Assessing the Reliability of Supply of Logistics Systems

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The reliability of supply of logistics systems is the one of the most important factors determining the competitiveness of businesses. The main purpose of this paper is to assess the reliability of supply of a given system with the use of warranty analysis, based on the Nevada chart. The reliability analysis performed is done in the following way: shipping and warranty return data of a given supply system are converted into a classic data form. Then, the life data analysis is performed, which allows to obtain the given reliability indicators and predict the future returns of the products and services. The paper consists of some useful reliability measures, that may be used in the assessment of reliability for the supply system. Used reliability indicators may be the basis for the development of the preventive tasks to reduce the future returns. The presented approach for reliability assessment of supply system discloses its applicability. Forecasting the future returns and determining the selected reliability measures may be applied in any supply system. It is valuable for the identification of the weakest product or service and it is necessary for developing further preventive activities.

Keywords: Reliability in logistic, logistics system, the Nevada chart, supply system.

1. INTRODUCTION

The assessment of the quality of logistic services relates to the fulfilment of several criteria. One of the most important criteria which refer to the level of competitiveness of businesses is reliability. Reliability of products or logistic services as one of the factors determining competitiveness include several parameters, such as: accuracy of supply, completeness of supply and punctuality of supply. It is also necessary to maintain the returns and faults in documentation on a low level. The reliability of the logistic services means that the supply will be realised according to the deadline, without any damage to the delivered goods; invoices will be properly prepared, without errors, the goods will be delivered to the right place and the ordered quantity will be correct. Reliability of the logistic services may be also interpreted as the ability to provide the accurate information to the customer, related to the state of the order. It is concerned with meeting scheduled deadlines and informing the customers when the supply cannot be completed within the assumed time [8, 9, 15].

Reliability involves almost all aspects related to the properties, such as cost management, customer satisfaction, the proper management of resources, passing through the ability to sell products or services, safety and quality of the product [2]. Reliability analysis as the one of the factors determining the level of satisfaction of the customer was the topic of the scientific researches, investigated by the many authors. For example, Meng Lian, Lin and Chen conducted a research in which they analysed inter alia: the Quick Response Systems, complete customer service, integration of system inventory, delivering on time and safety of service performed [12].

Nowadays, there is a need to increase the reliability of products and logistics services. It requires developing new methods or improving the existing ones for reliability analysis. The schematic approach is of particular importance, in which the logistics system is presented as the organized set of elements, such as transportation, storage and distribution. A warranty analysis as a schematic approach plays a significant role in assessing the reliability of the logistic systems. It allows to

forecast a number of returns of the failed products or services.

Based on the review of the selected scientific papers, the following research seems to be worth of investigation.

2. LITERATURE REVIEW

During the analysis of supply of logistic system, its reliability is related to, among others, the reliability of supply process. One of the concepts of reliability in the logistics area assumes this term as the ability of the system to undisturbed realisation of the process of delivering the necessary logistic sources (spare parts, crew, equipment, etc.) to the technical system. According to another definition, the reliability of the logistic system is an ability to meet end-customer demand through a supply chain in which the process of the materials flow is undisturbed by the supplier's possible failures. The reliability of the logistic chain is directly related to its ability to meet the customer requirements [3, 6].

In some investigations on the reliability of supply of logistic system, the authors concentrate on the overall measurement of reliability. Such measure includes the ability of a logistic system to perform all the tasks necessary to work without any faults [10].

The term of reliability used in the context of logistics still remains unclear. It is often perceived in two ways: probabilistic and deterministic term. A deterministic property includes fulfilling or not fulfilling a given criteria, whereas probabilistic approach models the complexity of random phenomena and uncertainty. In technical terms, reliability of a system is defined as a set of properties, concerned with, among others: availability and maintainability. Availability indicates the ability of an object to remain in a state of being able to realise the required functions under specified conditions, at a given moment or time with the assumption, that all required means are provided. Maintainability is the ability of an object to maintain or reproduce the state, in which it may fulfil the required functions, under given conditions and with the assumption that all the required means are provided. It is connected with maintenance of crews and services, within a specified period of time and operating conditions [13, 16, 19].

In order to assess the validity of reliability of the logistic supply as an important factor determining the competitiveness level of on

logistic company, a survey was conducted. A quantity research were investigated on the basis of the literature recommendations. A research questionnaire was sent to the representatives of service providers and service recipients to fulfil the research objectives. The study covered 46 companies providing the logistics services in the field of refrigerated transport and 269 companies use the above services. The study was conducted in two phases, which were carried out in 2010 and 2012. According to the opinion of almost 70% of representatives of service providers and over 40% of service representatives, reliability of the logistic supply is a very important factor determining the competitiveness of the company [14, 17].

