POSSIBILITIES AND LIMITATIONS OF QUANTITATIVE METHODS IN SHORT-TERM DEMAND FORECASTING IN A MANUFACTURING COMPANY

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Abstract

Quantitative forecasting methods based on the time series analysis have been most widely used in short-term demand forecasting thanks to the facts that they do not place high demands on time and finances, and that they are highly objective compared to qualitative forecasting methods. However, the success of demand forecasting depends on many other factors that are rarely mentioned in the literature. Based on the survey in a small manufacturing company, the paper focuses on the influence of temporal aggregation level on forecasting accuracy, and the specifics of small companies which have to deal with the insufficient technical support and sporadic demand. The paper aim is to analyse the forecasting accuracy of selected quantitative methods in relation to temporal aggregation level of forecasted demand and specify the application possibilities and limitations of the methods in the monitored company. The selected methods include the naïve method, the average method, the method of time series decomposition, the simple exponential smoothing method, the Holt's linear trend method, the Brown's linear trend method, the simple seasonal exponential smoothing method, the Holt-Winters trend and seasonal method. In-depth interviews with the managers of the company and time series analysis were used as research methods.

Keywords: Demand forecasting, exponential smoothing, forecast accuracy, FMCG, quantitative methods

1. INTRODUCTION

Future demand forecasting is now a necessary basis for most strategic and tactical and operational decisions of manufacturing companies. Demand forecasting is connected with a choice of a suitable forecasting method. Statistical quantitative methods are mainly applied in practice thanks to the fact that they are objective, they are not very labour-intensive, but also the fact that they do not place high demands on time and finance [1]. The basic prerequisite for creation of quantitative forecasting methods is availability of sufficient quantity of historical data, mostly in the form of sales time series. When choosing a suitable forecasting method, it is necessary to analyse mainly the development tendencies of sales time series, the character of the demand, and to specify the length of the time horizon, for which the forecast is to be created [2,3]. One of the most important criteria of choosing a forecasting method is their accuracy as the forecast accuracy has a significant impact on the effectiveness of logistics processes in the company.

In companies doing business on the market with fast moving consumer goods, demand forecasting represents an essential part of short-term logistics planning. The material flow through the entire chain must be predicated by jointly drawn or at least shared plans and must comply with current requirements of end users [4]. Forecasting methods that are most widely used in this area are those based on analysis of historical sales time series. They particularly include simple estimates grounded in the mean value of past sales (e.g. the average method, the simple exponential smoothing method), and so they can only be used in prediction of stationary time series. In non-stationary time series, it is possible to apply with advantage classical procedures of decomposition of time series to trend, seasonal, cyclic, and random components (the method of time series decomposition), or adaptive exponential smoothing methods, where partial components of a time series are smoothed using exponentially weighted moving averages [5,6].

Assessment of the possibility of using above mentioned forecasting methods was the subject matter of a survey conducted in a manufacturing company called PK ham, s.r.o., which does business on the Czech

market with meat products. The paper aim is to analyse the forecasting accuracy of selected quantitative methods in relation to temporal aggregation level of forecasted demand and specify the application possibilities and limitations of the methods in the monitored company. In-depth interviews with the managers of the company and time series analysis were used as research methods. Time series analysis was performed using the statistical software of IBM SPSS Statistics 22 and Microsoft Excel 2013.

2. RESEARCH BACKGROUND AND METHODOLOGY

The survey was conducted in a small manufacturing company called PK Ham, s.r.o through in-depth interviews with the managers of the company during March 2015. The company does business on the Czech market in the area of production and distribution of smoked meat products. Their production range includes more than 60 product items, but only five products have a bigger than 5% share in the total sales of the company. The company forecasts the demand through qualitative judgement made by the operations manager on the basis of many years' experience. Short-term demand forecasts are most applied in production and operations management (daily and weekly production planning, weekly purchase planning). It also showed as purposeful to monitor individual products from the point of view of seasonal demand fluctuations during a year, according to which it is possible to plan the capacity utilization of production facilities and distribution of the labour force in the period when the sales reach their peak. For these reasons, we analysed the forecasting possibilities at three levels of temporal aggregation of sales (daily, weekly, and monthly time series periods) for each product separately regardless of the customer to whom the products are sold.

