Developing an Inventory Management System for an Automobile-Spare Parts Local Distributor

Yahya Saleh

***Abstract*— This paper aims at developing an effective spare parts inventory management system at a local Palestinian distributor having an agency for a certain brand of auto spare parts. A set of spare parts is considered in the analysis by firstly classifying them into ABC classification based on real historical sales date. Proper forecasting models are derived for each category to estimate the future demand of each item. Then, estimates of relevant costs are identified for each category of spare parts items. Respective optimal ordering policies (with optimal order quantities and optimal ordering times) based on Economic Order Quantity (EOQ) models are determined such that the total annual spare parts inventory cost is minimized. A comparison with the current ordering policies adopted by the distributor with the ones obtained in by EOQ models is conducted where the EOQ-based policies outperform the current ones through yielding lower total annual inventory costs.**

***Index Terms*— automobile spare parts, inventory management, economic order quantity model, ABC classification, demand forecasting, local distributors**

I. INTRODUCTION

Management of spare parts inventory effectively is considered an important operational performance indicator for many heavy industries in both service as well as manufacturing sectors. To name but a few, such industries include telecommunication, education, governmental, health, airlines, logistics industries in service sector and chemical processing, steel, construction, high-tech, and automobile industries in the manufacturing sector. Inventory in any manufacturing system are usually classified into different types depending on the perspective of classification. More specifically, an accounting-based classification divide inventory in the system into three main categories; raw materials, work-in-process and finished products. Such a classification is highly used by accountants for costing purposes to determine the dollar values of inventories in the system at the end of each fiscal year. Another classification is based on a nature of the creation of inventory in the system where inventories could have the type of cycle inventory, pipeline inventory, anticipation inventory and safety stock inventory. This kind of classification helps in effective management and control of the stock levels of the first kinds of inventories in the "accounting-based" classification.

Spare parts are commonly considered a kind of raw materials maintained in stock mainly for the purposes of supporting corrective, preventive and predicative maintenance operations of machines in the manufacturing systems. Despite the awareness of the importance of spare parts by production and maintenance managers, many organizations encounter a challenge in keeping the optimal stock levels of the spare parts, (Porras and Decker, 2008). Keeping high levels of spare parts inventories will result in excessive associated holding (storage), insurance, opportunity, profligate, tax and obsolescence costs. On the other hand, maintaining small levels of spare parts inventory will result delays in fulfilling the demands of production by maintenance department and hence incur excessive costs associated with long stoppage, customer dissatisfaction (loss of good well), order delays penalties, fast shipping (transportation) and some poor quality-related costs. Therefore, it is very essential for the organization to have an effective spare parts inventory system for accurately managing and controlling the stock levels of the spare parts. The main function of an effective spare parts management system helps determine the optimal replenishment policy of spare parts. More specifically, the optimal ordering quantities, optimal stock levels as well as the optimal time between orders (TBO) of spare parts are determined such that the total spare parts inventory associated costs are minimized.

Automobile manufacturers face complicated supply chain structures due to the large number and high diversity of spare parts built in the manufacture and assembly of vehicles, (Li and Kuo, 2008). Likewise, the distributors and agents of cars around the globe encounter the challenge of keeping the right quantities of spare parts of cars in their stores which in turn guarantee the supply of right quantities of spare parts on the right times to their customers. They should have an effective inventory management system for their spare parts with needed quantities and qualities to serve customers during the warranty periods of the sold cars as well as after-warranty periods. Such after-sale service is an important quality characteristic considered by customers who do not only focus on the reliability and functionality of their bought autos, but also on the availability of spare parts of their autos for repair and replacement purposes. Consequently, having an effective spare parts inventory management system constitutes a critical local and global competitive advantage for auto manufacturers and distributors in the world.

As a developing country with a special particularity, cars are imported through Israeli ports from outside and entered to Palestine and sold to Palestinians through local distributers having agencies of almost all global brands. Likewise, they are many local agents and distributors who have the agencies of importing and selling spare parts of certain brands of cars in Palestine. Importers of cars and spare parts encounter many logistical problems mainly represented by long delivery lead times from the global manufacturer to the arrival of material to their stores as a result of inspection, control, testing, delay

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by Israelis on the imported commodities before releasing them to their importers. In addition, both Israel and Palestinian Authority impose extra taxes on the imported goods and hence an additional cost is incurred to the cost of the imported items. Working under this difficult and uncertain conditions, importers usually experience frequent shortages of spare parts due to long delayed lead times and frequent excessive inventories of some spare parts (with high cost) and sometime with risk of being obsolete or expired. Such a situation incurs additional cost to the importers in both cases of shortage and extra inventory of spare parts especially that many local spare parts distributors have no management system for their spare parts.

This paper aims at developing an effective spare parts inventory management system at a local Palestinian distributor having an agency for a certain brand of auto spare parts. A set of spare parts is considered in the analysis by firstly classifying them into ABC classification based on real historical sales date. Proper forecasting models are derived for each category to estimate the future demand of each item. Then, estimates of relevant costs are identified for each category of spare parts items. Respective optimal ordering policies (with optimal order quantities and optimal ordering times) based on Economic Order Quantity (EOQ) models are determined such that the total annual spare parts inventory cost is minimized. A comparison with the current ordering policies adopted by the distributor with the ones obtained in by EOQ models is conducted where the EOQ-based policies outperform the current ones through yielding lower total annual inventory costs.