Due to the importance of reliability in the logistics area for the competitiveness of companies, the methods of reliability assessment are of particular importance. They help to draw conclusions and take actions to increase the efficiency of the businesses and strengthen its position on the market. The analysis of reliability of supply of logistic system and forecasting the future failures of the products and services is concerned with warranty analysis and may be based on the return data [7].

The assurance of the quality, reliability and safety of the logistic services plays an important role in the functioning of businesses, especially in recent years [4]. It resulted in the release of numerous scientific papers related to the topic. Following [18], the authors proposed the two types of the methods of determining the warranty policies. A good example of a direct link between modelling the warranty policy and the reliability models of goods and services in the automotive industry. For example, work [1] includes a review of existing warranty models as well as the analysis of warranty costs. The authors, based on the empirical data, estimated the warranty cost of used cars, taking into account the selected factors, such as: the age, usage and maintenance data of the cars. The work contains also the advantages and disadvantages of the proposed method as well as proposal of the future research in the area of warranty modelling. The most of the methods used to warranty analysis are based on the basic reliability analysis, as shown in work [21].

Some recent works relate to two-dimensional warranty analysis. For example, Gupta et al. proposed a model for developing the warranty policies in case of incomplete data set. They elaborated the diagnostic tool for reporting the failure behaviour and changing the shape of hazard

function [5]. On the other hand, Tsoukalas and Agrafiotis conducted a research related to a warranty policy, in which they included the age and usage of the non-repairable objects. They took into account the different costs of replacement [20].

3. ANALYSIS OF RELIABILITY OF SUPPLY SYSTEM

3.1. NEVADA CHART FORMAT

Nevada chart is a data format which contains information about deliveries of products or services that have been placed on the market. The chart includes also the returns as a result of failures occurred before the warranty period. It is necessary to mention that some of the products and services may continue to operate after the end of warranty period. Therefore, a known number of failures (F) and suspensions (S) is associated with the certain amount of supply. Such data can be converted to well-known time to failure format, and used for further analysis of reliability with commonly applied techniques [22].

3.2. ASSUMPTIONS

Let's assume that a company recorded the following data set about sales of the products:

Table 1. Sales of the products.

QUANTITY IN-SERVICE	DATE IN-SERVICE
1,000	01/01/2016
1,200	01/02/2016
1,400	01/03/2016
1,600	01/04/2016
1,800	01/05/2016

Table 2 contains returns of the products, recorded month-by-month.

Let's consider sales and returns for the first month of supply. In January *1,000* products were delivered to the customer but *22* failed products were returned as the sum of returns from January to May. It means that *978* products are able to

continue the operation after five months ($S_{JAN,5}$ = 978). The total number of returns at the end of the five month of supply is a sum of returns in the first months of the sales *($F_1 = F_{JAN, 1} + F_{FER, 1} + F_{MAR, 1} + F_{APR, 1} + F_{MAY, 1} = 1 + 1 + 1 + 2 + 5 = 10$)*. Following the above scheme, the warranty returns data may be converted to life data with failures and suspensions (Life Data Analysis Reference, 1997-2007).

Failures at 1 month:
$F_1 = 10$

Suspensions at 1 month:
$S_1 = S_{MAY, 1} = 1795$

Failures at 2 months:
$F_2 = F_{JAN, 2} + F_{FER, 2} + F_{MAR, 2} + F_{APR, 2} = 2 + 4 + 3 + 5 = 14$

Suspensions at 2 months:
$S_1 = S_{APR, 2} = 1593$

Failures at 3 months:
$F3 = F_{JAN, 3} + F_{FER, 3} + F_{MAR, 3} = 3 + 5 + 6 = 14$

Suspensions at 3 months:
$S_1 = S_{MAR, 3} = 1390$

Failures at 4 months:
$F4 = F_{JAN, 4} + F_{FER, 4} = 6 + 8 = 14$

Suspensions at 4 months:
$S_4 = S_{FER, 4} = 1182$

Failures at 5 months:
$F5 = F_{JAN, 5} = 10$

Suspensions at 5 months:
$S_5 = S_{JAN, 5} = 978.$

Life data obtained from warranty returns are placed in the Table 3.

Table 2. Warranty returns of the products.

MONTH OF SALE	MONTH OF RETURN				
	February	March	April	May	June
January	1	2	3	6	10
February		1	4	5	8
March			1	3	6
April				2	5
May					5

Table 3. Life data obtained from Nevada chart.