The time series of historical sales were drawn up using the company database of orders implemented in the period of 2011-2014. The first view on obtained time series analysis pointed on sporadic character of time series in many cases due to the low sales. The chosen sporadicity criterion was the existence of zero values of sales in more than 30% monitored sections of time series [7]. Sporadic demand was identified in 29 products at all temporal aggregation levels. Although it is almost a half of the products the company sells, their total share in the takings is negligible (4.6%). Hence, sporadic time series were excluded from the following time series analysis. Unfortunately, the sporadic character of the demand also increased together with a decreasing level of aggregation, and so only 53% of monthly, 44% of weekly, and 16% of daily time series were chosen. Analysis of the time series that did not show sporadic demand identified an insignificant and variable trend. On the other hand, the seasonal character of the sales represented, in most cases, a very important factor, which should be taken into consideration when forecasting monthly or daily sales. Another typical periodic deviation was an extraordinary growth of sales in the period of some calendar holidays. The seasonal lows were mainly monitored in winter months, but the size of the seasonal component and its character were product-specific.

On the basis of time series analysis with regards to company requirements (utilization of simple methods without the needs of sophisticated software and large volume of data storage), eight quantitative methods were selected including naïve method (1), the average method (2), the method of time series decomposition (3), the simple exponential smoothing method (4), the Holt's linear trend method (5), the Brown's linear trend method (6), the simple seasonal exponential smoothing method (7), and the Holt-Winters trend and seasonal method (8).

$$\hat{Y}_{t+1} = Y_t \quad (1)$$

$$\hat{Y}_{t+1} = \frac{1}{t}\sum_{i=1}^{t} Y_i \quad (2)$$

$$\hat{Y}_{t+1} = T_{t+1} + S_{t+1} \quad (3)$$

$$\hat{Y}_{t+1} = L_t\,; \quad L_t = \alpha Y_t + (1-\alpha)L_{t-1} \quad (4)$$

$$\hat{Y}_{t+1} = L_t + b_t\,; \quad L_t = \alpha Y_t + (1-\alpha)(L_{t-1} + b_{t-1})\,; \quad b_t = \gamma(L_t - L_{t-1}) + (1-\gamma)b_{t-1} \quad (5)$$

$$\hat{Y}_{t+1} = L_t + \alpha^{-1}b_t\,; \quad L_t = \alpha Y_t + (1-\alpha)L_{t-1}\,; \quad b_t = (L_t - L_{t-1}) + (1-\alpha)b_{t-1} \quad (6)$$

$$\hat{Y}_{t+1} = L_t + S_{t+1-s}\,; \quad L_t = \alpha(Y_t - S_{t-s}) + (1-\alpha)L_{t-1}\,; \quad S_t = \delta(Y_t - L_t) + (1-\delta)S_{t-s} \quad (7)$$

$$\hat{Y}_{t+1} = L_t + b_t + S_{t+1-s}\,; \quad L_t = (Y_t - S_{t-s}) + (1-\alpha)(L_{t-1} + b_{t-1})\,; \quad b_t = \gamma(L_t - L_{t-1}) + (1-\gamma)b_{t-1}\,;$$

$$S_t = \delta(Y_t - L_t) + (1 - \delta)S_{t-s} \quad (8)$$

where Y_t is the value of time series at a time period t, $\hat{Y}_t$ is the forecasted value of time series at a time period t, T_t is the fit value of trend function from additive time series decomposition method at a time period t, L_t is the value of level component at a time period t, b_t is the value of trend component at a time period t, S_t is the value of seasonal component at a time period t, s is the length of time series periodicity, and α, β, δ are weight values in exponential smoothing methods. Weight constants α, β, δ were optimized on the basis of minimization of BIC and values for the other model parameters were estimated using the statistical software of IBM SPSS Statistics 22.

To prevent distortion of the equalizing constants for trends and seasonality, the time series were first purged of non-periodic fluctuations (e.g. a sales increase before Easter). The sales values achieved during these periods were replaced with a long-term average and forecast through an intervention model. The applied intervention model presumes that forecast in a regular period is the same as the value acquired from the original forecasting method, while in the period of intervention there is an average rise/drop in the sales compared to the value provided by the original forecasting method. The detailed principle of intervention model is included in the literature [8].