The rest of the paper is structured as follows. Section two provides the reader with some recent relevant literature on spare parts inventory management and control. Section three presents the forecasting results as well as the ABC classification of the investigated set of spare parts. Section four includes the estimation of pertinent inventory cost parameters. Section five presents derivations of the spare parts inventory review systems. Section six presents the optimal ordering policies of the classified spare parts under study. Section seven ends up the paper with some concluding remarks.

II. Literature Review

Spare parts inventory management has been considered one of the main research areas in inventory management for the last decades. Kennedy *et al.* (2002) point out that the literature is very rich with theoretical models of inventory management for slow-moving items since 1965, case studies discussing the literature review of spare parts inventory management in a comprehensive manner are few; most of such studies mainly concentrate on mathematical optimization of inventory.

Theoretical mathematical models for (s,S) and (S-1,S) inventory management policies have been extensively optimized in literature assuming Poisson distribution of demand, (Feeney and Sherbrooke, 1966). Poisson distribution implies randomness of demand with exponentially-distributed inter arrival between unit size demands of the slow-moving items. For larger unit size demands, other researchers (Williams, 1984; Silver *et al*., 1971) proposed the use of compound-Poisson distributions of demand, however, the nature of compounding makes the application in practice more challenging.

Many initial studies in literature on spare parts inventory management have concentrated on the using different forecasting methods for demand forecasting of slow- and fast-moving items rather than on developing and implementing inventory models. Forecasting aims at estimating the item's demand in some point of time in the future whereas inventory models evaluate a set of inventory control parameters for the entire demand distribution to achieve certain customer service level. Ghobbar and Friend (2003) present in a comprehensive study a comparison between 13 methods employed in forecasting spare parts. To assess the accuracy of these methods in forecasting, they rely on the mean absolute percentage error (MAPE) evaluation criteria for comparison, however, their article does not include any inventory models. They confirm the outperformance of weighted moving average and Croston's methods (Croston, 1971) over the exponential smoothing and regression methods, (Silver *et al.* 1998).

Many studies in literature have addressed spare parts inventory management from different perspectives. One study by Strijbosch *et al.* (2000) examines the performance of two different (s, Q) inventory models for spare parts in a production plant environment where inventory and forecasting are combined. The first model is a standard simple model in which the undershoot of the reorder level of inventory is not considered and the demand is assumed to be normally-distributed during the lead time. The second model is an advanced one in which the undershoots are considered, zero and nonzero demands during lead time are discriminated and gamma distribution is assumed for demand. Both models are provided with estimated forecasts of demand and the times of occurrences between separate demands intermittently. The results show the outperformance of the advanced model over the simple one in terms of the achieved customer service level. Behfard *et al.* (2015) develop a heuristic technique, in the existence of imperfect option of the failed parts, to find a near-optimal last time buy orders usually placed by original equipment manufacturer to cover demand for spare parts during the remaining service period of the equipment. Comparing the results of the heuristic techniques with simulation ones on numerical examples reveal that preference of repairing the failed spare parts over buying and waiting for a new one.

Another recent study considers inventory management of spare parts used for maintenance support in airline industries with uncertain demand. Unlike commonly-used reorder point and historical date-based forecasting models, Gu *et al.* (2015) develop two non-linear programming models to forecast the demand for spare parts based on their installed failure distributions. Optimal order quantities and times of spare parts could be obtained via minimizing the total cost. Both models proved to be effective in cost reduction as shown by some numerical examples. Bacchetti and Saccani (2012) investigate the gap between research and practice in spare parts management. More specifically, their paper presents a comprehensive critical literature review of theoretical models for demand forecasting and stock control of spare parts. Based on analysis and discussion of ten case studies in this field, the reasons for such gap are highlighted, mainly represented by limitations of developed theoretical models in literature and the maturity of companies' spare parts management systems. The researchers recommend some research directions to bridge the gap, namely through developing integrated approaches of spare parts management, defining contingency-based managerial guidelines and supplementing theoretical models with practical insights.

Relevant to automobile spare parts management, a recent study by Rego and Mesquita (2015), presents the results a large-scale simulation study that considers more than 10,000 stock-keeping units of automobile spare parts demand forecasting and optimal ordering policies at an auto maker plant in Brazil. Considering six years of demand data, six demand distributions, weekly and monthly historical data, each spare parts category's optimal ordering policies could be identified. On the other hand, Kareem and Lawal (2015) address the automobile spare parts classification problem in a new approach based on failure rates using ABC analysis. Such an approach helps dynamically determine critical equipment/spare parts of automobiles. Failure rates reduction could be achieved by applying modified classical inventory management models considering the heterogeneity in item failures. Li and Kuo (2008) develop an improved fuzzy neural network decision support system to manage and forecast the demands of automobile spare parts in a central warehouse. Analytic hierarchy process and genetic algorithms are employed for enhancing the accuracy of the network results. Real life case studies are used for learning and testing the network to support the accuracy of its results. Lengu *et al.* (2014) investigate the demand classification of spare parts inventories through conducting a detailed empirical investigation of the Passion goodness of fit testing on demand data. Their investigation supports certain demand distributions which in turn facilitates the task of selecting proper distributions in real life spare parts inventory contexts. Many more other articles on spare parts inventory management are available in the literature. The reader is encouraged to refer to Karsten and Basten (2014), Tiacci and Saetta (2011) and Kim and Park (2008).

