PREDICTING DELIVERY VOLUMES FOR PETROL STATIONS UNDER CONDITIONS OF STOCHASTIC DEMAND

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Abstract

Technological processes of freight transport are characterized by stochasticity of indicators describing its efficiency. The mentioned randomness is usually could be explained by the stochasticity of demand for transport services. Consideration of the demand parameters stochasticity is especially important in planning deliveries of petrol products, as far as additional costs caused by delays in the deliveries, in this case, could be extremely high. Thus, the accurate prediction model could contribute significantly to the reduction of costs for the distribution of petrol products.

The paper proposes an approach to forecasting the delivery volumes for petrol stations. The authors have developed the prediction model based on time series. The paper illustrates results obtained with the use of the developed model for different cases of the season duration as the predicting model parameter. The obtained results show that the optimal season duration differs for various types of petrol products.

Keywords: Petrol demand forecast, delivery planning, Winter’s model, loss function

1. INTRODUCTION

Planning the supply of fuels on gas stations is a complex process. The frequency and size of the delivery floats a number of factors, often characterized by a high level of randomness. It is important to forecast demand, supply and prices. All three elements are closely related. The fuel company stores as much fuel as it estimates that the customer will buy at a given price. In Poland, there are only two refineries supplying fuel to distributors: PKN Orlen SA Refinery. with headquarters in Płock and Rafineria Gdańsk Grupa Lotos S.A. Other points are Nafto-distributor bases or other companies. The fact that they supply all petroleum bases in Poland results in the fact that the maintenance of adequate fuel storage by distributors is a very complicated process.

This publication uses archival data on delivery volumes for one of the fuel companies, therefore quantitative methods have been used to predict supply volumes. Using computational methods for predicting fuel supplies must decide whether forecasts are taken long term or short term. Considering that a fuel company must have guaranteed inventory on an annual basis, long-term forecasting should be taken into account. However, in the process of further fuel distribution, short-term monthly and even weekly forecasting takes place at fuel stations. Fuel prices also have an impact on demand, according to the research carried out by Australian scientists the largest prices mostly peak on Thursday/Friday and then decline until they hit their cyclical trough mainly on Sunday/Tuesday [19]. This is forced by high variability of demand in individual regions.

The fuel demand at the station depends on many factors, the most important of which is the location of the station. It is obvious that the largest demand for deliveries has stations located on expressways, highways. Subsequently, attractive points are stations on the suburbs of large cities. However, it is worth mentioning immediately that each station has different capacity of fuel tanks. Depending on the year in which the station was built or in what location, the fuel tank may be suitable for the current demand, but it may also be too small, which forces frequent fuel deliveries. In some cases, replacement of the underground fuel tank with a larger one is indicated, however, it is not always feasible for various independent reasons, e.g. landform, spatial development or ecological factors.

Another important point is the need for a specific type of liquid fuel product. The most common fuel, diesel (ON), will be used for analysis. It is worth remembering that in fuels there is seasonality. Customers are more likely to buy fuels with additional mixtures in the winter due to lower temperatures, in addition to the gasoline, the parameter of vapor pressure is important. For summer fuel, the vapor pressure is max. 60kPa, and for winter fuel this value may not exceed 90kPa. From the point of supply of fuels it is very valuable information. Especially when the petrol station has low sales of gasoline products and relatively large tank capacities. The planner, when estimating fuel supplies to particular stations, has to take into account the seasonality of sales. It is mainly about attractive locations for tourists. It is obvious that during the holidays (June-September) or other holiday periods there will be an increased demand for fuels, for example seaside resorts, mountain resorts, on the suburbs of major cities.

The planning of the fuel supply route (IRP) has been addressed in many publications [1], [5], [7], [15], [18], among others in [4] authors considered problem belongs to the class of Inventory Routing Problems (IRP), of which it is a particularization. In particular, it draws its concepts from two different classes of distribution problems, the Periodic Vehicle Routing Problem (PVRP) and the Petrol Station Replenishment Problem (PSRP). In the publication [10] authors propose a Mixed Integer Programming (MIP) model and a heuristic approach with and without fleet size costs, to observe the impact of these costs on the solutions that are obtained. The heuristics model is based on constructive heuristics with two Variable Neighborhood Descent (VND) search types: a local intra-period search and a large inter-period neighborhood search. In the paper [8] the Petrol Station Replenishment Problem with Time Windows (PSRPTW) the aim is to optimize the delivery of several petroleum products to a set of petrol stations using a limited heterogeneous fleet of tank-trucks was considered. The methods used for petrol delivery planning are presented in **Table 1**.

