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Simulation-Based Approach to Operating Costs Analysis of Freight Trucking

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Abstract **− The article is devoted to the problem of costs uncertainty in road freight transportation services. The article introduces the statistical approach, based on Monte Carlo simulation on spreadsheets, to the analysis of operating costs. The developed model gives an opportunity to estimate operating freight trucking costs under different configuration of cost factors. Important conclusions can be made after running simulations regarding sensitivity to different factors, optimal decisions and variability of operating costs.**

Keywords **− Costing, modelling, Oracle Crystal Ball, risks, simulation, transportation.**

I. Introduction

Road freight transportation is a critical part of the economic activity, and world economies would not function without it [1]. Transportation – a type of logistics activity, whose aim is to ensure the carriage of material resources or products using a particular transportation type; besides, it includes ancillary services. Transport services are understood not only as freight transportation, but they also include any operation that is associated with arrangement and implementation of carriage [2].

Transporters face different prices of cost components, different routes and truck characteristics; therefore, it is difficult to obtain accurate estimates of transportation costs. Accurately calculated costs of transportation are extremely important to negotiate desirable rates [3]; besides, it is necessary to compare the company's performance against competitors in the market [4].

Transportation process faces different kinds of uncertainties, for example, time of necessary procedures for border crossing, fuel price, theft losses, accidents etc. In other words, a company faces some risks and it is obvious that these risks affect the cost of freight transportation and it should be taken into consideration while setting the prices for provided services.

The calculation of costs is not a difficult task, especially by means of nowadays information technologies. Unfortunately, inputs for calculations are not precise and contain errors. The errors of each input are accumulated in various aggregations until the total costs are counted that include each individual error; therefore, the final costs are unreliable. The need to consider the possible errors and risks of input factors appears during the costs analysis. The formulated problem of the research study is uncertainty of costs in providing road freight transportation services. The formulated problem helps to identify the main aim of the study, i.e., the development of simulation-based approach to the analysis of freight trucking operating costs.

Road accidents cause the loss of goods and time and potentially expensive lawsuits. Damage costs that are usually taken for both goods and vehicles are often covered by insurance.

When freight is moved across the international border, trading tariff and delays for customs procedures appear [5]. Another factor is loading/unloading time that results in time loss; the shorter the trip, the greater the influence on the waiting time [3].

Direct transportation process involves some fixed and variable costs; therefore, the so-called operating costs are more informative. As a result, in this paper only operating costs are estimated.

General definition of operating costs is as follows: "costs which are related to the operation of a business, or to the operation of a device, component, piece of equipment or facility. They are the costs of resources used by an organisation just to maintain its existence" [6]. In transportation, in 1974 Daniel suggested to divide operating costs into two categories [7]:

- running costs (include fuel consumption, engine oil consumption, tyre costs and maintenance costs);
- standing costs (license, insurance and interest charges).

In 2003, there was a suggestion to estimate operating costs based on fuel, repair, maintenance, tyres and depreciation costs [7]. According to W. F. Chen, operating costs include fuel, maintenance, insurance, licensing and related taxes. In the long term, costs that are related to vehicles and parts replacement or repair are added as well [5].

The introduced approached is developed for the company "X" that is specialising in international freight trucking; however, over the past two years the company has been transporting freight only across Europe–Russia borders. In the research, the most popular route (Riga–Moscow) is investigated.

Operating costs associated with Riga–Moscow trip consist of two main parts – drivers' salary and fuel costs. The salary is a function of time; in turn, time depends on distance, border crossing time, loading/unloading time, waiting for return freight and potential time loss caused by breakdowns or accidents. Total fuel costs depend on fuel price, distance, truck fuel consumption and its increase due to the freight weight. Less significant parameters that contribute to operating costs are tyre amortisation and direct costs that are associated with breakdowns and accidents.

II. Description of the Approach

The introduced approach includes several steps. In order to define risk factors of possible operating costs, the risk management process is studied based on [8]–[12]. Additionally, it is necessary to investigate the process of international freight trucking process [5], [13]–[15] and costing problems in the transportation field [5], [6], [14], [15]. The determined uncertainties that contribute to uncertainty of total operating costs are listed further in the article.