Many studies in literature have been devoted to address the problem of spare parts management for the purpose of supporting maintenance operations. One study by Cheng and Tsao (2010) develop an approach for selecting a maintenance strategy for rolling stock of spare parts and obtaining the optimal spare parts quantities and time intervals of replacement of such stocking rolls. Analytic network process is used for obtaining the proper preventive and corrective maintenance strategies. The obtained strategies helps determine the optimal ordering and safety stock quantities of spare parts in the facility where the application is in the spare parts of railways. Another study conducted by Panagiotidou (2014) considers the joint maintenance and spare parts ordering policies for identical items subject to types of failures (major and minor). Both optimal continuous and periodic review inventory policies are determined and compared as a result of optimization the total expected inventory and maintenance costs function.

On the other hand, Zanjani and Nourelfath (2014) address the problem of coordinated spare parts logistics and operations planning by a third party maintenance provider. A mathematical model is formulated to solve the problem of the third party maintenance provide who encounters strict due dates for providing the needed services. The developed model could identify the optimal number of maintenance jobs that could be completed on time as well as the optimal ordering quantities of spare parts such that the procurement, inventory and equipment delivery costs are minimized. Costantino *et al.* (2013) consider the problem of allocation of spare parts of aeronautical system in the Italian Air Force in an innovative model. The model aims at minimizing backordering concurrently achieving a 99% of spare parts availability, taking into account various skills of maintenance centers in hierarchical multi-echelon, multi item and multi-indenture structure. The impact of spare parts inventory management on maintenance and replacement decisions under technological change are examined and formulated as a Markov chain process by Nguyen *et al.* (2013). The results reveal that under some technological change, the do nothing and repair alternatives have more significant value compared to the replacement alternatives. Tracht *et al.* (2013) investigate the problem of spare parts planning for offshore wind turbines under some limiting maintenance conditions. More specifically, they develop a model for spare parts planning taking into consideration restrictions existing in the offshore maintenance field. The developed model investigates the influence of such restricting maintenance conditions on maintenance and operations costs and on the spare parts supply processes. Scenario analysis is used to determine the preventive maintenance activities' times as well as to investigate the stock out costs caused by restrictive accessibility to spare parts. Other articles deal with spare parts management for maintenance management purposes are available in the literature, to name but a few, the reader could refer to Wang and Syntetos (2011), Wang (2012), Kelly (2006), Godoy *et al.* (2013), Molenaers *et al.* (2012), Dekker *et al.* (1998) and Xie *et al.* (2014).

Many articles considers the problem of spare parts management from a supply chain perspective. A study by Khajavi *et l.* (2014) investigate the impact of additive manufacturing improvements on the configuration of spare parts through scenario modeling of a real-life spare parts supply chain applied in aeronautics industry (F-18 Super Hornet Jet). More specifically, four different scenarios are examined with varying supply chain configurations and additive manufacturing machine specifications. Tiemessen *et al.* (2013) model the problem of the real time demand fulfillment in spare parts networks, with customers having different service contracts with different penalty costs. The model adopts the one step look ahead policy which yields a small optimality gap and outperforms the widely-used static allocation policies. Many other articles consider different aspect of supply chain management in spare parts inventory, including but not limited to, Dekker *et al.* (2013), Soumala *et al.* (2002), Jouni *et al.* (2011) and Kleber *et al.* (2011).

III. Classifying and Forecasting the Spare Parts

3.1 ABC-Classification of Spare Parts

Researchers have developed many techniques for classifying inventories in the organizations for the purposes of effective control especially in the case of large inventoried items. One classical classification is the ABC one which is based on Pareto principle (80/20 rule). ABC classification is an easy to understand to apply technique which classifies items into three main categories (A,B, C) according to their usage values. Class A items include the fewer ones but with the highest importance, class C items encompasses the larger ones but with the lowest importance, and class B items are in between, (Torabi *et al.,* 2012). Traditional ABC classification adopts one criteria in ranking items based on their annual dollar usage. In accordance with this, A-items are the 20% of items which tie up 80% of the total annual usage, B-items are the 30% of items which tie up 15% of the total annual usage and C-items are the 50% which tie up 5% of the total annual usage. Such ranking criteria is adopted in this paper for classifying the spare parts under study. The local distributer of the spare parts has more than 200 items in their warehouses. However, some of those items have relatively small dollar values compared to others. Therefore, it is was decided to only consider 77 spare parts items for analysis which have the highest interest to be effectively controlled by the distributer. The justification for limiting the analysis to those 77 items is two-fold; because they are the highly-demanded items by clients and they have reliable historical data records including their quantities and other costing elements. Based on the historical data available on these items, the ABC classification could be obtained as shown in Table (1) and Figure (1).

