventory models with probabilistic demand and with or without backorder in order to consider fuzzy costs. Therefore, they propose a decision support system, which incorporates a simulation tool and has a user friendly interface for efficient and effective use of the proposed models. By an example analyzed with the built-in simulation tool of the proposed system, they prove the effectiveness of the proposed fuzzy models, which can be used as a decision aid tool by a user. Then, the proposed inventory models will be executable models for the decision maker in the real world.

(P. Ignaciuk 2012) consider an inventory system where the goods at a distribution center used to fulfill the customers' demand are acquired with delay from a supply source. Such area is frequently encountered in production-inventory systems where a common point (distribution center), linked to a factory or an external, strategic supplier, is used to provide the goods for another production stage or a distribution network. The task is to design a control strategy which, on one hand, will minimize the holding and shortage costs, and, on the other hand, will ensure smooth flow of goods despite unpredictable changes in market conditions. The proposed policy employs the Smith predictor for compensating the adverse effects of order procurement delay.

As a result, the stability of system is guaranteed for arbitrary delay and any bounded demand pattern. The ordering signal generated by the designed policy smoothly adapts to the demand changes, and thus it is easy to follow by the supplier. Authors demonstrated also that the stock level resulting from the application of the proposed policy does not increase beyond the precisely determined warehouse capacity, which eliminates the need for costly emergency storage and facilitates capacity planning at the distribution center. They prove the effectivness of their model by a numerical example.

In the same context, (Zhan Pang 2010) present a single-item, continuous-review inventory-pricing model with lost sales and batch ordering. Demand arrives as a Poisson process with a price-sensitive arrival rate. The main feature of the model is that it allows positive (non-exponential) lead times. First, under the assumption that there is no more than one order outstanding at any point in time, they demonstrate that the optimal inventory-pricing policy can be characterized by (delivery) state dependent switch levels and an optimal reorder point. Then, authors relax this assumption by allowing multiple outstanding orders, and prove that both the optimal reorder point and the price-switch levels are state-dependent. They also investigate the effect of changes in delivery status on optimal pricing and ordering decisions.

Also, (Ö. B. Mehmet Murat Fadıloglu 2010) propose a dynamic rationing policy together with the associated dynamic priority clearing mechanism for continuous review back ordering systems with constant lead-time and unit Poisson demands for two demand classes. The policy uses the age information for all the outstanding orders in order to decide whether a lower priority demand should be satisfied instantaneously or should be back ordered (or lost depending on the setting). Authors conduct a simulation study to evaluate the performance of the proposed policy. Since the analytical evaluation of the policy is not tractable without simplifying assumptions, simulation is the only tool available. They characterize the settings where the dynamic policy performs well and the rationing is a valuable tool to differentiate customers. They show that rationing is an attractive tool when total demand rate is high and setup cost is low. Furthermore, if the demand rates of the customer classes are close to each other, the benefit of the static rationing over the common stock policy increases.

- **For periodic review systems**

In this area, (Chiang C., 2003) develop dynamic programming models for an inventory system where regular orders as well as emergency orders can be placed periodically. They identify two important cases depending on whether or not a fixed cost for placing an emergency order is present. Authors demonstrate that if the emergency supply channel can be used, there exists a critical inventory level so that if the inventory position at a review period falls below this level, an emergency order is placed. They also develop simple procedures to compute the optimal policy parameters. In all cases, the optimal order-up-to level is obtained by solving a myopic cost function. Thus, the proposed ordering policies are easy to implement esides, (A. Foul 2007) examines a product recovery system and assumes that there is no difference between newly produced and recycled items, i.e., they apply the as-good-as-new principle, so that the customer makes no distinction between manufactured and remanufactured products. Demand is satisfied either from production or remanufacturing of returned products. Therefore, authors deal with a deterministic model with dynamic demand and return. They also assume that the item in either stock (serviceable and returned) may be subject to deterioration. Items deterioration is of great importance in inventory theory. They assume that the interest firm to them adopts a periodic-review (instead of a continuous-review) policy. Finally, authors study the optimal control of the system when not all system parameters are known and illustrate their models with numerical examples.

Moreover, (Przemyslaw Ignaciuka, 2010) develop new supply policies for a periodic review inventory system using strict control-theoretic methodology. The objective of the control action is to always satisfy the entire demand from the readily available stock and currently arriving shipments. In this way any cost associated with backorders and lost sales is eliminated. In addition, they expect from the policy to generate smoothly varying order quantities in subsequent review intervals. This will constitute a planning benefit for the supplier, and consequently reduce the risk of the supplier non-conforming to the established contracting agreement due to otherwise abrupt and highly unpredictable order changes. For this aim authors apply quadratic cost functional which is well known for its rate smoothening properties in production–inventory systems and a good mathematical framework for conducting the optimization procedure.