The data are gathered during the research period – October 2014 – January 2015 (observations of 240 trips); for some rare events the company "X" provided accumulated statistical data from the last four-year period (3980 observations).

Modelling and simulations are used not only for better understanding of the process but also for the future event predictions (in this case prediction of possible fluctuations of total operating costs). In reality, the model predictions are affected by uncertainties of input data and model parameters [16]. The quantification of uncertainty is a process of assignment of probability to every possible future state or outcome [17]. Gathered historical data are used to choose the right distribution and corresponding parameters, sometimes defined assumptions are additionally evaluated by the experts. Distribution fitting and its parameter analysis are carried out using Oracle Crystal Ball software, which is MS Office Excel add-in software. There is a possibility to match data against some or all continuous or discrete probability distributions available in software. Crystal Ball performs mathematical fit of parameters for each distribution that describes input data in the best way, then closeness of each fit is evaluated using standard goodness-of-fit tests. The comparison chart reviews the distributions sorted in order of their fit for the test and the user can visually evaluate the quality of the fit; this chart includes goodness-of-fit statistics on three tests (Kolmogorov-Smirnov, Andersen-Darling and Chi-square) and calculated *p*-value [18]. An example of distribution fitting of waiting time in the queue before the border crossing is provided in Fig. 1.

The model is defined by interrelated mathematical equations, for example, (1) displays the equation for calculation of total fuel costs taking into account possible fuel price fluctuations and difference in Euro/Rouble currency rate and historical oil price changes.

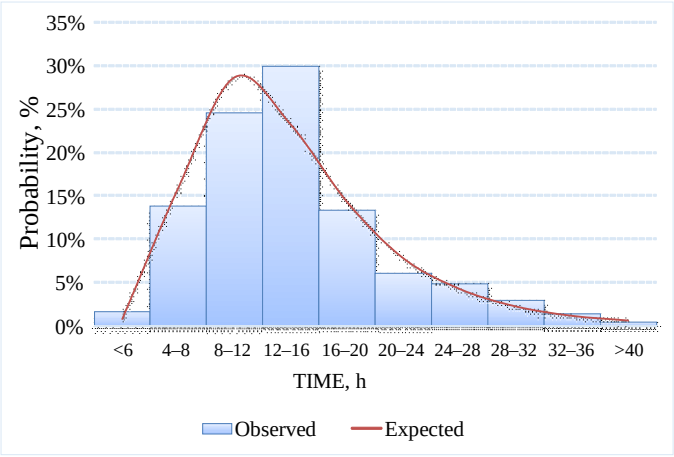


Fig. 1. Example of random variable distribution fitting for waiting time in the queue before the border crossing.

$$TFC=(FFP\cdot(FFP+FPF))\cdot\frac{FCET+FW\cdot FCI}{100} \quad (1)$$

where *FCET* is fuel consumption of empty truck, l/100 km; *FCI* is a fuel consumption increase, l/(tonne·100 km); *FFP* is a fixed fuel price, €; *FPF* is a fuel price fluctuation, %; *FW* is a freight weight, tonnes; *TFC* is total fuel costs, €.

For the graphical representation of the model Microsoft Visio and influence diagram notation is used. Influence diagram is a powerful tool for reasoning and is a convenient method for developing model and discussions among the experts [19].

Information is graphically visualised that helps to understand how particular decisions and uncertain events (and their combination) will affect the final outcome [20]. The influence diagram is a directed and open graph. It is represented by five (sometimes four) types of nodes and arrows that represent their dependence [21]–[23] (see Fig. 2). Influence diagram concept is quite general, that is why it is a useful tool not only for the decision making process but also for any formal description of the interrelations between elements of model and, as a result, is an important tool for modelling work [19]. The developed conceptual model is represented in Fig. 3. Full forms of abbreviations used in Fig. 3 are listed in Table I.