Table (1): ABC-classification of spare parts.

A	16	20.8%	70.7%
B	23	29.9%	20.9%
C	38	49.3%	8.4%
Total	**77**	**100%**	**100%**

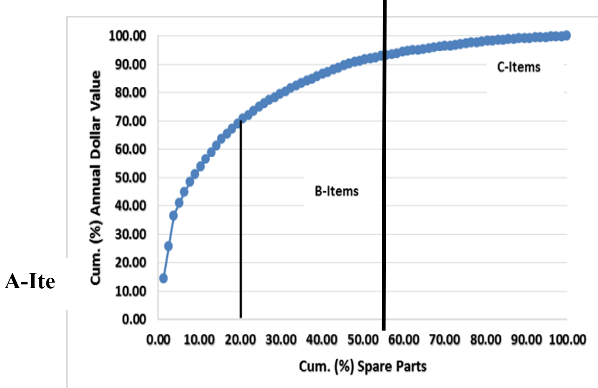

Figure (1): ABC-classification of spare parts.

3.2 Demand Forecasting of Spare Parts

Demand forecasting of spare parts is considered one of the most important inputs in inventory planning. Having an effective forecasting system with good demand forecast estimates supports inventory management activities by providing accurate order policies of spare part items. Two general methods are commonly used for demand forecasting. The first methods are qualitative in including judgmental methods, which translate the opinions of managers, expert opinions, consumer surveys and sales force estimates into quantitative estimates. The second are the quantitative methods including causal methods (regression analysis) and time series analysis (naïve, simple moving average, seasonal, exponential smoothing, Winter's and some advanced methods). In this section, we rely on the most recent historical data of the 77 spare parts annual sales stored in the databases at the local distributor to be used for forecasting the demands in the future. Four time series methods are used for forecasting the spare parts demands. These are the naïve, moving average, weighted moving average and exponential smoothing methods. Choosing the most accurate method is based on comparing the accuracy of forecasting by computing mean absolute percentage error (MAPE), where the most accurate method is the one which minimizes MAPE, (Krajewski and Ritzman, 2002). MAPE relates the forecast error to the level of demand and is useful for putting forecast performance in the proper perspective and is given by equation (1).

$$MAPE = \frac{\sum[|E_t| * (100)]/D_t}{n} \ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

Where $\sum[|E_t| * (100)]$: the sum of absolute error multiplied by 100, D_t : the actual demand of time period t , n : number of time periods and $E_t = D_t - F_t$ is the forecasting error which is the actual demand minus the forecasted demand value.

The historical data covering the last two years actual sales for the 77 classified spare parts were used to determine the most accurate forecasting method (with minimum MAPE) for demand forecasting of the considered spare parts. Table (2) summarizes the most accurate methods for forecasting class A, B and C items. The tabulated results show the number of items in each class with the most accurate (best) forecasting method which yields the smallest value of MAPE compared to other methods. Clearly, all methods outperform the Naïve method where no items should be forecasted with Naïve methods since it yields MAPE values larger than that obtained by other methods.

Figure (2) depicts the forecasted values for the 16 A-spare parts using the four adopted time series methods. Such forecasted values could be used in determining the optimal order quantities of the spare items. The simple moving and weighted moving average methods outperform other methods since they yielded the minimum MAPE values for most of the items in this class.

Table 3.2 Forecasting accuracy for spare parts demand based on minimum MAPE.

A (16 items)	Exponential smoothing: 2 items Simple moving average: 7 items Weight moving average: 7 items Naïve: 0 items
B (23 items)	Exponential smoothing: 3 items Simple moving average: 12 items Weighted moving average: 8 items Naïve : 0 items
C (38 items)	Exponential smoothing average: 4 items Simple moving average: 20 items Weighted moving average:14 items

	Naïve: 0 items

Figure (3) and Figure (4), respectively, depict the forecasted values for B-class and C-class spare parts items. Such forecasted values would be used in computing the optimal order quantities of spare part items. Simple moving average and weighted moving averages result in the minimum values of MAPE compared to other methods for most of the items in both classes.

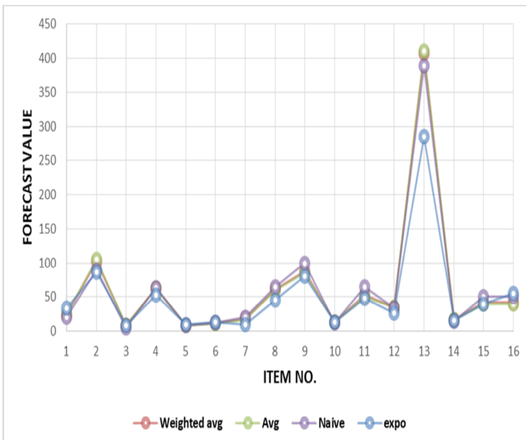

Figure (2): Forecast values of A-class spare part items.