Table 1 Forecasting method used for petrol delivery planning or similar cases

	Publication	Published	Used method
1	[3]	2004	Artificial Neural Network
2	[13]	2010	Linear trend model, a quadratic trend model, an exponential trend model, a single exponential smoothing model, Holt's linear model, Holt-Winters' model, a partial adjustment model (PAM), and an autoregressive integrated moving average (ARIMA) model
3	[12]	2014	Base model of a separated grid area
4	[17]	2014	Fuzzy forecasting model, neural networks (multilayer percep- tron, Kohonen, counterpropagation, RBF, GMDH), regression trees, random forests, neuro-fuzzy nets, cluster analysis methods, naïve methods, nearest neighbor method, kernel estimators and artificial immune system
5	[11]	2015	Own authors model: single-equation market demand model
6	[6]	2016	The econometric model
7	[2]	2016	Autoregressive integrated moving average (ARIMA) method
8	[20]	2016	Time series modeling with Cobb-Douglas specification, Engle-Granger's two step method for cointegration
9	[9]	2016	Integrated simulation-design of experiments (DOE) model
10	[14]	2017	The method of moving averages with the Holt, Brown model and determining the trend line
11	[16]	2017	Prigogine method, naive method, linear regression method, "three methods method" method - expert forecast, creeping trend method, Holt method
12	[21]	2017	Naive method, Winters method, opinions of the management

In one of the articles [16] the Prigogine method was used to forecast the electricity demand for one of the transformer stations. It came out best in the 5-year forecast. The Holt method (parameters α and β additionally extended by the γ parameter) and the crawling trend method were the least favorable methods of analysis.

Another example presented in the literature is Brown and Holt model for forecasting total productivity. Productivity is determined at regular intervals, therefore it is based on the analysis of time series. It is often used for smoothing moving average, Brown model, Holt and determining the trend line [14]. In the case analyzed by the authors [14] Holt's method proved to be the best method. However, despite all it differs significantly from the correct results.

2. MATHEMATICAL MODEL FOR PREDICTING THE PETROL DELIVERIES

As it was discussed, the commonly used mathematical models for forecasting delivery volumes of petrol products are based on models of time series. In this research, we propose to predict delivery volumes on the grounds of modified Winter's model.

The Winter's model is based on exponential smoothing and includes three partials shaping the forecast - data smoothing, trend smoothing, and seasonal change smoothing. In practice, two types of the Winter's model are distinguished - the multiplicative version and the version with additive seasonality. It is natural to assume that the elements for the time series model of petrol products deliveries are delivery volumes per day. As far as daily delivery volumes for petrol stations could be equal to zero, the version of the Winter's model with additive seasonality should be used for forecasting, because in the multiplicative version will produce the division by zero for such data.

For petrol deliveries forecasting, we propose to truncate at zero the value $\hat{y}_t$ obtained on the grounds of the Winter's model:

$$\hat{y}_t = \begin{cases} 0, F_{t-1} + S_{t-1} + C_{t-1} \le 0, \\ F_{t-1} + S_{t-1} + C_{t-1}, F_{t-1} + S_{t-1} + C_{t-1} > 0, \end{cases} \tag{1}$$

where F_t, S_t, and C_t are the prediction model partials [liters]:

$$F_t = \begin{cases} \frac{1}{r} \cdot \sum_{i=1}^{r} y_i, t = r+1, \\ \alpha \cdot (y_t - C_{t-r}) + (1-\alpha) \cdot (F_{t-1} + S_{t-1}), t > r+1, \end{cases} \tag{2}$$

$$S_t = \begin{cases} -F_{r+1} + \frac{1}{r} \cdot \sum_{i=r+1}^{2 \cdot r} y_i, t = r+1, \\ \beta \cdot (F_t - F_{t-1}) + (1-\beta) \cdot S_{t-1}, t > r+1, \end{cases} \tag{3}$$

$$C_t = \begin{cases} y_t - F_{r+1}, t \le r, \\ \gamma \cdot (y_t - F_t) + (1-\gamma) \cdot C_{t-r}, t > r, \end{cases} \tag{4}$$

y_t is the *t*-th empirical value of the forecasted parameter [liters];

α, β, and γ are smoothing coefficients: $\alpha \in [0; 1]$, $\beta \in [0; 1]$, $\gamma \in [0; 1]$;

r is the season duration [days].