One of the main costs is a driver's salary that depends on total trip time. Time in turn depends on time for border crossing, breakdowns and accidents, distance etc. Another significant part of the costs is fuel costs, which depend on fuel price, distance and fuel consumption (depending on freight weight and truck type). The distance is the factor that influences not only fuel consumption but tyre usage as well. Tyres should be changed after 200 000 km run; the truck has 12 tyres, with the price of 350 EUR per each. Additionally accidents and breakdowns affect costs directly and at this stage the second decision appears regarding CASCO insurance franchise deductible rate (for accidents).

Some constant costs (such as toll roads, security deposits) associated with the trip are not included in the model because they are not exposed to uncertainty, they complicate the model but do not contribute to cost variance. In case the need to

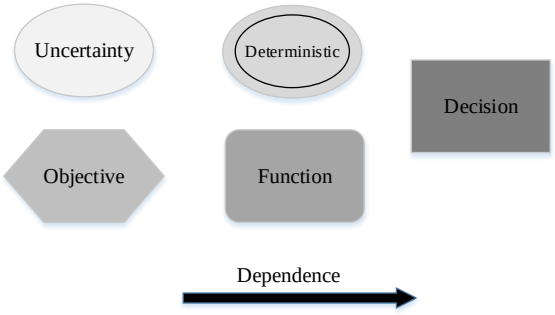


Fig. 2. Elements of influence diagrams.

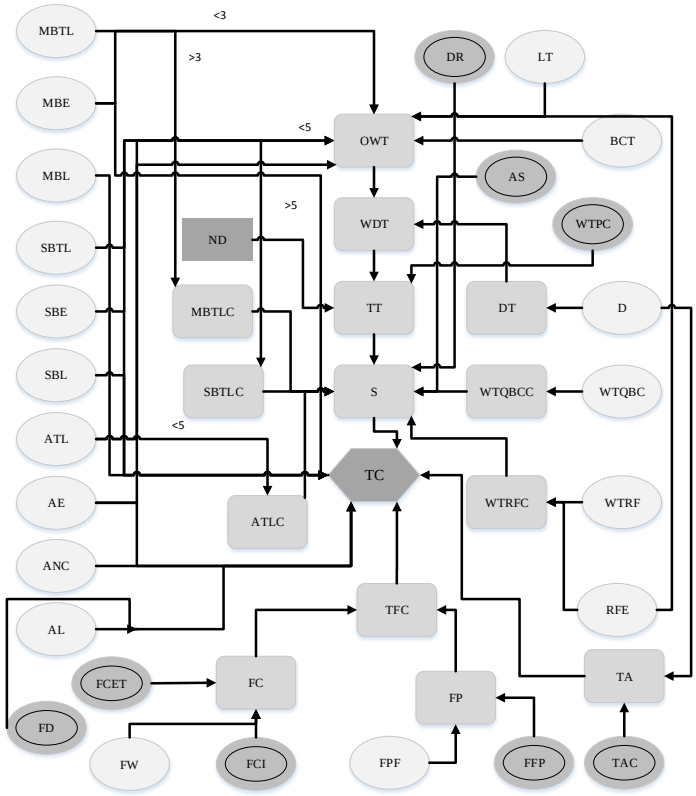


Fig. 3. Influence diagram for operating costs analysis for company "X".

consider these costs appears they can be easily added to the final value of total operating costs.

The risk factors are all uncertainties that are included into the model (actually random factors); they all directly or indirectly affect the total operating costs.

Having considered assumptions and mathematical interrelation between the model elements, it is time to run the simulation. The simulation is carried out using Oracle Crystal Ball Enterprise Performance Management, Fusion Edition software. Crystal Ball carries out random variable generation based on assumptions that are defined in the model and formulas describing interrelations between model elements. Crystal Ball offers different options and functions for representation of simulation results. The user can display information graphically or numerically, generate reports or extract data for further processing in other software.

III. Research Results and Discussion

The results are automatically displayed as the frequency chart (possible to display cumulative frequency chart and reverse cumulative chart) that also includes the vertical probability axis. Values that are separated in bins are displayed on the horizontal axis. The values displayed in the chart in different colours reflect whether they fall in or out of the confidence interval. Software allows changing the confidence interval in the frequency chart or manually change "tails" and instantly get recalculated results (certainty min and max).

