DEMAND FORECASTING FOR SPARE PARTS – A PERSPECTIVE FROM THE MARINE PORT INDUSTRY

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Introduction

Spare parts (also known as service parts) are those parts that are used in the course of production of goods or services, such as during maintenance of equipment, but they are not constituents of the intermediate or final product. Service parts can be divided into two categories: Repairables (which in case of failure, are swapped with new parts and sent to a repair centre) and consumables (which are not technically or economically repairable) (Botter and Fortuin, 2000). Furthermore, there are two fundamental types of maintenance – scheduled (preventive) maintenance, and unplanned (corrective) repair (Kennedy et al., 2002). For preventive or scheduled maintenance, the demand for spare parts is predictable and it may be possible to order parts to arrive just in time for use, but for unplanned repair, the consequences of stock-outs often include production loss.

Compared to other types of inventories, spare parts inventories are unique in several aspects (Kennedy et al., 2002). Maintenance policies, rather than customer usage, dictate the need for spare parts inventories. Reliability information is generally not available to the degree needed for the prediction of failure times. Demands for parts are sometimes met through cannibalism of other parts or units. The costs of stock-outs generally include quality deficiency as well as lost production, and these costs are difficult to quantify. Obsolescence may be a problem as the machines for which the spare parts were designed become obsolete and are replaced by newer models. Consequently, spare part inventories cannot be managed by standard inventory control methods, since the conditions for applying the underlying models are not satisfied (Botter and Fortuin, 2000).

This research seeks to investigate via a case study the forecasting practices for spare parts from an industry perspective of a marine port operator. The secondary objective is in describing the challenges in achieving good forecast accuracy across commodity groups at the subject company.

Literature Review

The field of research in management of spare parts (or service parts) is not new. The reader is referred to the papers by Kennedy et al. (2002) and Rego and Mesquita (2011) for in-depth literature reviews on the subject. This review presents only a selection of relevant papers and is divided into three main parts. An overview of selected research on spare parts inventory control is first introduced. A review of the developments in the field of analytical forecasting of intermittent demand is then conducted, followed by a brief discussion on judgmental forecasting methods.

Botter and Fortuin (2000) presented a framework for service parts inventory control for a two-echelon network of warehouses, to answer the questions of which, where and how many parts should be stocked. Strijbosch et al. (2000) developed a compound Bernoulli model (CBM) for spare parts inventory control, which incorporates undershoots, differentiates between zero and nonzero demand during lead-time, and utilizes the gamma distribution as the demand distribution. They found that the model yields a close-to-desirable service level in a case study on a production plant of a confectionery producer. Louit et al. (2011) presented risk and cost models for the optimization of inventories of both non-repairable and repairable spares. Most of these models are based on a Poisson process approximation for spares demand.

Bacchetti and Saccani (2012) investigated the gap between research and practice in spare parts management. They found that very few empirical studies compare spare parts management practices of companies, but those that did point out that substantial benefits can be achieved through the adoption of simple but formalized methods or of an organizational perspective towards spare parts inventory management. They proposed several directions for research in order to bridge the gap, among them to define contingency-based managerial guidelines and to supplement theoretical models with practical relevance.

In general, forecasting techniques may be classified into time-series statistical methods and judgement/environment based approaches. Webby and O'Connor (1996) used a contingency framework and identified the characteristics of the time series (which include the periodicity of the data, trend, seasonality, noise, instability, number of historical data points and number of forecasts required) and those of the judgment/environment (experience, context, motivation).

Several time-series based methods have been developed for demand forecasting, yet only a few with the special focus on spare parts demand forecasting (Hellingrath and Cordes, 2014). Intermittent demands are particularly difficult to predict (Hua et al., 2007). Two methods are commonly used in practice: Croston’s method and the Syntetos-Boylan Approximation (SBA) method. Croston (1972)’s method separates the estimation of intervals between demands of the amounts demanded in each occurrence, while the SBA method (Syntetos and Boylan, 2001) corrects the bias in the original Croston’s method.