NUMBER IN STATE	STATE, F OR S	STATE END TIME (MONTH)
10	F	1
1795	S	1
14	F	2
1593	S	2
14	F	3
1,390	S	3
14	F	4
1,182	S	4
10	F	5
978	S	5

4. RESULTS AND DISCUSSION

Based on the life data set, a goodness of fit analysis was conducted. Using the Maximum Likelihood Estimation methodology, the parameters of 2P-Weibull distribution were estimated to be: $\beta = 1{,}7724$; $\eta = 43{,}0649$ month. Quality of the Weibull distribution fitness is shown in Figure 1. Based on the estimated parameters, the selected reliability characteristics were also obtained, such as: reliability of supply, unreliability of supply, failure rate of supply (Figures 2-4, the dotted lines). The plots include two-sided confidence bounds (Figures 2-4, the continuous lines) at the level of 0,9 (Life Data Analysis Reference, 1997-2007).
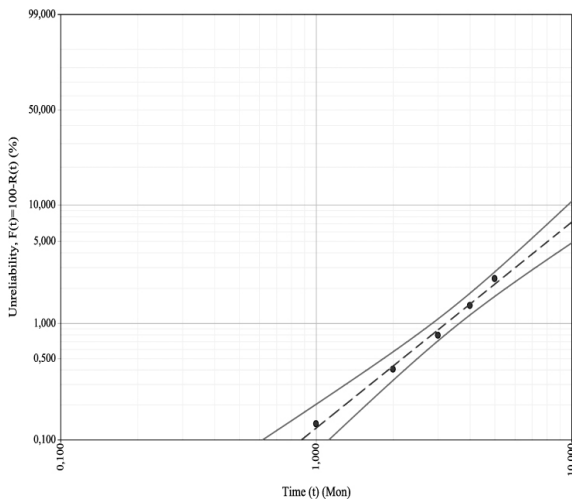

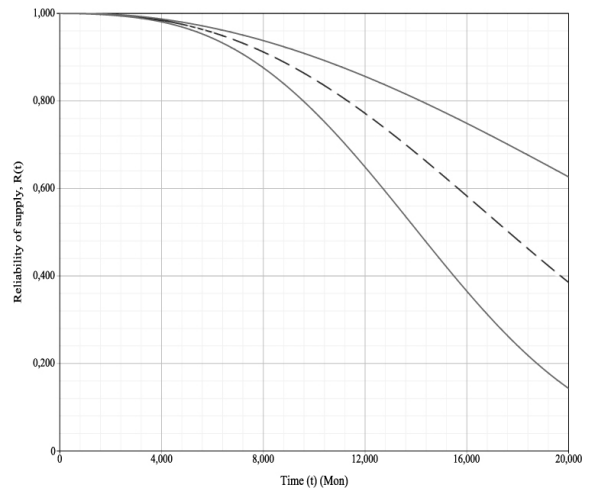Fig. 1. Weibull Probability Plot.

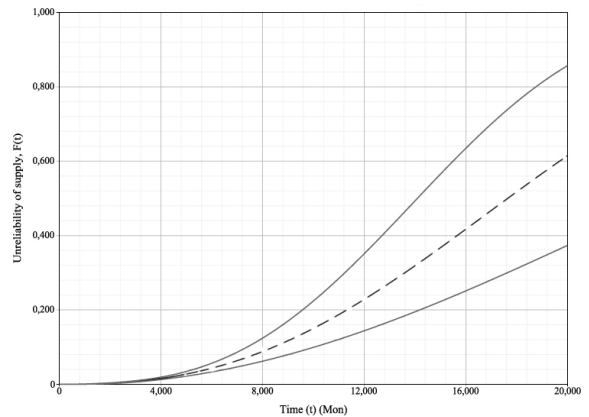Fig. 2. Reliability of supply vs. time plot.

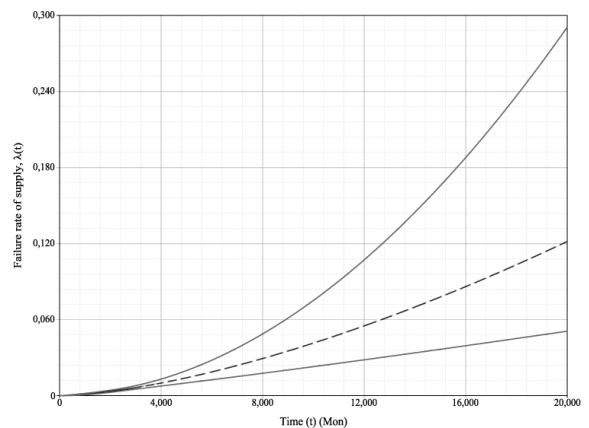Fig. 3. Unreliability of supply vs. time plot.

Fig. 4. Failure Rate of supply vs. time plot.

As it may be observed, the selected characteristics show the change in the probability of successful supply in the period of twenty months. The longer the supply period, the greater the probability of return and hence, the greater number of returns of the products or services. The confidence bounds show the range of the possible values of probability at a given level of 0.9. They

are expanding due to the increase in the period of supply.