Besides, this histogram includes a number of trials displayed (outliers are not displayed in the chart). The frequency chart for completed simulation is provided in Fig. 4.

Confidence interval for total operating costs lies down between 910 and 1456 EUR; dispersion is quite significant (standard deviation 171) and pricing process should take into account this significant dispersion.

Distribution fitting for total operating costs has demonstrated that the best choice for distribution of total costs is logistic (next best choices are Student's *t*, Lognormal, Gamma) that is asymmetric and skewed to the left tail.

Mean and median have different values and skewness has a non-zero value; therefore, the output data distribution is

TABLE I

List of Abbreviations for Fig. 3

Abbre-viation	Full form	Abbre-viation	Full form
AE	accident event	MBTL	minor/medium breakdown time loss
AL	accident losses	MBTLC	MBTL costs
ANC	accident losses not covered by MTPLI event	ND	number of drivers
AS	average speed	OWT	other work time
ATL	accident time loss	RFE	return freight event
ATLC	ATL costs	S	salary
BCT	border crossing time	SBE	severe breakdown event
D	distance	SBL	severe breakdown losses
DR	day rate	SBTL	severe breakdown time loss
DT	driving time	SBTLC	SBTL costs
FC	fuel consumption	TA	tyre amortisation
FCET	FC of empty truck	TAC	TA coefficient
FCI	FC increase	TC	total operating costs
FD	franchise deductible	TFC	total fuel costs
FFP	fixed fuel price	TT	trip time
FP	fuel price	WDT	working and driving time
FPF	FP fluctuation	WTPC	working time proportion coefficient
FW	freight weight	WTQBC	waiting time in the queue before border crossing
LT	loading/unloading time	WTQBCC	WTQBC costs
MBE	minor/medium breakdown event	WTRF	waiting time for return freight
MBL	minor/medium breakdown losses	WTRFC	WTRF costs

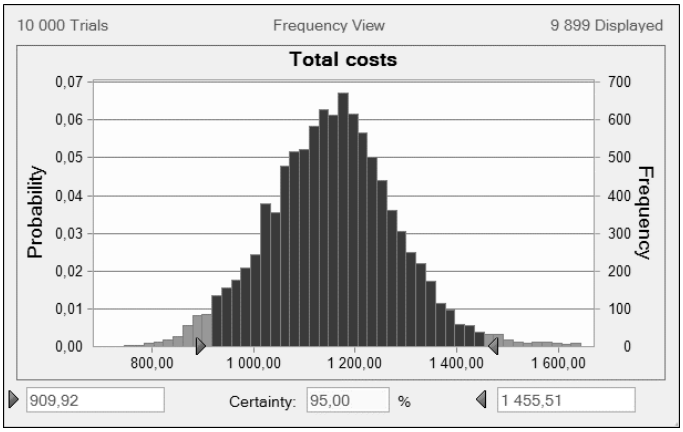


Fig. 4. Frequency histogram of total operating costs.

asymmetric. Statistics considers the value of standard deviation that allows the user to have a viewpoint on data dispersion.

The next step in the result analysis is the sensitivity chart. The sensitivity chart allows the user to determine how changing a parameter or combination of parameters influences the total variance of forecast variable.

For the visualisation of results, some parameters are grouped, for example, accident event, accidents not covered by MTPLI, accident losses and accident time loss are grouped under one name "accidents".

In Fig. 5, the contribution of uncertainty factors to variance of total operating costs sensitivity chart is provided. This chart helps to answer the question "What percentage of the variance or uncertainty in the forecast is caused by each assumption?" The sensitivity chart shows that factor mostly affecting the total operating costs is the distance, with a numerical value 31.6 %. The second important factor is probability of return freight (26.3 %), followed by waiting time for return freight (14.5 %).