Among recent advances in the forecasting of intermittent demand in the past 15 years, Willemain et al. (2004) used the bootstrapping technique to assess demand distribution during lead-time, considering autocorrelation and introducing small demand variations to the original series (jittering). Comparing the new model to Croston’s method and exponential smoothing, Willemain et al. (2004) concluded that the first provides better results, especially for small historical series. Hua et al. (2007) further proposed an Integrated Forecasting Method (IFM) that combines bootstrapping and regression analysis in demand forecasting of parts in the petrochemical industry, with promising results compared to exponential smoothing, Croston's method, and the Markov bootstrapping method. More recently, Gu et al. (2015) developed models that consider parts aging and focus on impending demands.

Despite the availability of statistical methods in forecasting, forecasts in most organisations are either entirely based on judgment or judgmental adjustments are applied to the forecasts of a statistical method (Goodwin, 2002). There is relatively little recent research on the use and performance of judgmental forecasting (or judgmental adjustments) for demand of spare parts, even though Lawrence et al. (2006) note that there is an “explosion of research interest” in the area of judgmental forecasting. They reviewed the literature on the importance of human-interaction factors in forecasting and conclude that the accuracy of judgmental eyeballing may be roughly equivalent to the statistical methods, but the major contribution of judgmental approaches lies in the ability to integrate this non-time series information into the forecasts. On the contrary, Goodwin (2002) suggests that the choice of forecasting method may even have little to do with the accuracy associated with the method, but the voluntary integration (of judgmental inputs to statistical methods) is more likely to lead to forecasts that are more likely to be acceptable to the forecaster and decision makers.

To round up, the review of literature has revealed that many researchers have focused extensively on technical approaches towards forecasting intermittent demand for spare parts. Others suggest that judgement-based forecasting methods have a role to play, such as in cases when spares parts usage are not truly random (due to planned maintenance programs, inter-dependent part failures or aging of equipment). However, there has been almost a surprising lack of insights derived from the industry’s perspective and current practices on spare parts management, which is a gap that this paper aims to address.

Background & Methodology
This research is centred on Company A, which has been selected as the subject of the case study, not least because internal historical data is reliable and well-archived within an Enterprise Resource Planning (ERP) system. Company A is one of the world's largest marine port operators and operates numerous berths at its container terminals. Equipment used in running the port business include quay and yard cranes, empty stackers and prime movers. It is important to ensure that such equipment are in good working condition in order to avoid down-time during operations. As such, adequate spare parts and consumables are necessary to be available for any repair or maintenance works.

To establish the background to the case, interviews were conducted with store personnel, technicians and engineers at Company A, on the procedure on how spare parts are procured, how they are requested from inventory and how work orders are approved.

Company A makes use of term contracts to work with suppliers to ensure that the spare parts are available just in time or on a consignment basis. The company outsources the management of spare parts to vendors and the term contracts are signed based on demand forecasts provided by Company A. Suppliers are responsible for stocking the spare parts (or procuring them at short notice) if they are awarded the contract. Company A will issue a purchase order as and when the items are required. A contract would lapse at the end of the agreed term or when the value of consumed parts reaches the agreed contract sum, whichever comes first. Thus, it is important to ensure forecasts of demand are close to the actual demand.

In Company A, the procurement department works with the engineering department directly on the term contract in terms on pricing, technical requirements and delivery details. On the other hand, the inventory management department is in charge of extracting past parts usage data, working with the inventory stores and technicians if a work order (WO) is required. Once a WO has been approved, it is sent the procurement department as a purchase request (PR). If there is a valid term contract available, the PR is used to issue a purchase order to the assigned supplier.

Despite the use of term contracts, certain spare parts may at times be required in quantities that are much higher than the average forecasted quantity. This may catch suppliers by surprise, as they may not be prepared to meet the sudden surge in demand, leading to stock-out issues in Company A and therefore maintenance delays and down times. Suppliers may also be obligated to pay liquidated damages if deliveries are not fulfilled on time. Occasionally, urgent ad-hoc purchase orders have to be made to minimise machine down times. Inaccurate forecasts would therefore not only affect the operational running of the business, but would also result in extra costs from urgent purchases and expedites. On the other hand, if Company A does not fully consume the quantity of items as forecasted in the term contract, it may (depending on the terms of the specific contracts) be required to purchase the unconsumed parts. Alternatively, the supplier would have to bear the cost of the unused spare parts. Both scenarios put strains on the working relationship between Company A and the supplier.