Based on the above characteristics, a forecast of the returns from the future sales may be obtained. The Figure 5 shows the growing trend in the expected number of returns with taking into account the confidence bounds in the period of six months. These results may be useful for the companies to develop the future preventive actions that may improve the quality of a product or service and then to reduce the number of returns. It is worth mentioning that the number of returns is strongly related to warranty costs.

The obtained results should be interpreted as follows: among the expected average number of return in July, each of 9 were delivered in January, and April, 10 were delivered in February and March and 8 were delivered in May. Therefore, the mean number of returns expected in July is 46. What is more, there is a probability 0.9 that the actual value of return will be within the range of 34 to 65. The rest of the table may be analysed in the same way.

5. CONCLUSION

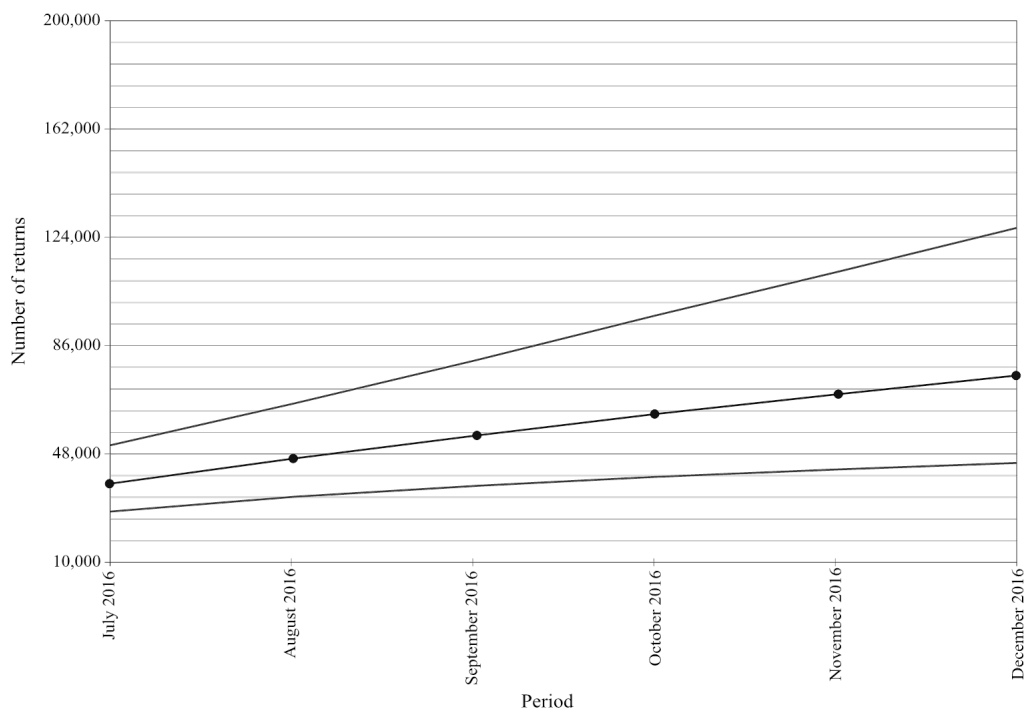The presented paper discusses the application of

Fig. 5. Expected number of returns plot.

The exact values of forecasted returns are shown in Table 4. According to the forecast, the total number of returns in December will be more than two times greater than the number of returns in June.

the warranty analysis, based on the Nevada chart format in the area of logistics. It has been shown that the reliability of supply is one of the key factors determining the competitiveness of businesses, in the opinion of both providers and

Table 4. Expected number of returns.

Returns / Deliveries	June			July			August			September			November			December		
	L	M	U	L	M	U	L	M	U	L	M	U	L	M	U	L	M	U
January	5	8	7	6	9	14	6	10	17	7	11	19	7	12	21	7	13	23
February	6	8	8	7	10	15	7	11	17	7	12	20	8	13	23	8	14	25
March	6	8	9	7	10	14	8	11	17	8	13	20	9	14	23	9	16	26
April	6	7	10	7	9	12	8	11	16	9	13	20	9	15	23	10	16	27
May	4	5	11	7	8	10	8	11	14	9	13	18	10	15	22	11	17	26
TOTAL	27	36	45	34	46	65	37	54	81	40	62	97	43	69	112	45	76	127

M – mean, L – lower band, U – upper band.

recipients. Therefore, there is a need for gathering the information about the expected number of the future returns of goods and services. To meet this purpose, one can apply the suggested method of warranty analysis. Using the data about the current number of returns, a forecast for the future returns may be conducted. The application of the method is not limited only to the given example. Forecasting can generally involve the occurrence of other undesirable events, such as: failures, downtimes, exceeding the limits of the given values of the certain physical quantities, etc.

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