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On the Effect of Combination of Statistical and Judgemental Stock Control Methods

Inna Kholidasari[1*]

Abstract: Stock control is the most important aspect in an inventory system. It determines the safety stock in order to ensure that products are readily available when the customers require them. The decision makers in organizations tend to rely on software solution in obtaining stock control solutions since they have to manage a massive number of Stock Keeping Units (SKUs). However, managers intervene in the system and use their judgement to adjust or decide on various quantitative elements. This research discusses the effects of combination of stock control methods. An extended database of approximately 1,800 SKUs from an electronics company is analyzed. Then, a simulation experiment is performed in order to evaluate in a dynamic fashion what are the effects of applying combined stock control methods. The findings indicate that the combined method of stock control seems to improve the performance of the inventory system, especially in reducing inventory investment.

Keywords: Stock control, judgemental adjustment, combine methods.

Introduction

In an inventory system, stock control is the crucial aspect since it plays an important role in improving the service level and reducing the operation cost of logistic systems. It will support a company's competitive strategy, for example, if this strategy requires a very high level of responsiveness (high customer service level), the stock control function can be used to achieve this by locating large amounts of stock close to the customer.

Nowadays, since the organizations have to manage a massive number of Stock Keeping Units (SKUs), the stock control system needs to be fully automated. The decision makers in organizations tend to rely on software solution in obtaining stock control solutions. However, although such systems are indeed in principle fully automated, what most often happens in practice is this: managers intervene in the software system and judgementally adjust various quantitatively/statistically derived outputs (such as demand forecasts or replenishment quantities). Judgement may be used when insufficient data is available to support statistical methods, or situations arise where exceptional events are known to be occurring in the future. In another words, we can say that adjustments should ideally reflect information that it is not available in the statistical software. (Any qualitative or quantitative piece of information that may have not been reflected on the time series data.) However, adjustments often reflect a mere desire for a sense of ownership on the part of the managers (Goodwin [1]; Yaniv [2]).

[1] Faculty of Industrial Technology, Industrial Engineering Department, Universitas Bung Hatta, Jl. Gajah Mada 19, Gunung Pangilun, Padang 25143, Indonesia.
Email: i.kholidasari@bunghatta.ac.id

*Corresponding author

In the area of forecasting, many studies have discussed the effects of human intervention on statistical forecasting models. For example, a survey of corporations in the United States (Sanders and Manrodt [3]) found that 57% of respondents always used judgemental methods, and 21% did so frequently. Furthermore, 45% of the respondents said that they always adjusted their statistical forecasts and 37% did so sometimes. Moreover, in a study of Canadian firms, Klassen and Flores [4] reported that 80% of the respondents that used computer-based forecasts used judgement to adjust them. However, in terms of inventory systems, practitioners often adjust the stock replenishment order, not the forecast. In addition, to the best of our knowledge, there is a very limited studies of the issue of judgemental adjustments of stock control available in the literature academic. Thus, the discussion on the issue of judgemental adjustments of stock control, especially in applying its model is needed. This research attempted to investigate the effect of combining the replenishment order methods. The analysis of combination between statistical and judgemental adjustments stock control method has been conducted through an experimenttal simulation. By combining these methods, we expect that the performance of an inventory system (service level, fill rate, and cost) will be better compared to only one single method.