All the forecasting methods were applied to all the predicted time series at three temporal aggregation levels for the purpose of analysis of the forecasting method accuracy. The method accuracy was assessed through the root of the mean square error (RMSE) and the median of absolute percentage errors (MdAPE), which is independent of the scale of the data and in comparison to the average it is not distorted by remote values [6].

3. RESULTS AND DISCUSSION

3.1. Analysis of Forecasting Method Accuracy

Table 1 shows the outcomes of the analysis of the methods accuracy when forecasting daily sales time series. The table includes the frequency of the products in which the given method identified as the most accurate (the accuracy criterion was minimization of the RMSE). Using the relative MdAPE, it is possible to compare the total accuracy of the methods that were applies in products with different volumes of sales.

Sporadic demand was identified in most products at the lowest level of temporal aggregation of sales, and so the forecasting method accuracy was analysed in ten products only. Another difficulty in smoothing daily time series was a high demand variability and occasional occurrence of zero values, even in those time series that were not considered as sporadic. For this reason, the forecasting error MdAPE did not reach lower values than 35% in any of the products. The single seasonal exponential smoothing method showed the smallest forecasting error in all products with a share in the total corporate sales exceeding 5%.

Table 1 Forecasting method accuracy in daily time series

Forecasting method	Percent of products	Mean of RMSE (kg)	Minimum of MdAPE	Maximum of MdAPE	Median of MdAPE
Naïve	0%	70	83%	100%	100%
Average	0%	49	53%	104%	69%
Decomposition	0%	40	42%	96%	60%
Simple	0%	33	48%	80%	62%
Holt	0%	33	47%	83%	63%
Brown	0%	33	48%	82%	62%
Seasonal	70%	27	35%	72%	50%
Holt-Winters	30%	27	36%	71%	50%

The analysis outcomes in **Table 2** point to the forecasting method accuracy in weekly sales time series. The forecasting error MdAPE in the five bestselling products was between 15-21%, but smoothing of time series in products with a small share in the sales was often problematic. The highest accuracy was achieved by the methods based on the principles of the single exponential smoothing method.

Table 2 Forecasting method accuracy in weekly time series

Forecasting method	Percent of products	Mean of RMSE (kg)	Minimum of MdAPE	Maximum of MdAPE	Median of MdAPE
Naïve	0%	93	22%	100%	38%
Average	0%	84	20%	76%	40%
Decomposition	0%	85	18%	77%	42%
Simple	70%	72	16%	78%	28%
Holt	22%	71	16%	78%	29%
Brown	8%	68	16%	78%	31%

The smallest forecasting errors were achieved in application of methods to monthly sales time series. The MdAPE error in the five products with the biggest share in the total corporate sales was within the range of 8-16%. The accuracy of the studied methods was surprisingly comparable, but the best results were achieved by the Holt-Winters trend and seasonal method. **Table 3** shows the outcomes of the analysis of accuracy when forecasting monthly sales time series.

Table 3 Forecasting method accuracy in monthly time series

Forecasting method	Percent of products	Mean of RMSE (kg)	Minimum of MdAPE	Maximum of MdAPE	Median of MdAPE
Naïve	0%	216	11%	93%	27%
Average	0%	228	12%	134%	36%
Decomposition	9%	171	13%	81%	23%
Simple	0%	183	13%	83%	22%
Holt	0%	193	13%	100%	24%
Brown	0%	150	10%	88%	22%
Seasonal	22%	185	13%	139%	22%
Holt-Winters	69%	147	8%	68%	22%

For the comparison of forecasting method accuracy in relation to the level of time series aggregation, see **Table 4**. The mean error of a forecasting method was measured by the median from MdAPE values acquired within application of the given method to all the analysed time series.