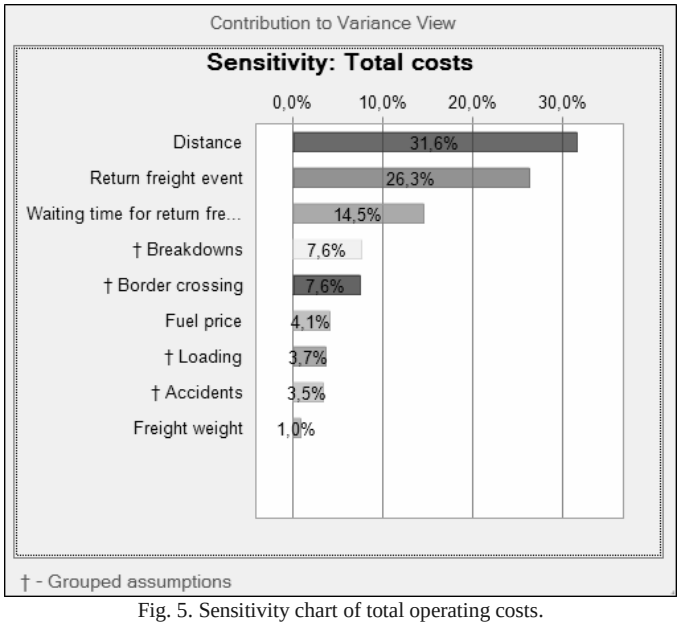


Fig. 5. Sensitivity chart of total operating costs.

Within the framework of the research, the task of finding optimal solutions to some problems has been solved; one of them is decision on CASCO insurance type. For this purpose, OptQuest tool has been used, which is an optimisation add-in for Crystal Ball that enhances models by automated search for the optimal solution by finding the combination of variables providing better results. Several companies offer different insurance types depending on annual rate per truck and franchise deductible rate. Usually higher franchise deductible goes with lower annual rate; it is also possible to notice this tendency in Table II that summarises insurance offers.

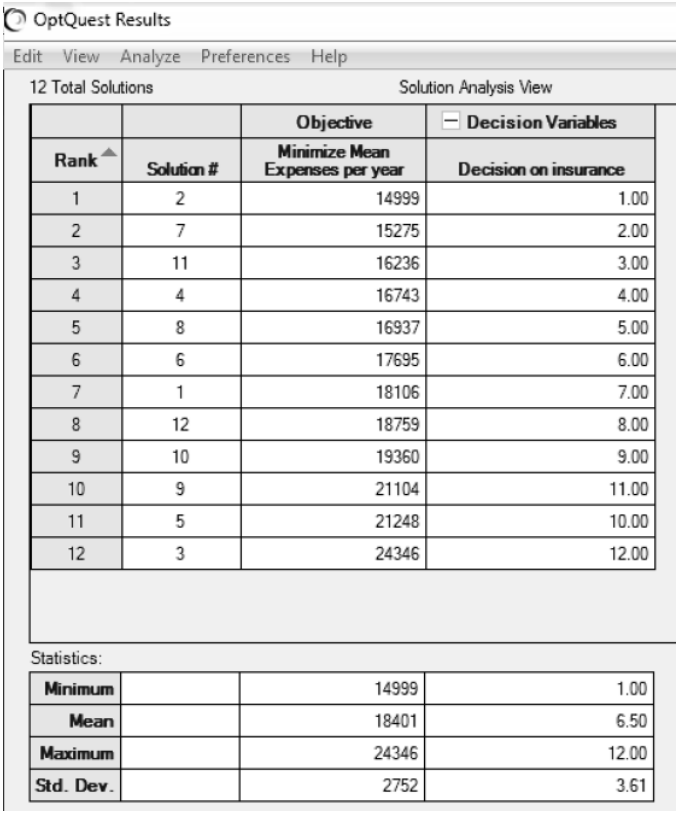
After simulation the user can see the solution analysis view (see Fig. 6).

The OptQuest offers the best solution – No. 1 with franchise deductible 2500 and annual rate of € 250 per truck. There is a tendency in a solution view – insurance with a higher franchise deductible and lower annual rate is more profitable. This could be explained by the fact that the expected annual accident losses per truck are € 156 (product of probability of accident, mean of accident losses and annual average number of trips per truck), which is significantly lower than minimum of offered franchise deductible.

Verification of the model includes the evaluation of reasonableness of outputs under a variety of input parameters. Logic of functional interrelations was additionally evaluated using graphical representation of the model. Besides, experts evaluated the feasibility of midline and final outputs of the model.