The challenges that Company A has in meeting demand for planned and unplanned maintenance is best epitomized by Figure 1, which shows the example of monthly time-series usage data for an MRO part (a sensor that is used in an empty stacker) over 10 years. It can be observed that the monthly usage pattern is highly intermittent, with some months seeing very high demand, followed by almost zero demand in the following periods. Overall, there is a trend of higher and more frequent usage of parts as time passes (i.e. the time-series is non-stationary and exhibits a trend), which is partly attributed to the ageing of equipment whose parts need to be replaced. Furthermore, scheduled replacements and preventive maintenance are sometimes conducted (e.g. in December 2014) whereby the sensors in the entire fleet of empty stackers were replaced.

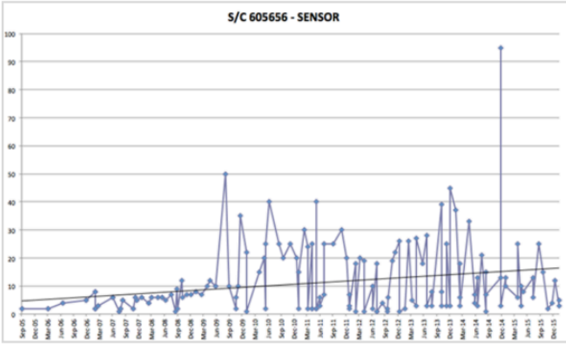

Figure 1: Monthly usage for sensor (year 2005 To 2015)

Company A makes use of both Enterprise Resource Planning (ERP) and Enterprise Asset Management (EAM) systems to manage their finances, inventories and assets. Frequently purchased items are assigned with individual stock codes and are called “stock items”. There are more than ten thousand stock items listed in the ERP system. Primary data from up to 5 years ago is generally available to be extracted, e.g. item description, last purchase price, purchase frequency information and duration of term contract.

Company A groups its spare parts in terms of commodity types (such as vehicle spares and empty stackers spares) or in term of brands. Thus, there are numerous items listed in the same term contract in different categories. For example, some are for daily usage whereas some are for replacements during repair.

Interviews with store personnel, technicians and engineers also yielded some further insights on how requests for spare parts are processed. When a particular spare part is required, the technician will refer to the physical part manual and enter the required stock code into the EAM system to request for a work order (WO). Approval of the WO is not required if that spare part is stocked in inventory and listed in the term contract. Once the WO has been created, the technician can collect the spare part directly from stock. If the spare part subsequently is found to be defective, the technician will have to follow-up with the procurement and inventory department to resolve the problem (e.g. one-to-one exchange with the supplier). On the other hand, if the technician has withdrawn the wrong spare part, he/she could amend the WO and do a reverse of inventory. A new WO for the correct spare parts can also be requested but they are not necessarily required to return the item that was wrongly issued.

To ensure that the procurement department has sufficient time to prepare for a new contract, an alert will be triggered as soon as more than 70% of parts procured under a term contract has been utilized or 3 months before the contract is due to expire, whichever comes first. If the purchase request for individual stock item is higher than the estimated quantity remaining in the term contract, this is usually resolved by calling an interim term contract or renewing the term contract before its expiry date.

Apart from qualitative insights obtained from interviews and quantitative data obtained from the ERP system, a survey of participants in the demand forecasting process was conducted. A questionnaire was sent to the spare part coordinators via email, with questions mainly related to the type of spares handled, the forecasting methods used and factors in the making of these forecasts.

Results & Discussions

To limit the scope of parts to be analysed in the study, the term contract for spare parts of empty stackers was selected for analysis. An empty stacker is a vehicle used in Company A to transport empty containers across the entire terminal. The term contract for empty stacker spare parts is suitable because it contains all major groups of parts, such MRO parts, consumables and repairable parts. The contract also includes parts that can be grouped by whether they are usually replaced under preventive or corrective maintenance.