The smoothing coefficients are calculated with the use of the least squares method (if the time series size is too big to implement the least squares method, other heuristic approaches are used, e.g. the gradient descent method) for the following loss function:

$$Loss(\alpha, \beta, \gamma) = \frac{1}{2} \cdot \sum_{i=1}^{n} (y_i - \hat{y}_i)^2 \to \min, \quad (5)$$

where n is the empirical time series size.

The season duration is usually considered as the constant value while predicting by the Winter's method. However, for the petrol products deliveries, this parameter is usually different for a set of the serviced gas stations.

3. EXPERIMANTAL RESULTS DISCUSSION

In order to obtain the optimal season duration (resulting the best forecasting precision), we investigate the dependence of the loss function (5) on the value of the season duration for deliveries of different fuel types in a distribution network in Poland. The testing time series represent delivery volumes during 2 years for a chosen gas station: thus, the time series size is equal to 730. Four types of fuel are considered: ULG95 (Unleaded 95), DK (Diesel ON), ULTSU (Ultimate Unleaded), and ULTDK (Ultimate Diesel.)

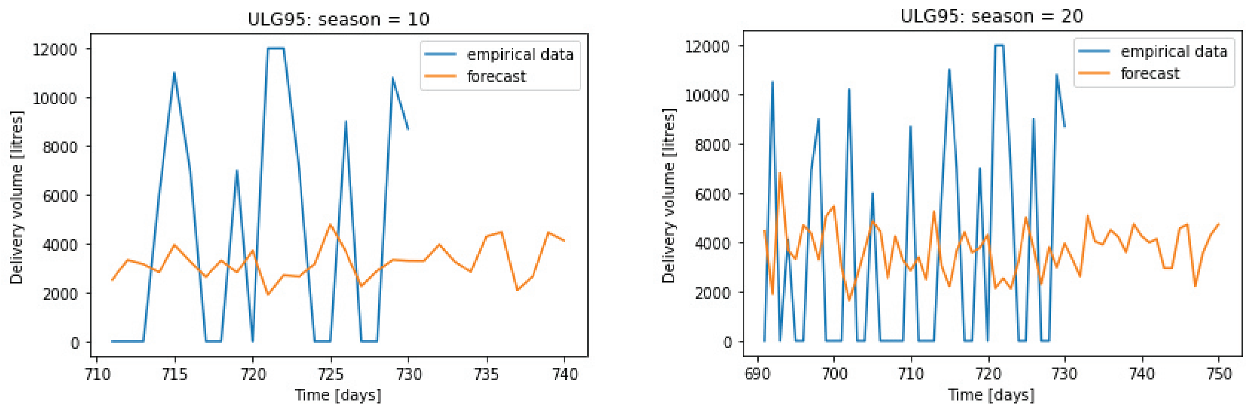

Figure 1 Predictions of ULG95 deliveries for the season duration equal to 10 and 20 days

The presented Winter's model in the trunkated form was implemented in Python programming language (the code and the analysed dataset are available at the git-repository and could be forked from https://github.com/naumovvs/WintersForecast.git). The input data for the forecasting procedure could be loaded from csv-files. Results of the forecasting are the time series presented in a form of a dictionary - a set of key-value data points, where the key represents the day and the value stands for the predicted delivery volume returned by the model. The forecast examples for ULG95 type of fueal are presented in **Figure 1**.