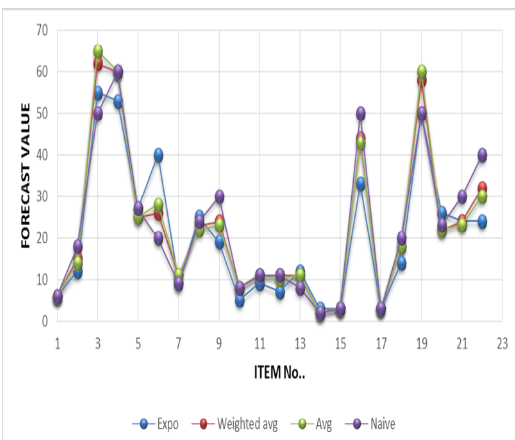

Figure (3): Forecast values of B-class spare part items.

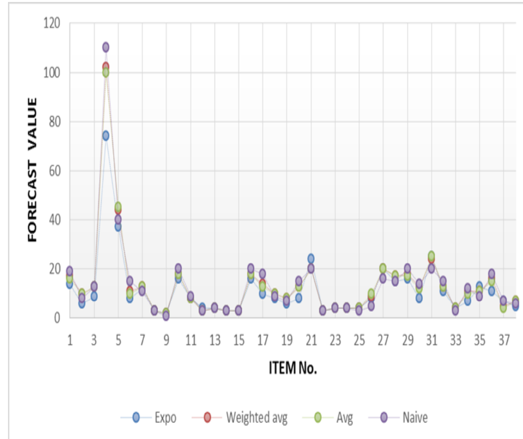

Figure (4): Forecast values of C-class spare part items.

IV. Inventory Costs Estimates

Inventory costs are usually computed annually. A rough estimate of inventory holding costs is about 20% to 25% of the material's value. The cost of holding inventory in an organization is composed of capital and non-capital cost elements. More specifically, the capital cost is represented by capital funding coming from equity and debt funding, where the cost of capital is defined as the opportunity cost of all capital invested in the organization. We neglect the cost of capital in this study because the local spare parts distribution company is not an equity company and has no debt finding. On the other hand, the non-capital cost of inventory includes all cost elements related to holding, handling and managing the inventories in the company. Specifically, these include warehousing rental, transportation, obsolescence, pilferage/theft, damage, insurance, tax and duty and administration cost (accounting, management). The difficulty in estimating the non-capital costs arises from the inability of some companies to capture the costs accurately and hence come up with underestimated numbers. Some costs elements are very hard to be estimated like damage and pilferage costs. The accounting department at the local distributor helped in estimating the non-capital costs associated with the spare parts under study. More specifically, they estimated holding and ordering costs of the 77 spare parts under study as shown in Table (3).

Table (3): Estimates of the holding cost of spare parts as a percentage of the spare parts' value.

Warehouse Rent ($/year)	**Administrative Costs ($/year)**	**Taxes ($/year)**	**Total Non-Capital Cost ($/year)**	**Average Aggregate Spare Parts Inventory Value (S/year)**	**Holding Cost as percentage of the item cost**
9850	50,000	7250	67,100	300,000	22.36%

In addition, since spare parts are frequently ordered from regional as well as international suppliers, there is an ordering cost every time an order is issued to the supplier. Regardless of the ordered quantity, the ordering cost is constant each time a quantity is ordered. Practically, the ordering costs consists of all costs incurred in preparing the order items, logistics and truck sending costs, all phone calls, faxes and contacts made with the supplier each time a spare part is ordered. The accounting department estimates the average ordering cost to be $40 per order. For the sake of simplicity of computations and due to some real operational practices by the distributor, it is assumed that each individual spare part item has a separate supplier from which it is ordered. The 77 spare part items under study were carefully selected by the researcher and the distributor for study in order to comply with this assumption of non-combined ordering of spare parts. Next, we present the results of the optimal ordering policies of each spare part item under study.

5. Spare Parts Inventory Management Models

5.1 Inventory Review Systems

Effective management of spare parts inventory is very essential to the management of the local distributor in order to manage the supply of spare parts items to satisfy customers' needs while maintaining the total incurred inventory costs at minimum. Demand for automobile spare parts continues its growth as demand for new cars is increasing. This trend has raised the necessity to keep the appropriate quantities of spare parts on shelves at the local distributor's stores to satisfy the demand requirements. The local distributor of spare parts in this study faces the same tend as well as the demand on her spare parts has been increasing and this creates a need for extensive service commitments and more spare parts to be kept. However, as spare parts inventories are expensive, the distributor does not desire to hold excessive unnecessarily stocks of spare parts. Therefore, it becomes essential to have a trade-off between the company's cost considerations and customer service requirements. In order to build an effective inventory management system, first, we need to discuss the common inventory review and control systems, namely, a continuous review and a periodic review as mentioned in Silver *et al.* (1998). Both review systems help determine the optimal order quantity of each spare part and the time of ordering.