The analysis on forecast accuracy involves the calculation of forecasting error, which is the deviation of the actual usage from the forecasted quantity, such that:

Forecast Error = (Actual Demand – Forecast Demand)/(Actual Demand)

Table 1 shows a sample of the spare parts and their associated forecast errors. Within the list, it could be observed that most of the items with poor forecast accuracies are consumables (e.g. springs, nuts, seal rings and wheel bolts) and MRO parts (e.g. wiper arms and magnetic valves). On the other hand, parts that are used as part of planned or scheduled maintenance schemes tend to have good forecast accuracies.

Part Description	Category	Planned?	Forecast	Actual	Error	Error (%)
Over-forecasts						
Seal Ring, Grease Seal Spindle	Consumable	No	37	4	-33	-825%
Thermostat	Repairable	No	15	2	-13	-650%
Shim, Lock Plate Single	Consumable	No	20	3	-17	-567%
Retaining Ring, Spindle Bottom	Consumable	No	32	5	-27	-540%
Spring, Accelerator Padel Return	Consumable	No	20	4	-16	-400%
Screw, Spindle Bottom	Consumable	No	192	40	-152	-380%
Brake Shoe Lining, Parking	MRO	Yes	46	10	-36	-360%
Sensor, Tm Oil Pressure	MRO	Yes	12	3	-9	-300%
Gasket, Exh Manifold	MRO	Yes	8	2	-6	-300%
Shim, Spindle	Consumable	No	22	6	-16	-267%
Magnetic Valve Parking	MRO	No	22	7	-15	-214%
Light, Side Tail Lamp Assy	MRO	No	14	5	-9	-180%
Hose Lower Radiator	MRO	No	19	7	-12	-171%
Retaining Ring, Tilt Minder Shaft	Consumable	No	32	12	-20	-167%
Plug, Engine Oil Sump-Kalmar	Consumable	No	10	4	-6	-150%
Lifting Cylinder Rubber Guide	MRO	Yes	30	14	-16	-114%
Wiper Arm,Front	MRO	No	17	8	-9	-113%
Bolt, Spindle	Consumable	No	2	1	-1	-100%
Shaft, Tilt Cylinder Pin	MRO	No	14	7	-7	-100%
Seal Ring, Drain Plug	Consumable	No	10	5	-5	-100%
Potentiometer, Accelerator	MRO	No	4	2	-2	-100%
Screw, Air-Con Belt Tensioner	Consumable	No	27	14	-13	-93%
Slide Plate, Spreader Side	MRO	No	380	200	-180	-90%
Washer, Sealing	Consumable	No	38	21	-17	-81%
O-Ring, Drive Axle	Consumable	No	10	6	-4	-67%
Nut, Wheel Bolt Front Axle	Consumable	No	36	22	-14	-64%

Part Description	Category	Planned?	Forecast	Actual	Error	Error (%)
Under-forecasts						
Spring, Toc Pin	Consumable	No	8	56	48	86%
Shim, Lock Plate Double-Kalmar	Consumable	No	42	185	143	77%
Hose, Air Intake	MRO	No	4	17	13	76%
Magnetic Valve,Spreader	MRO	No	2	6	4	67%
O-Ring, Service Hrake Hub Outer	Consumable	No	28	83	55	66%
Screw, Half Shaft	Consumable	No	16	44	28	64%
Ring, Stop, Twist Lock	Consumable	No	4	11	7	64%
Wheel Bolt, Front Axle	Consumable	No	52	142	90	63%
Bushing, Top, Twistlock	Consumable	No	6	16	10	63%
Relay, Signal Light Flasher Unit	MRO	No	4	10	6	60%
Good forecasts						
Over Centre Valve	MRO	No	3	3	0	0%
Hydraulic Pump	Repairable	Yes	4	4	0	0%
Piston Rod End, Telescopic	MRO	No	2	2	0	0%
Seal Kit, Lifting Cylinder	MRO	Yes	18	18	0	0%
Control Valve, Hydraulic Main	MRO	Yes	9	9	0	0%
Steering Wheel Panel	MRO	No	2	2	0	0%
Control Unit, ECU4	Repairable	Yes	2	2	0	0%
Control Unit, ECU1	Repairable	Yes	2	2	0	0%
Fuel Gauge	Repairable	Yes	3	3	0	0%
Unlock Light, Assembly, Red	MRO	No	12	12	0	0%