Table 4 Mean error of forecasting methods in relation to the time series aggregation level

Aggregation level	MdAPE of Forecasting Method							
	Naïve	Average	Decomposition	Simple	Holt	Brown	Seasonal	Holt-Winters
Day	100%	69%	60%	62%	63%	62%	50%	50%
Week	38%	40%	42%	28%	29%	31%	-	-
Month	27%	36%	23%	22%	24%	22%	22%	22%

When smoothing periodic time series, the best results were clearly achieved by exponential smoothing methods, which include estimates of the seasonal component in the forecast. The mean error of these methods was almost a half of that reached by reference methods. Weekly time series can also be reliably smoothed by

exponential smoothing methods, and the mean error deviation between these methods was negligible (± 0.2%). The outcomes also show an apparent significant decrease in the error together with a growing level of sales aggregation.

3.2. Possibilities and Limitations of Selected Forecasting Methods

The forecast accuracy belongs to the most important criteria for choosing a suitable forecasting method. The analysis of the accuracy of the selected quantitative methods proved that exponential smoothing methods almost always provide more accurate forecasts compared to naïve method which is usually used in the monitored company during judgmental forecasting. The analysis also confirmed that the choice among similar methods that smooth the same time series components (trend, seasonality) is not essential. Therefore, it is possible to use the same forecasting method for all the products in the company without a significant decrease in the accuracy of the arising forecasts. It is the temporal aggregation of sales what affects the choice and method accuracy much more. The sporadic character of sales at low aggregation levels makes it impossible to use not only the common quantitative methods, but usually also the qualitative forecasting procedures. In such a case, the literature [7,9] recommends shifting the customer order decoupling point in the company, which directly results in creation of forecasts at a higher level of temporal and also product aggregation. In the monitored case, it would be more convenient to manage the production in accordance with weekly plans based on weekly forecasts and, within a shorter time horizon, to manage the production flexibly on the basis of accepted orders.

Another limitation of the selected forecasting methods resides in the necessity of method application to time series that are not distorted by extraordinary (non-periodic) events, i.e. they only include the trend and seasonal components. The forecast accuracy can then be increased by purging the time series of extraordinary deviations and their forecasting through causal methods (intervention model). However, in the monitored case this would only lead to a negligible decrease in the forecasting error MdAPE (at most 2%), and so their application cannot be considered as necessary.

From the other criteria for choosing a suitable forecasting method, it is not possible to omit the cost of forecasting, availability of a sufficient quantity of representative data, and technical support for demand planners [10]. The researched company, as well as most small manufacturing companies in the Czech Republic, does not have any software with implemented quantitative forecasting methods. However, the monitored forecasting methods can also be relatively easily applied to the sales data in the environment of a common spreadsheet processor (e.g. MS Excel), which significantly decreases the barriers of implementation of the selected methods in practice. In view of the more labour-intensive optimization of model parameters, a model considering fewer parameters will always seem to be more advantageous. Therefore, it is possible to recommend that the company applies the single exponential smoothing method for forecasting non-periodic time series, and the Holt-Winters trend and seasonal method for forecasting periodic time series. We did not manage to quantify the economic benefits of implementation of the selected quantitative methods in the company as the company does not monitor the accuracy of qualitative forecasts. Nevertheless, the in-depth interviews conducted with the operations manager implied that qualitative estimates are based on the same principles as the naïve method, which did not bring satisfactory results in the research. If we considered the company's need for repeated creation of forecasts for all their products within a short time horizon, lower labour-intensity and lower cost of the process of forecasting should be achieved through introduction of automated procedures in any of the available software.

4. CONCLUSION

The paper aim was achieved due to the performed analysis of selected quantitative methods accuracy and evaluation of qualitative research in the monitored company. The outcomes provide the basic information for assessment of the application possibilities and limitations of selected quantitative methods for sales forecasting

in the company. Using the methods of exponential smoothing, it is possible to make relatively reliable forecasts of the development of time series of monthly and weekly sales, and the method accuracy rises significantly together with an increasing level of sales aggregation. However, due to the sporadic character of the demand it is practically impossible to use the monitored methods for forecasting daily sales. The low demands that the selected methods place on the used software (a spreadsheet processor is fully sufficient), but also the small number of forecast items predetermine the low financial and time demands of their implementation in forecasting process. Quantitative forecasts, in combination with the experience and intuition of the company staff, should lead to an increase in the forecasting performance. Moreover, the analysed methods brought very good results in products with the biggest share in the total sales of the company, and so application of quantitative methods could bring the company a significant economic effect.

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