Inventory review indicates the time interval elapsed between counting spare parts inventory levels, provided that spare parts demand transactions are recorded upon their occurrence. This is called the review interval*,* which is the time elapsed between two consecutive moments at which we know the stock level, Silver *et al.* (1998). In a continuous review system, the stock level is always known and monitored on a continuous time scale. An order is placed with same order quantity, Q, whenever the inventory on hand decreases to a certain specified level called the reorder point (R). On the other hand, in the periodic review system, the stock is determined only every r time units, where a considerable amount of uncertainty may exist between the reviews In a periodic system, an order is placed for a variable quantity after a fixed period of time (P) determined by the company. The advantage of the continuous-review policy is that it requires less safety-stock to achieve the highest level of customer service. In a continuous review policy, the safety inventory is used to cover the demand uncertainty over the lead time L. With a periodic review policy, the safety inventory is used to cover the demand uncertainty over the lead time and the review interval $L+P$. The advantage of the periodic review is that it is capable of detecting spoilage of slow-moving stock items and trusses a prompt an evaluation of the situation, Nahmias (2004).

Russell (2011) points out that the disadvantage to maintaining a continuous record of the amount of inventory on hand can be costly to implement when compared to a periodic review system whereas the disadvantage of periodic review policy is that less direct control is needed. Both the continuous and periodic reviews are considered in our study. More specifically, a continuous review system is used for the high demand A and B items, which have frequent evaluations, and require close monitoring. These items are cycle-counted more often with low tolerances for error and have daily updates to the records. On the other hand, the Periodic review system is suitable for C items which are numerous in variety and with low demand, requiring less frequent reviews, as recommended in Silver *et al.* (1998).

5.2 Economic Order Quantity Model

The Economic Order Quantity (EOQ) model is considered one of the simplest classical models in inventory management. EOQ is the order quantity that minimizes the total annual holding and ordering inventory costs. The simplicity of the EOQ model is accompanied by a set of assumptions. However, the modeling assumptions do not mean that the model cannot be relied on to produce good results for real problems in practice. For example, these models have been effectively employed in automotive, pharmaceutical, and retail sectors of the economy for many years, Muckstadt and Sapra (2010). In addition, the EOQ model gives the optimal solution in a easy to compute way and in a closed form which allows for gaining theoretical and practical insights about the behavior of the inventory management system.

In the following discussion, we present the notation and the underlying assumptions of the EOQ model. Demand of a single item is assumed to deplete continuously with a constant depletion (consumption, usage) rate of D units per year. Remember that D for each spare part in the future item could be obtained by forecasting as shown previously. The continuous nature of demand implies that order quantities might be non-integer, which is not a significant problem as long as the spare parts are ordered in not very small. Whenever an order is placed, a fixed ordering cost K is incurred. In addition, each unit of a spare part costs \$$I$ per stock per year per dollar invested in the inventory (the value of I in our study is 22.36% as computed in Table (3)). Therefore, if the unit's purchasing costs is C, it will cost IC to keep one unit of that item for one year. Also, a placed order of EOQ arrives after t years after the placement and this is assumed to be deterministic. All model parameters are assumed to be unchanging over time, with an infinite planning horizon and no backordering is allowed (all the demand is satisfied on time). Figure (5) depicts the inventory order cycle in the EOQ model.

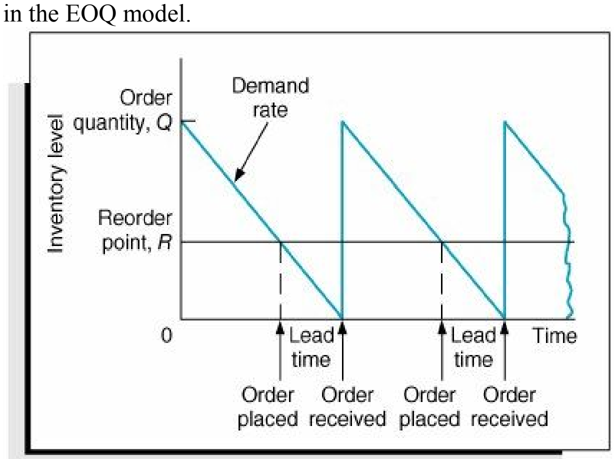

Figure (5): Inventory order cycle in the EOQ model (Source: Taylor III, 2010)

In order to determine the optimal EOQ, we need first to construct the total annual inventory cost function which should be minimized with respect to ordering quantity *Q*. Since the annual demand per year is *D*, then the total annual purchasing cost is *CD*. Also, the total number of orders placed per year is obtained by (*D/Q*). Thus, the total annual average cost of ordering is (*KD/Q*). The derivation of the total annual holding (carrying) cost needs more elaboration. We will start by first computing the average inventory per cycle. Since inventory cycles are identical, the average inventory per year is constant and is obtained, from Figure (5), by (0.5*QT/T=Q/2*). Therefore, the annual holding cost is obtained by multiplying the average inventory with annual unit's holding cost, or mathematically it is (*ICQ/2*). Collectively, the total annual inventory cost is obtained by adding the annual purchasing cost, annual ordering cost and annual holding cost, and is given in equation (2). The total annual cost function, depicted in Figure (6), needs to be optimized with respect to (*Q*) in order to determine the optimal *Q* which is the EOQ.

$$\min_{Q\geq 0} \; Z(Q) = CD + \frac{KD}{Q} + \frac{ICQ}{2} \quad \ldots\ldots\ldots\ldots\ldots(2)$$