Table 1: Forecast accuracy for selected parts

The online questionnaire was sent out to 30 engineers and coordinators from the procurement department within Company A. They are all involved in providing estimates and also the formation of term contract. The questionnaire received a total of 24 responses, with 75% of responses from the engineering department and 25% from the procurement department.

Survey results show that within the organization, the majority of respondents deal with spare parts that are repairable (Figure 2a) and that preventive replacement methods are used more often used than corrective methods (Figure 2b).

Figure 2: (a) Type of spare parts handled (b) Replacement method adopted by survey respondents

Figure 3 shows the most important factors that respondents think would affect the usage of spare parts. A majority of respondents think that the amount of equipment down-time is an important factor. This can be explained by the incidence of inter-dependent part failures and/or low quality components that leads to repeated equipment malfunctions. Moreover, a significantly minority of respondents think the availability of stock is important, which is somewhat surprising, as this suggests that spare parts coordinators may be inclined to inflate their forecasts if they perceive that the on-hand inventory of a spare part is going to be low.

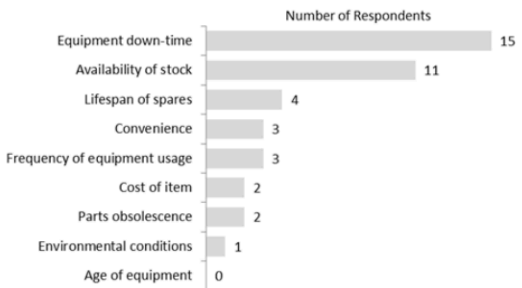

Figure 3: Respondent's views on important factors in forecast quantities and accuracies

Furthermore, it can also be observed that contrary to what might be expected from the review of literature (e.g. Gu et al., 2015; Botter and Fortuin, 2000), the age profile of equipment is not seen as a factor when forecasting demand for spare parts. One plausible reason for this is that while respondents may agree that the usage of spare parts would increase with age of equipment, such information may not be readily available to technicians and spare parts coordinators.

On an aggregated basis (regardless of spare parts type), the most often used forecasting method is past usage pattern (30% of respondents) followed by planned and schedule replacement (27%), statistical forecasting methods (17%), casual forecasting methods (9%), judgmental forecasting methods (8%) and consensus-based forecasting methods (6%).

The results are further broken down to analyse each part type against the forecasting methods used (see Figure 4). Planned replacement, past usage pattern and judgement-based methods are commonly used regardless of the type of parts. Both statistical and causal-based methods are less preferred for consumables and MRO parts, while consensus-based forecasting is used only for MRO parts.

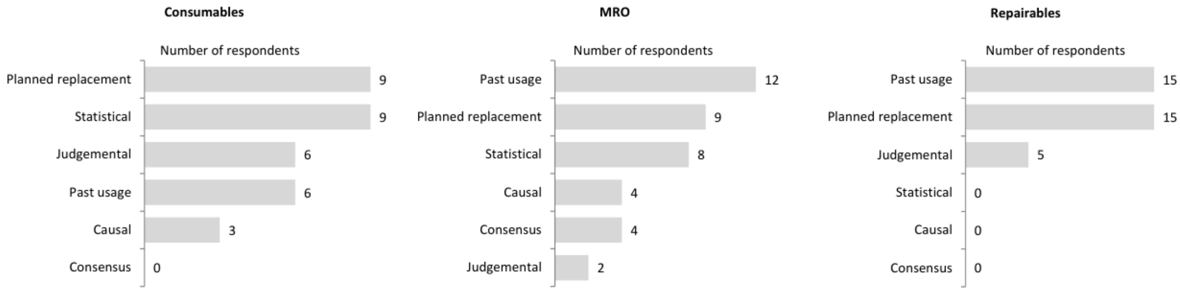

Figure 4: Survey results on forecasting methods used for consumable, MRO and repairable spares

The results also show that the forecasting methods for MRO parts are highly diverse, with all 6 methods employed within the organization. On the other hand, the demand for repairable parts are most often forecasted using information related to past usage and future planned replacement, which is consistent with the findings from Kennedy et al. (2002).