Likewise, (Karel H., 2011) study a single echelon inventory system having a positive lead-time, a fixed case pack size and stochastic discrete demand per period. Demand which is not met from stock is lost. They suppose that the sequence of events during a period is as follows: first demand is subtracted from the inventory during the period, performance measures such as the service level are calculated, goods arrive, and finally the orders are placed. To evaluate the quality of the approximations to be derived, they simulated a very large number of inventory systems by changing all six system-parameters in a systematic way: the average demand, the variance to mean ratio for the demand, the case pack size, the lead-time, the review period and the safety stock.

In the same context, (G.P. Kiesmuller 2011) propose a simple periodic review policy, called (R, S, Q_{min}) policy, where no order is placed as long as the inventory position, defined as the stock on-hand plus stock on-order minus backorders, is equal or larger than the level S. Otherwise an order is placed to raise the inventory to S. However, if this order is smaller than Q_{min} they increase the order quantity to Q_{min}. Formulating the associated Markov Chain model, they can derive exact expressions for the holding and penalty costs for a given policy. They conclude that the simplicity of the policy and the expressions for the computation of the policy parameter as well as cost performance of the (R, S, Q_{min}) policy justify an implementation in practice. Finally, the objective of their work is to analyze the (R, S, Q_{min}) policy and determine an optimal level S^{opt} which minimizes the average holding and back order costs per period in a stationary state.

In industrial and service operations of engineering tasks, spare parts inventory control knows more and more complexities. Many factors like demands unpredictability, parts indigenization, high service levels, large investments and parts revenues, and the imperative to accurately forecast spare parts requirements and to optimize existing inventory policies require significant decision support. In this area, (Ugochukwu C. Okonkwo 2011) develop a model for the determination of fill rates and average number of back orders in the system for high priority (breakdown) and low priority (preventive) demands, after presentation of schematic diagrams that facilitated the formulation. Considering the enormity of computation involved, a program with a graphical user interface platform was written, for easy computation of results of the developed model. The results generated from the model were validated via a simulation approach, and the results of the mathematical approach with that of simulation show good agreement. The insight from the study will significantly enhance the decision making process of spare parts inventory control.

In the table below, we summarize the main recent references in the current literature in the field of replenishment policies in static and dynamic inventory control.

Tableau 3: Summary of references

Bib. ref.	Inventory Control		Economic Order Quantity		Replenishment policies in static inventory control		Replenishment policies in dynamic inventory control	
	In supply Chain	Of spare Parts	Original EOQ	EOQ modified or extended	Continuous	Periodic	Continuous	Periodic
(M.A. Driessen 2014)		X		X				
(Azizah Aisyati 2013)		X			X			
(Vaisakh P. S. 2013)		X		X				
(Kwangyeol Ryu, 2012)	X		X					

(Ruggero Golini, 2011)	X							
(Barth, 2011)	X				X	X		
(Henrik Andersson, 2010)	X						X	X
(Jay D.Schwartz, 2010)	X						X	
(George Nenes, 2010)	X					X		
(Petri Niemi, 2009)	X				X			
(Jörg Lindenmeier, 2008)	X						X	
(Kadir Ertogral, 2005)	X				X	X		
(Lawrence Nicholson, 2004)	X					X		
(Ilaria Giannoccaro P. P., 2003)	X				X	X		
(Minner S. , 2003)	X						X	X
(Verwijmeren, 2000)	X						X	X
(Minner S. , 2001)	X							
(Daina R. Dennis, 2000)	X				X			
(K.N. Prasad, 1996)	X							
(Willem van Jaarsveld, 2011)		X					X	
(Andrea Bacchetti, 2011)		X	X				X	X
(Engin Topan, 2010)		X					X	
(Karin S.de Smidt-Destombes, 2009)		X						
(Tongdan Jin, 2009)		X						X
(Alami, 2009)		X		X				
(Eric Porras, 2008)		X	X		X	X		
(S.G. Li, 2008)		X					X	
(Godichaud, 2008)		X						
(Hartanto Wong D. V., 2007)		X						
(Karin S. de Smidt-Destombes, 2006)		X						
(Pao-Long Chang, 2005)		X	X		X			
(Gupta, 2005)		X	X					
(Kostas-Platon Aronis, 2004)		X		X				
(Tadashi Dohi 1997), ,		X	X		X			
(Koen Cobbaert 1996)		X		X				
(Haffar 1995)		X	X			X		
(Kun-Jen Chung 2011)	X		X					
(L. A.-J.-B. Juan García-Laguna 2010)	X		X					
(C.T. Ng 2009)	X		X					
(Sphicas, 2006)	X		X					
(Hoon Jung 2006)	X		X					
(Wu Min 2006)	X		X					
(M. Khan 2011)	X			X				
(S. Khanra 2011)	X			X				
(Kuo-Hsien Wang 2011)	X			X				
(Zhang R., 2011)	X			X				
(Sana, 2011)	X			X				
(Sana, 2010)	X			X				