The combination of statistical and judgemental forecasting methods has been investigated widely. These forecasting methods make valuable and complementary contributions to improving performance. While a statistical method may be able to filter time series patterns from noisy data (when judgemental forecasters tend to see false patterns in noise and to overreact to random movements in series), judgement can be used to anticipate the effects of special events that occur in the future (Goodwin [5]). This study investigated the process of integrating judgemental forecasts with statistical methods. The forecast accuracy between judgemental and statistical forecasting when using three strategies (correcting the judgemental forecasting using Theil's optimal linear correction, combining the simple average of judgemental and statistical time series forecasts, and using both the above approaches) was compared. Analysis of laboratory studies and the use of empirical data provided by companies were considered. The results showed that the most appropriate role of statistical methods is to correct judgemental forecasts. Another laboratory study to test the performance of the combination of judgemental and statistical forecasting was done by Goodwin [6]. Using a voluntary integration approach, that is when the judge is able to use the statistical forecast during the process of forming the judgemental forecast, the experiment's results showed that overreaction to noise in judgemental forecasting might be mitigated by providing a statistical forecast; the forecaster then indicates explicitly the changes (and also the reason for making these changes) to the statistical forecast. A simple model-selection criterion to select among forecasts was used in a simulation experiment conducting by Hibon and Evgeniou [7]. The results showed that combination forecasts were superior, but that the best individual method performed similarly if the forecasters always used the same method. The same result was found when the experiment was run with a forecaster who used different methods or combinations for each time series. Thus, there is no inherent advantage in combining the forecasts. This finding challenged the belief that came from most of the forecast combination studies (which stated that combining forecasts is better than using individual forecasting methods). In addition, this study found that choosing an individual method (chosen by the selection method used in this study) is more risky than choosing the combination methods. Another study, Boylan and Johnston [8] developed theoretical rules to specify the parameters in the combination of moving averages forecasting models in a steady-state condition. Three parameters of moving average method were considered for the combination: length of greater moving average, length of shorter moving average, and the weighting to be given to the former. The robustness of combinations of moving averages and exponentially weighted moving averages (EWMA) was compared, and it was found that the combination approaches (especially for equal weight combinations) were more robust than EWMA.

A plethora of studies look at the phenomenon of judgemental adjustments in regards to forecasting. However, in terms of inventory systems, practitioners often adjust the stock replenishment order, not the forecast. Kolassa *et al.* [9] report that judgemental adjustment occurs more often than forecast-related adjustments. Thus, it seems very important to investigate the effect of the combination of statististical and judgemental adjustment stock control method.

In this section we discussed in more detail the studies in the area of inventory management. The differences between laboratory and empirical inventory studies is reviewed. The combined forecasts methods are also discussed. Moreover, the development of research question of this current study is explained.

Laboratory vs Empirical Inventory Studies

Laboratory inventory studies involve experiments or simulations to represent and analyse a real system. Commonly, laboratory inventory studies discuss inventory problems in the supply chain domain. Many studies in supply chain management use the framework of Beer Game for their experiments. For example, Ancarani *et al.* [10] used Beer Game in their human experiments to investigate the impact of stochastic lead-times on inventory holdings and the extent of the bullwhip effect. The participants of this experiment were graduate students with background in Operations Management. This study found that, in terms of stochastic lead-times, a higher variance of orders at every echelon of the supply chain. Furthermore, the experiment result indicates that subjects tend to hold fewer inventories when supply chain is characterized by both demand uncertainty and stochastic lead-times. The Beer Game also used to analyze the influence of with regard to the bullwhip effect in environments of reverse logistic (Adenso-Diaz *et al.* [11]). The experiments results confirmed that the stock and work in progress adjustments controllers are the factors that increase bullwhip more significantly, followed by forecasting technique used, the sharing information among the links, and the final customer demand variability.

Mileff and Nehez [12] established a model to investigate inventory holding under a classical single-customer and single-supplier problem with the game theory method. Moreover, Croson and Donohue [13] studied the phenomenon of bullwhip effect (the tendency of orders to increase in variability as one moves up a supply chain) from a behavioural perspective in the context of a simple supply chain subject to information lags and stochastic demand. This study conducted two experiments and found that the bullwhip effect still exists when normal operational causes (e.g. batching, price fluctuations, demand estimation, etc.) are removed, and also remains when information on inventory levels is shared. Other research by Anderson and Morrice [14] developed a simulation game designed to teach service-oriented supply chain management principles and to test whether managers use them effectively. They found that simulation design is useful in investigating the impacts of information sharing between managers in service capacity decision making.