Conclusion

This research has contributed to the literature on spares management in three ways. First, it has provided a valuable perspective from the industry. As Rego and Mesquita (2011) note, case studies are needed to reduce gaps between theory and practice on the applications of models and techniques for inventory control of spare parts in real companies. Our study has reaffirmed the observation from literature that judgmental forecasting methods tend to be more widely practiced for spare parts that have planned or scheduled maintenance schemes. Similarly, results suggest that judgmental forecasts are more accurate for repair and refurbished parts, but less so for consumables and MRO spares. Overall, there is no one single method that practitioners in the case company use in forecasting the demand for spare parts.

Secondly, this paper has also shed some light on reasons for the prevalence of judgmental-based forecasting by practitioners, as well as some pitfalls of relying in human judgment in forecasts. Results of the interviews suggest that there are some challenges faced by the case company, which favour judgmental forecasting methods. For instance, usage may be occasionally distorted by the withdrawal and subsequent non-return of wrongly issued parts. Quality issues with batches of spare parts may also lead to one-time jumps in usage. Both of these issues would not be easily accounted for in time-series based forecasting. This is in line with the prevailing view in the literature that the major contribution of judgmental approaches lies in the ability to integrate non-time series information into the forecasts (Webby and O'Connor, 1996). However, results of the survey also indicate some evidence (albeit inconclusive) that judgmental forecasting may be susceptible to behavioural bias, such as technicians' tendencies to inflate forecasts when shortage is expected (Lee et al., 1997) or to make trivial forecasts based on past usage.

Thirdly, while the literature has no lack of academic studies on ways to improve forecasts for the intermittent demand of spare parts, few seem to make reference to how spare parts are actually managed in the industry. As this research illustrates, the use of term contracts to manage spare parts is a way that some companies have approached the problem. While at first glance the term contract management of spare parts appears to simply transfer responsibility (and the associated challenges) of inventory control to the supplier, it does confer significant advantages in that it enables risk pooling to be carried out. Backed by the port operator's committed usage forecasts over the contract term, suppliers can aggregate the demand for spare parts for (say) quay cranes with other ports in the region, thereby greatly diminishing the importance of making accurate time-series forecasts for intermittent demand. Nonetheless, the trade-off is that the port operator gives up significant control over inventory levels to the vendor and is obligated to make forecasts of demand at the onset of the term contract. Another practical implication of findings from the study is that while demand may be intermittent, they are often not truly random. Instead, there is scope for managing intermittent demand for spare parts based on a set of contingent managerial guidelines (Bacchetti, and Saccani, 2012), for example by classifying parts as MROs, consumables and repairables, and whether they are used as part of a planned maintenance or corrective repair regime.

This research is however not without its limitations. As is the case with case studies, results are based on the data and experience from just one company in the port industry. The case study method is inherently unable to generalise from a single case study beyond theoretical propositions (Yin, 2013). Secondly, this study is focused on the accuracy of forecasts over the period of a term contract (typically two years), rather than from a time-series perspective. This has to do with the nature of spare parts procurement and the use of term contracts at Company A, but nonetheless the accuracy of forecast of demand over a contract period is appropriate for the purpose of this study.

The purpose of this paper is certainly not to advocate one forecasting method over another, nor is it to assert that the company in this case study has adopted good practices (or otherwise) in spare parts management. Rather, it is to better understand the gaps that exist between academia and industry (Bacchetti and Saccani, 2012) on forecasting demand for spare parts. While there appears to be a strong focus in the academia on statistical forecasting methods, evidence from the literature suggests that the industry remains heavily reliant on judgmental forecasting methods (Goodwin, 2002).