(David, W., 2009)	X			X				
(Shib Sankar Sana 2008)	X			X				
(Hojati 2004)	X			X				
(Matsuyama 2001)	X			X				
(Knut Richter 1999)	X							
(Willem K. Klein Haneveld 1998)	X			X				
(Seyed Hamid Reza Pasandideh 2011)		X			X			
(H. Moslemi 2011)		X			X			
(Xin Chena 2006)	X				X			
(Alstrom 2001)	X		X		X			
(Soren Glud J., 2000)	X		X			X		
(Esmail Mohebbi 1999)	X				X			
(Choi 1998)	X		X		X			
(Yunzeng Wang 1996)	X		X		X			
(Hill 1996)	X				X			
(Gad Rabinowitz 1995)	X				X			
(Ester Guijarro 2012)	X					X		
(Manuel Cardos 2011)	X					X		
(R.H. Teunter 2010)		X				X		
(Teunter 2009)		X				X		
(Edward A. Silver 2008)	X					X		
(I. Konstantaras 2007)	X					X		
(Jiang Zhang 2007)	X							
(Kanchana Kanchanasuntorn 2006)	X					X		
(Urban 2005)	X					X		
(Tae-Myung Shin 2004)	X					X		
(Bor-Ren Chuang 2004)	X					X		
(Chi 2001)	X					X		
(Matthieu C. van der Heijden 1998)	X					X		
(Soren Glud J., 2000)	X					X		
(P. Ignaciuk 2012)	X						X	
(Lin Wang 2012)	X						X	
(Dey O., 2011)	X						X	
(X. Wang 2011)	X						X	
(Özden Engin Çakıcı 2011)	X						X	
(Zhan Pang 2010)	X						X	
(A.Hariga 2010)	X		X				X	
(Ö. B. Mehmet Murat Fadıloglu 2010)		X					X	
(G. Yazgı Tutuncu 2008)	X		X				X	
(Cerag Pince 2008)	X						X	
(Babak Ghalebsaz-Jeddi 2004)	X						X	
(Kefeng Xu 2003)	X		X				X	
(Gerchak 2001)	X						X	
(Chu C.W., 2001)	X						X	
(Metin Cakanyildirim	X		X				X	

2000)									
(Junlin Chen 2012)	X		X						X
(Ugochukwu C. Okonkwo 2011)									X
(G.P. Kiesmuller 2011)		X							X
(Karel H., 2011)		X							X
(Przemyslaw Ignaciuka 2011)	X								X
(Przemyslaw Ignaciuka, 2010)	X								
(Saibal Ray 2010)			X						X
(Dey O., 2009)	X								X
(Chiang C., 2009)	X								X
(Jun-Yeon Lee 2009)	X								X
(Chiang C., 2008)	X								X
(Lin 2008)	X		X						X
(A. Foul 2007)	X								X
(Amit Eynan 2007)	X		X						X
(Chiang C., 2006)	X								X
(Pao-Long Chang 2005)		X	X						X
(Chiang C., 2003)	X								X
(Gin Hor Chan 2003)	X								X
(Frank Y. Chen 2002)	X								X
(Chiang C., 2001)	X								X

For readers interested in all these references in a table in Excel format, I ask you to contact me by e-mail mentioned at the beginning of this article.

V. Conclusion

A review of recent literature on policy replenishment in static and dynamic inventory control is presented in this paper. This work focused primarily on the spare parts control. As a result of this generalist review, recent research was presented on an essential concept which is to determinate the EOQ. Selected works treat the static and dynamic EOQ. This work will serve all researchers interested in entering the field, taking advantage and better identifying scientific problems.

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