Laboratory studies rely upon the use of participants in a laboratory (i.e. controlled) environment. Such studies have been criticized for not being representative of real-world settings (Bunn and Wright [15]). This kind of research gives rise to some insights and it may render experiments reliable in a statistical sense; however, the behaviour of the participants may be different from that which occurs in a natural setting.

In contrast with the laboratory study, empirical studies are using experts/managers in a real-world setting provide the greatest potential for the demonstration of the validity of human judgement. Since no artificial ceiling is put on human performance, this provides good descriptive research. However, as the researcher has no control, cause and effect is difficult to determine (op. cit).

A very limited studies of empirical judgemental adjustments inventory is available in academic literature. Kolassa *et al.* [9] reported that judgemental adjustments to stock control quantities occur more often than forecasting-related adjustments. Syntetos *et al.* [16] explored the effects of adjusting forecasts and/or replenishment orders by deploying a system dynamics (SD) methodology in a simulated three-stage supply chain. Nevertheless, this research was based on very realistic assumptions. This research found that human intervention in forecasting seems to have more significant effects than judgemental order adjustments. In particular, it was found that the impact of the forecast and order adjustments is less prominent as the intervention point moves upstream in the supply chain; and also, the re-order point s, order-up-to-level S inventory control policy appears to be less sensitive to judgemental adjustments. In addition, some applicable suggestions for managers may be developed from the results of the experiment.

The Development of Research Question

In the forecasting area, it has been shown that combining the forecasts produced by different methods may lead to a performance that is better than that of the individual forecasts themselves (Goodwin [17]). The case study organisation implemented three replenishment order methods: *System OUT replenishment level*, the *SMA-Based OUT replenishment level*, and the *Final OUT replenishment level*. By combining these methods, it is reasonable to expect that the performance of the inventory system (service level, fill rate, and cost) may improve as compared to that resulting from the replenishment suggestions of a single method. Accordingly, our research question is: What is the effect of combining methods on the calculation of the OUT level?

Methods

The empirical data of this research is provided by a manufacture company. The company represents the European logistics operations of a major international electronics manufacturer. In total, 359 A-class and 1,454 B-class SKUs are considered for the purposes of this research. Moreover, the organization has implemented an ERP package, SAP R/3 (SAP-AG, Germany) to manage their forecasting and stock control tasks. In addition, managers in the company under consideration adjust inventory quantities, often providing a qualitative justification for their action.

Simulation Experiment

A comprehensive database needs to be constructed for a simulation experimentation. The construction of the database was a very difficult exercise since the company provided only fragmented information which needed to be constructively put together. Since empirical data was provided in files that correspond to months, the first task was to compile this information into a single file. The working principle in this stage was to have one SKU per row. The complete database is accomplished by deploying Excel Visual Basic for Applications (VBA). Syntetos and Boylan [18] identified the process of constructing the database needed for experimentation purposes as a very important one in empirical research. This aspect of empirical research is generally underestimated in importance although it arguably constitutes one of the most important factors towards conducting a comprehensive experiment. The process of constructing and validating the database used for the purposes of this research was a very challenging one and particularly demanding in terms of time investment.

The next step is developing the conceptual modeling. Conceptual modelling, the process of abstracting a model from a proposed real system, is a very important aspect of simulation (Law [19]). Robinson

[20] argued that it contains objectives, inputs (experimental factors), output (responses), and model content (assumptions and simplifications of the model). The objective of our simulation experiment is to evaluate the inventory performance of unadjusted and adjusted replenishment order policies. Moreover, the empirical database is used as the experimental factors or inputs of the simulation. The empirical database available for this research consists of the individual data series of 359 and 1,454 SKUs for A and B-class items respectively. However, only 179 A-class and 228 B-class SKUs are being utilized for simulation purposes on the basis of having at least eight consecutive replenishment order observations. Demand data series over 26 periods (monthly), the prices of SKUs and the replenishment order (unadjusted and adjusted) data is needed for this experiment. Lead time is equal to two months (average lead times are 60 days).