In conclusion, this study has illustrated the typical challenges faced by large corporations in forecasting demand for spare parts, due to the sporadic nature of the demand. The company in this study has not adopted a standard forecasting method for its spares, but has instead used a myriad of methods, depending on type of spares and even the individuals who are responsible for providing the forecasts. Most respondents in the survey also professed a large degree of reliance on their own judgment in the projections of spare parts usage. As Goodwin (2002) puts it very well, human behaviour is perhaps the most important factor in the choice of forecasting methods and decision makers are more likely to accept forecasts if they have a sense of ownership of the forecasts, because they have contributed to the process that derived them. As such while sophisticated forecasting techniques exist, judgment-based approaches are likely to remain important among practitioners in the industry.

References

- Bacchetti, A., & Saccani, N. (2012). “Spare parts classification and demand forecasting for stock control: Investigating the gap between research and practice”, *Omega*, Vol. 40 No. 6, pp. 722-737.
- Botter, R., & Fortuin, L. (2000). “Stocking strategy for service parts-a case study”, *International Journal of Operations & Production Management*, Vol. 20 No. 6, pp. 656-674.
- Croston, J. D. (1972). “Forecasting and stock control for intermittent demands”, Journal of the Operational Research Society, Vol. 23 No. 3, pp. 289-303.
- Goodwin, P. (2002). “Integrating management judgment and statistical methods to improve short-term forecasts”, *Omega*, Vol. 30 No. 2, pp. 127-135.
- Gu, J., Zhang, G., & Li, K. W. (2015). “Efficient aircraft spare parts inventory management under demand uncertainty”, *Journal of Air Transport Management*, Vol. 42, pp. 101-109.
- Hua, Z. S., Zhang, B., Yang, J., & Tan, D. S. (2007). “A new approach of forecasting intermittent demand for spare parts inventories in the process industries”, *Journal of the Operational Research Society*, Vol. 58, No. 1, pp. 52-61.
- Hellingrath, B., & Cordes, A. K. (2014). “Conceptual approach for integrating condition monitoring information and spare parts forecasting methods”, *Production & Manufacturing Research*, Vol. 2 No. 1, pp. 725-737.

- Kennedy, W. J., Patterson, J. W., & Fredendall, L. D. (2002). "An overview of recent literature on spare parts inventories", *International Journal of Production Economics*, Vol. 76 No. 2, pp. 201-215.
- Lawrence, M., Goodwin, P., O'Connor, M., & Önkal, D. (2006). "Judgmental forecasting: A review of progress over the last 25 years", *International Journal of Forecasting*, Vol. 22 No. 3, pp. 493-518.
- Lee, H., Padmanabhan, P. and Whang, S. (1997). "Information distortion in a supply chain: the bullwhip effect", *Management Science*, Vol. 43, pp. 546-558.
- Louit, D., Pascual, R., Banjevic, D., & Jardine, A. K. (2011). "Optimization models for critical spare parts inventories—a reliability approach", *Journal of the Operational Research Society*, Vol. 62 No. 6, pp. 992-1004.
- Rego, J.R. & Mesquita, M.A. (2011). "Spare parts inventory control: a literature review", *Produção*, Vol. 21 No. 4, pp. 656-666
- Strijbosch, L. W. G., Heuts, R. M. J., & Van der Schoot, E. H. M. (2000). "A combined forecast—inventory control procedure for spare parts", *Journal of the Operational Research Society*, Vol. 51 No. 10, pp. 1184-1192.
- Syntetos, A. A., & Boylan, J. E. (2001). "On the bias of intermittent demand estimates", *International Journal of Production Economics*, Vol. 71 No. 1, pp. 457-466.
- Webby, R., & O'Connor, M. (1996). "Judgemental and statistical time series forecasting: A review of the literature", *International Journal of Forecasting*, Vol. 12 No. 1, pp. 91-118.
- Willemain, T. R., Smart, C. N., & Schwarz, H. F. (2004). "A new approach to forecasting intermittent demand for service parts inventories", *International Journal of Forecasting*, Vol. 20 No. 3, pp. 375-387.
- Yin, R. K. (2013). *Case Study Research: Design and Methods*, Fifth Edition, SAGE Publications, Thousand Oaks, CA, USA