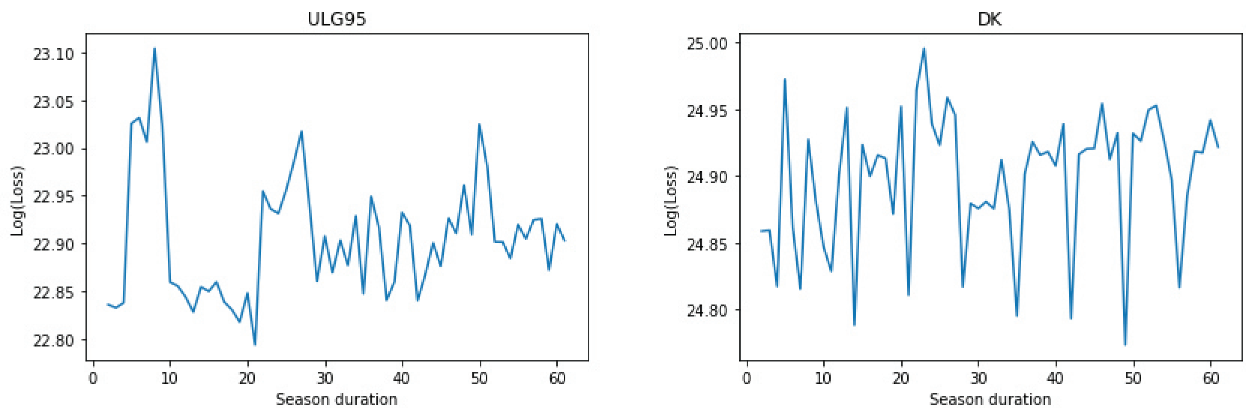

Figure 2/1 Dependence of the loss function logarithm on the season duration for different types of fuel

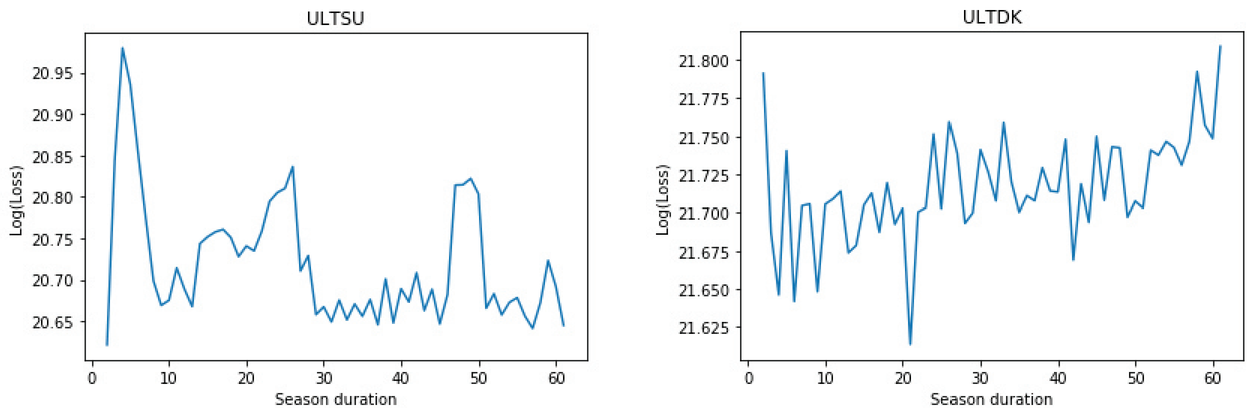

Figure 2/2 Dependence of the loss function logarithm on the season duration for different types of fuel

In the computational experiment, carried out with the use of the developed software on the grounds of dataset containing delivery volumes for a chosen gas station, the minimum loss function values (regarding the Winter's model coefficients) were calculated for the season duration values in the range between 2 and 61 days. The simulation results in the logarithmic scale of the loss function values are presented in **Figure 2**.

According to the obtained results, the optimal value of the season duration equals to 22 days for ULG95 and ULTDK types of fuel, equals to 50 days for the DK fuel, and to 58 days for the ULTSU fuel. Despite the commonly used practice to predict deliveries of petrol products on the base of 7 days cycle, the values of the loss function for such the season duration are too high for any type of fuel.

4. CONCLUSIONS

The petrol dispatch planners try to maximalist the volume of petrol dropped from tankers trains to the station tank. The main reason for it is to minimalize the frequency of the supply and the shorten the route. The result of it is that some petrol stations receive the delivery every few days, sometimes once a week. The Winters method is quite good for similar cases but forces more frequent deliveries. The planners generally use data just for 7 last days, and base of their experience know typical rules like higher petrol demand at the weekends and non-working days. Because lack of long-term data, and complexity of the problem sometimes planners make forecast mistakes. In the proposed model every non-working day was taking into account all non-working days, so the risk of the risk of lack of fuel at the station is lower. The disadvantage of that is more frequent deliveries. In the future work the authors would like to minimalize the routing distance, and maximalist the fuel drop to the station tank, taking into account the station tank capacity, long-term seasonality, short-term seasonality and the other factors like petrol station density nearby, distance from the highway, main route, large city, etc. The Winters method is a good base for that case.

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