Three opportunities for replenishing stock is considered in this research: the System OUT replenishment level (unadjusted OUT level), the Final OUT replenishment level (adjusted OUT level), and the Simple Moving Average-Based (SMA-Based) OUT replenishment level. The System OUT replenishment level is defined as the OUT level produced by the SAP system, the Final OUT replenishment level constitutes the judgementally adjusted order up to replenishment level, whereas SMA-Based OUT replenishment levels are calculated every month by multiplying the SMA(24) forecast by 19 (8 weeks safety stock + 9 weeks lead time + 2 weeks order frequency adjustment) in the case of A items, and 23 (12 weeks target safety stock + 9 weeks lead time + 2 weeks order frequency adjustment) in the case of B items. In terms of the output of the simulation experiment we record the inventory investment (inventory holding cost), cycle service level (CSL) and fill rate for each SKU. Two scenarios are considered for simulation purposes. The first one is an intuitively appealing representation of the process, whereas the second is the standard one used in analytical evaluations of the OUT policy.

The Combination Methods of Replenishment Order

The next step of the empirical data analysis is the comparison of the performance between the System OUT, the Final OUT, and the SMA-Based OUT replenishment level. Furthermore, the analysis of the effect of combining different methods for the calculation of the OUT level also applies to the analysis of the inventory performance. For the purpose of combination analysis, we combine all three methods to obtain the total of inventory investment and the average of CSL and fill rate, first between System OUT replenishment level and Final OUT replenishment level, secondly between System OUT replenishment level and SMA-based OUT replenishment level, and finally between Final OUT replenishment level and SMA-based OUT replenishment level. The combination value is calculated by averaging (50%-50% weight) the OUT replenishment level resulting from each method.

Results and Discussion

Simulation Results

The simulation results using three individual methods - System OUT, the Final OUT, and the SMA-Based OUT replenishment level are presented in Table 1 and Table 2 for A and B items respecttively. As can be seen from Table 1, the total inventory investment related to adjusted orders is slightly lower than the unadjusted ones for both scenarios. Considering the trade-off between inventory cost and service, it seems that judgemental adjustments account for an improvement in terms of inventory investment at the expense though of an expected service reduction. Turning now to the results for B items, it can be seen from Table 2 that the Final OUT replenishment level is associated with a higher inventory investment as compared with the System OUT replenishment level for both scenarios. Comparing the inventory investment of SMA-based OUT replenishment level with the adjusted one, it can be seen that the latter produces lower cost, but the difference is indeed very small (1.67% and 1.06% for scenario 1 and 2 respectively). This, in theory, indicates that adjustments lead not only to less safety stocks (as expressed through the inventory investment) but also to better service provision. It is true that the differences observed are very small but nevertheless the results favor conclusively the judgementally adjusted OUT levels. The results indicate that there may be less benefit resulting from judgementally adjusting stock control decisions than statistical demand forecasts. This finding is in agreement with the Syntetos *et al.* [21] findings which showed that judgemental forecast adjustments have more prominent effects than judgemental order adjustments.

The Analysis Results of the Combination Methods of the OUT level

An investigation to analyze the performance of stock control system using three combination methods is conducted. The results are shown in Table 3. It can be seen from Table 3 that, although it is not very significant, mainly, the inventory investment resulting from all the individual methods seems to have a higher value compared to the inventory investment of the combination methods, whereas for

Table 1. The simulation results for A items

Scenario	System OUT replenishment level			Final OUT replenishment Level			SMA-based OUT replenishment Level		
	Total inventory investment (€)	Average CSL	Average fill rate	Total inventory investment (€)	Average CSL	Average fill rate	Total inventory investment (€)	Average CSL	Average fill rate
Scenario 1	1,075,021	0.991	0.993	1,068,503	0.991	0.993	1,036,225	0.991	0.993
Scenario 2	750,396	0.924	0.948	726,701	0.905	0.930	685,263	0.861	0.892