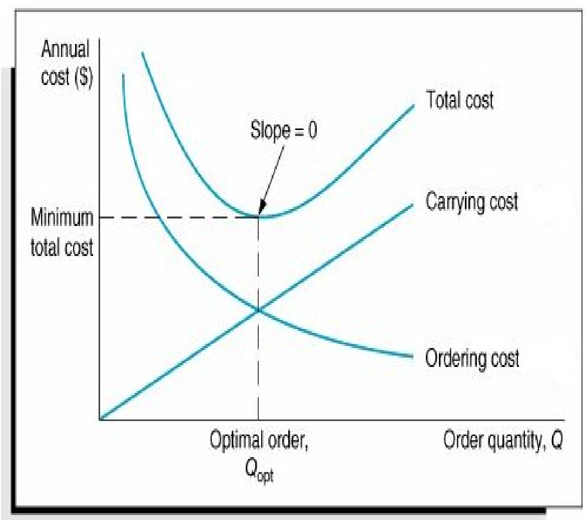

Figure (6): The EOQ- cost model (Source: Taylor III, 2010).

To compute the optimal order quantity, EOQ=Q*opt.*, we take the first derivative of *Z(Q)* with respect to *Q,* equal it to zero and then solve for the optimal quantity. Doing so results in the optimal order quantity given in equation (3).

$$EOQ = Q_{opt} = \sqrt{\frac{2KD}{IC}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(3)$$

Clearly, from Figure (6) and one can easily test the second derivative of *Z(Q)* which imply the convexity of the cost function, and hence the optimal quantity in equation (3) is a unique global optimal quantity.

The EOQ in equation (3) answers the question of how much to order but not when to order. The latter question is the function of models that identify the reorder point (*R*) in terms of a quantity where the reorder point occurs when the on hand inventory drops to a predetermined amount. This amount generally includes expected demand during the lead time plus some safety stock to reduce the probability stockout due to shortages during the lead time, Stevenson (1999). If the demand and lead time are both constant, then the reorder point is *R=dL,* where *d* is the demand rate (units per lead time units) and *L* is the lead time (days, weeks, months, ….etc). On the other hand, when uncertainty presents in demand and/or in lead time, it is essential to hold some additional inventory (safety stock) to protect yourself against shortages and stockouts. Consequently, the reorder point becomes

R = Expected demand during lead time + safety stock………(4)

Now, if only demand is uncertain, then equation (4) becomes

$$R = \bar{d}L + z\sqrt{L}(\sigma_d.) \ldots\ldots\ldots\ldots\ldots\ldots\ldots(4.1)$$

If only lead time is uncertain, then equation (4) becomes

$$R = d\bar{L} + zd(\sigma_L) \ldots\ldots\ldots\ldots\ldots\ldots\ldots(4.2)$$

And if both demand and lead time are uncertain, then equation (4) becomes

$$R = \bar{d}\bar{L} + z\sqrt{\bar{L}\sigma_d^2 + \bar{d}^2\sigma_L^2} \ldots\ldots\ldots\ldots\ldots\ldots(4.3)$$

Where $\bar{d}$ is average daily or weekly demand, σ_d is standard deviation of demand per day or week, *L* is the lead time in days or weeks, *z* is the number of standard deviations (assuming normal distribution of random variables, which is the case in our study), *d* is daily or weekly demand, $\bar{L}$ is the average lead time in days or weeks and σ_L is the standard deviation of lead time in days or weeks.

The spare parts inventory control in both the continuous review and periodic review systems depends on the inventory position (*IP*), which is the measure of the spare part item's to satisfy the future demand. More precisely, *IP* is given by equation (5) as

IP = On-hand inventory (OH)+Scheduled receipts (SR)-Backorders (BO)………(5)

<u>*Continuous Review System*</u>

IP behavior in the continuous review system goes as depicted in Figure (7).

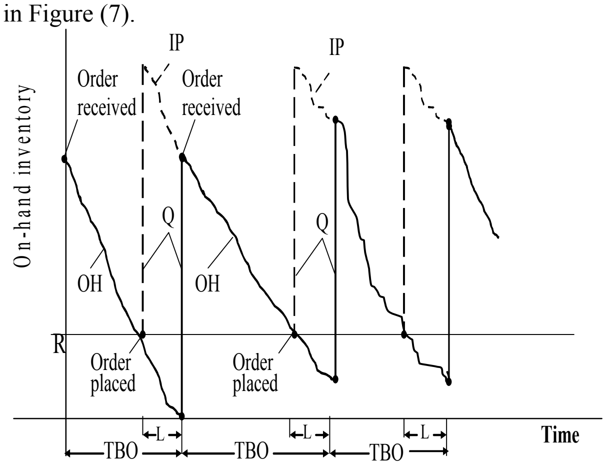

Figure (7): Continuous review system (Source: Krajewski, 2006).

The ordering policy under this system is given by: "*Order an amount (Q) (typically the EOQ given in equation (3)) when the inventory position (IP in equation (5))) falls to the "reorder point" (R in equations (4.1)-(4.3))".*

<u>*Periodic Review System*</u>

IP behavior in the review system goes as depicted in Figure (8).