However, simulation model development requires the validation of the model, in the context of the present research it has not been carried out. The current classification of costs in the company's "X" accounting does not comply with consideration of costs in the model; moreover, costs associated with breakdowns/accidents and remaining costs are gathered from different departments, therefore, cannot be compared and matched. Additionally, some important factors of uncertainty (e.g., fuel price fluctuation) change over time; even if the accounting system of the company "X" could provide costs in the necessary classification, they would be incomparable because of the changes over time.

The existing model could be transformed or extended for different purposes. The model could be transformed for the new routes (in this case there is a need to change distance, border parameters, fixed fuel price, etc.). There is a possibility of extending the model to make some business decisions (for example, to choose the best suitable truck depending on consumption of empty and loaded truck or breakdown probability and relegated severity or different driver payment strategies, etc.). Demand analysis and pricing policy would widen the scope of implementation of the existing model from operating costs to profit by a trip analysis.



OptQuest Results

Edit View Analyze Preferences Help

12 Total Solutions — Solution Analysis View

Rank	Solution #	Objective: Minimize Mean Expenses per year	Decision Variables: Decision on insurance
1	2	14999	1.00
2	7	15275	2.00
3	11	16236	3.00
4	4	16743	4.00
5	8	16937	5.00
6	6	17695	6.00
7	1	18106	7.00
8	12	18759	8.00
9	10	19360	9.00
10	9	21104	11.00
11	5	21248	10.00
12	3	24346	12.00

Statistics:

Minimum		14999	1.00
Mean		18401	6.50
Maximum		24346	12.00
Std. Dev.		2752	3.61

Fig. 6. Simulation results for the decision support.

IV. Conclusion and Recommendations

Transportation is a significant part of the world economy, the road transportation has bigger turnover than any other transportation type. Freight trucking process is full with uncertainties and is exposed to some risks, for example, theft losses, customs delays, accidents; these risks result in variability of costs for trucking services. Awareness of costs associated with transportation operations is essential to negotiate the rates for provided services. Transportation costs are the function of decisions made by managers, trip and truck characteristics, resulting in a unique costs structure for a particular company and route. Undoubtedly, one of the main factors contributing to transportation costs are uncertainties. There are different approaches to transportation costs evaluation; besides, costs classification may also vary. For the costs evaluation of a direct transportation process, operating costs, which include both fixed and variable costs, are more informative. The company should plan a pricing strategy with respect to large uncertainty of operating costs.

One of the most important issues in simulation is determining the content of the simulation model. Conceptual model is an important step of the simulation study that helps to understand the core of the problem. The influence diagram is a convenient method for the visualisation of the model and this approach pays more attention to effects and types of the model elements. Oracle Crystal Ball is an easy-to-use tool for the simulations and result analysis that includes various tools that are helpful for a certain problem solving.

TABLE II

Insurance Companies Offers for CASCO Insurance

Offer No.	Franchise deductible, €	Annual rate per truck, €
1	2500	250
2	1400	266
3	1500	290
4	1000	312
5	700	327
6	500	358
7	350	382
8	500	386
9	350	415
10	570	447
11	420	454
12	280	555

Crystal Ball offers different possibilities and functions for representation of simulation results. Confidence interval for total costs lies between 910 and 1456 Euro; dispersion is quite significant (standard deviation 171) and pricing process should take it into account.

Total operating costs are mostly affected by variability of distance, the probability and waiting time for return freight and border crossing time. The contribution to variance of these factors is more than 14 %. The contribution of other factors is less significant.

The results of the simulation help to notice tendencies, relations, levels of impact, etc. and formulate recommendations for the company "X" to optimise its costs and improve activity. First of all, company "X" needs to pay more attention to the distance variability, as far as Moscow and the surroundings occupy quite a large area and it would be more reasonable to set the price per kilometre rather than a one-way trip. Besides, results show that the probability of a return freight and waiting time for the freight are quite important; therefore, to minimise the costs variability it is sensible to find permanent partners in Moscow to ensure the return freight or try to find the return freight in advance before setting the price for the customer.

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