Table 2. The simulation results for B items

Scenario	System OUT replenishment level			Final OUT replenishment Level			SMA-based OUT replenishment Level		
	Total inventory investment (€)	Ave. CSL	Ave. fill rate	Total inventory investment (€)	Ave. CSL	Ave. fill rate	Total inventory investment (€)	Average CSL	Average fill rate
Scenario 1	131,876	0.986	0.962	133,133	0.987	0.965	135,393	0.988	0.968
Scenario 2	108,468	0.889	0.891	108,580	0.889	0.893	109,746	0.886	0.892

Table 3. The simulation results for A and B items

Combination replenishment order method	Scenario	A items			B items		
		Total Inventory Investment (€)	Ave. CSL	Ave. Fill Rate	Total Inventory Investment (€)	Ave. CSL	Ave. Fill Rate
System OUT replenishment level – Final OUT replenishment level	Scenario 1	1,065,855	0.991	0.993	131,766	0.987	0.965
	Scenario 2	730,134	0.905	0.938	107,034	0.885	0.888
System OUT replenishment level – SMA-based OUT replenishment level	Scenario 1	1,036,582	0.991	0.993	130,917	0.987	0.966
	Scenario 2	711,256	0.882	0.919	107,420	0.883	0.892
SMA-based OUT replenishment level – Final OUT replenishment level	Scenario 1	1,046,356	0.991	0.993	132,600	0.988	0.967
	Scenario 2	705,006	0.886	0.909	108, 285	0.890	0.894

CSL and fill rate, the individual and the combination methods seem to produce very close values. This is true of both scenarios for A and B items. Thus, we may say that the combination methods seem to make valuable contributions to improving the performance of inventtory systems, especially for reducing the inventory investment.

Furthermore, we find that the CSL and fill rate seem to have very close values for both scenarios of A and B items. Or we may say that there is no significant difference of CSL and fill rate values between the three combination methods. Mainly, the lowest inventory investment of A and B items results from the combination where there is an SMA-based OUT replenishment level method. This indicates that the SMA-based OUT replenishment level performs better when incorporated with the judgemental stock control method compared with other statistical methods (in this case is the System OUT replenishment level).

The above findings indicate that a combination method in stock control seems to improve the performance of the inventory system. Goodwin [5] argued that forecast accuracy can improve when combination methods between statistical and judgemental methods are used, since the statistical method may be able to filter time-series patterns from noisy data, where the judgement can be used to anticipate the effects of special events that occur in the future. This rationale may exist on the judgementally adjusted stock control decision when statistical methods are incorporated into the process of decision making.

Conclusion

This research is an empirical research in the area of Operations Management (OM), focusing on inventory system. Using the empirical data from a manufacturer company, an extended database is developed and a simulation experiment is conducted for the analysis of combined methods of replenishment order. In this paper, literature review of relevant issues is also discussed. The studies of combining forecasts have been reviewed extensively; they mostly come to the conclusion that combining forecasts may improve the accuracy of forecasting. However, there is not a single study of combined replenishment order methods which are incurporating judgemental adjustments aspect, to the best of our knowledge, available in the academic literature.

An analysis of combined methods (the combination of System OUT replenishment level and Final OUT replenishment level, System OUT replenishment level and SMA-based OUT replenishment level, and Final OUT replenishment level and SMA-based OUT replenishment level) for calculating the inventory performance was also conducted. The combination value was calculated by averaging (50%-50% weight) the OUT replenishment level resulting from each method. The findings indicate that the combined method of stock control seems to improve the performance of the inventory system, especially in reducing inventory investment. This issue is in line with the research results in area of forecasting where it is found that combining forecasts may produce better forecast accuracy than individual forecasting methods (Goodwin [5,6]). However, other additional combination methods need to be carried out in order to achieve a better understanding of this issue.

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