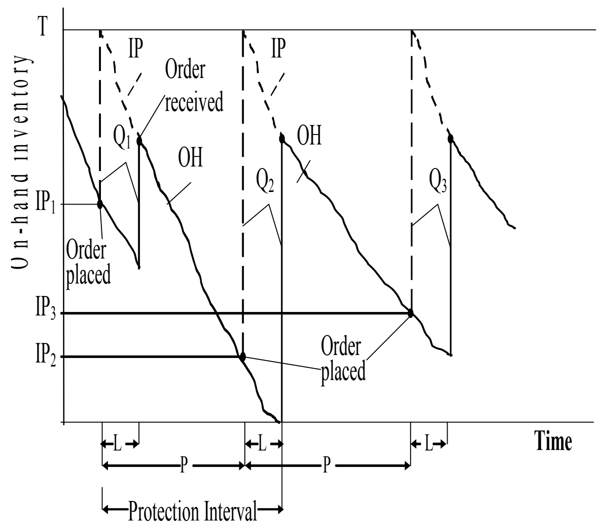

Figure (8): Periodic review system (Source: Krajewski, 2006).

The ordering policy under this system is stated as follows: "*the review period P is typically either determined by management or computed using the EOQ. In the latter case, the review period in days equals to P = (EOQ / D)(# of days per year).*

The target inventory level is given by:

$$T = \bar{d}\,(L+P) + \text{safety stock (ss)} = \bar{d}\,(L+P) + z\sigma_d\sqrt{L+P} \quad \ldots\ldots\ldots\ldots\ldots(6)$$

Order quantity Q = T – IP."

6. Optimal Ordering Policies of the Classified Spare Parts

In this section, the optimal order policies are identified under both the continuous review and the periodic review system for the 77 classified spare parts items. The total annual inventory costs are calculated for all items in the same class under both systems and the results are compared to the total annual inventory costs the distributor is incurring under her current ordering policy. In all computations of the 77 items, the following parameter values are assumed to be: *K =$40, I=0.2236, C: unit purchasing cost (available for all spare parts), D: annual demand for each spare part (available for all spare parts and found to be normally-distributed upon testing normality), current Qs for all spare parts (provided by the distributor), customer service level of 95% which corresponds to z value equals to 1.65 and lead time L is known and deterministic for each supplier of each spare parts.*

Having all necessary parameters information determined, the optimal ordering quantities and ordering times are calculated and from which the corresponding total annual inventory costs are computed. Also, the total annual inventory costs for all items are computed under the current ordering policies. Table (4) summarizes the annual inventory costs results for each class of spare parts. The tabulated results include the savings the distributor could gain if she abandon the current ordering policy and adopt either continuous or periodic reviews policies. Clearly, the current ordering policies adopted are inferior to both continuous and periodic review policies. Also, the optimal continuous review policies outperform the optimal periodic review ones since they incurred total annual inventory costs under the continuous system is lower than those under the periodic system for all spare parts classes.

Table (4): Total annual inventory costs of spare parts items.

Spare Parts Class	**Total Annual Inventory Costs, *Z(Q)*, ($/year)**		
	Current Ordering Policy	**Continuous Review Policy**	**Periodic Review Policy**
A (16 items)	81,440	62,463	63,722
Annual Saving (%) with respect to current ordering policy	Zero	23.30%	21.76%
B (23items)	52,040	30,042	37,408
Annual Saving (%) with respect to current ordering policy	Zero	42.27%	28.12%
C (38 items)	63,439	43,973	39,193
Annual Saving (%) with respect to current ordering policy	Zero	30.69%	38.22%
Total Annual Costs	**196,919**	**136,478**	**140,323**
Total Annual Saving (%)	**Zero**	**30.69%**	**28.74%**

Conclusions

This study aims at developing an effective inventory management system for an important set of automobile spare parts at a local distributor in Palestine. The local distributor does not have any management system for the automobile spare parts she is holding in her warehouses and selling to Palestinian customers. Although they have fair technical experience in the automobile spare parts they are dealing with, however, they lack the expertise in managing their spare parts effectively. This has resulted in severe shortcoming in the business process of their company. After reviewing the historical data records of the automobile spare parts in the company, 77 items were identified to be of the highest importance for being managed and controlled optimally. We classified the 77 identified items into three categories (A, B, and C) based on Pareto principle. Then, relevant cost data and historical actual sales data were, respectively, estimated and collected from the distributor's databases.

Commonly-used quantitative supported by qualitative forecasting methods were tested on the collected actual sales data to come up with the "best" forecasting method for each of the 77 classified items. Then, based on the EOQ model, optimal ordering policies were identified for each spare part item, where the computations show that the outperformance of the continuous review system over the current as well as the periodic review systems. The optimal continuous review systems, if adopted, would save in total about $60,441 (31%) in annual total spare parts inventory costs. The manager of the automobile spare parts distribution company started implementing the new management systems at their company through adopting the continuous review policies where initial feedback shows satisfactory results about the improvement in inventory management performance. The company's administration has already started an initiative to computerize the system for the ease of its practical use.

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