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STUDY OF SELECTED PROBLEMS OF RELIABILITY OF THE SUPPLY CHAIN IN THE TRADING COMPANY

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ABSTRACT. The paper presents the problems of the reliability of the supply chain as a whole in the dependence on the reliability of its elements. Different variants of reserving of canals (prime and reserve ones) and issues connected with their switching are discussed.

Key words: supply chain, reserving of canals, reliability of service level, switching of canals in supply chain.

The increasing competition on the market of logistic services, increasing complexity of logistic systems, growing demand of very high level of service of the final client which influences each part of supply chain, growing opportunities of the usage of information technologies are the most important factors influence the quality of services expected in present supply chains.

The theory of logistic systems and supply chains, being the scientific approach to this topic, seems to be of great help to the practice. It enables to determine and to define basic concepts and ideas, to justify expectations for reliability of separate objects and whole systems by taking into account technical, organisational, technological, economical, social and ecological factors, to prepare solutions of given tasks and to evaluate the reliability of objects at different stages of life cycles of goods and services. These activities can be processed and evaluated at every point of the considered process.

The increase of the reliability of a logistic system can be described by the process of the optimization of stocks' level kept in the company. For the presented example the statistical data for the goods are given in the table 1.

In this situation the quantity of stocks is calculated using the formula (1):

$$\mathbf{Q} = \bar{\mathbf{b}} + \mathbf{u} \times \boldsymbol{\sigma}_{\mathbf{b}} \tag{1}$$

where:

Q - daily stock of goods in units,

$\bar{b}$ - average daily sale of the goods,

u - coefficient of Gauss distribution,

σ_{b} - - square of difference from average value of sales.

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Table 1. Statistical data of goods belonging to company
Tabela 1. Dane statystyczne dotyczące towarów firmy

period of time	**sale**	$\bar{b} - b_i$	$(\bar{b} - b_i)^2$
1	300	93	8 649
2	200	193	37 249
3	600	- 207	42 849
4	500	- 107	11 449
5	650	- 257	66 049
6	700	- 307	94 249
7	360	33	1 089
8	250	143	20 449
9	150	243	59 049
10	220	173	29 929
Total	3 930	-	371 010

The average daily sales and standard deviation of sale are calculated by using the formulas (2) and (3).

$$\bar{b} = \frac{\sum_{i=1}^{n} b_i}{n} = \frac{3930}{10} = 393 \qquad (2)$$

$$\sigma_b = \sqrt{\frac{\sum_{i=1}^{n}\left(b_i - \bar{b}\right)^2}{n}} = \sqrt{\frac{371010}{10}} = 192{,}6 \qquad (3)$$

The quantity of stock calculated with Gauss formula is equal to:

$$Q = 393 + u \times 192{,}6 \qquad (4)$$

The coefficient of standard (Gauss) distribution seems to be the most important from the point of view of obtaining the proper solution of this formula. There is an unequivocal dependency of this parameter of the reliability of the expected event P(x), which means the reliability of deliveries. This factor, treated with some approximation, can be used as a measure of the quality of logistic service. The most characteristic values of a coefficient of Gauss distribution and level of stock connected with given values of this coefficient are presented in table 2.

Table 2. Stock level and corresponding service level
Tabela 2. Poziom zapasu i odpowiadająca jemu wartość poziomu obsługi

parameters	variants of levels of logistic service								
u	0	0,50	1,00	1,50	1,65	2,00	2,33	2,50	3,0
P (x), %	50,00	69,15	84,13	93,32	95,05	97,72	99,0	99,38	99,87
Q	393	489	586	682	710	778	842	874	971

The choice of the level of the reliability of system depends on its specific functions. The systems connected with the provision of goods necessary to fulfill basic needs of people, should have the maximal available reliability (war techniques, energetic resources, transport, especially planes). As presented in the table 2, such level of reliability almost equal to maximum (99,87%) is received when the coefficient of standard deviation is $\sigma = 3{,}0$.

In a normal situation such level of the reliability is not necessary, only the optimal reliability of the logistic service level connected with the maximal profit of the whole system is desirable. In the specialist literature is often expressed that overcoming this level above 95% results in the lowering of the company's profit but without given the explanation for that. As it can be seen in the table 2, the similar level of reliability (95,05%) is connected with coefficient of standard deviation $\sigma = 1{,}65$, at which the quantity of stocks (710 units) is practically equal to the maximum quantity of the presented case ($G_{max} = 700$) (table 1). Such a situation (the rule 1,65 σ) is taken as the optimal one on the assumption of correlation: expenditures – results.

Based on these results one can make the conclusion, that a company will be interested in raising its service level of logistic system up to 95%, not higher. Achieving higher level of the service is connected with increasing level of stocks without higher effectivity of the whole system that means greater part of goods kept in stock is not in the circulation.

Following, the different subsystem of logistical chain will be analyzed. In a general situation, the logistic system of deliveries or part of this system can be presented as the chain of possible activities (Fig. 1).

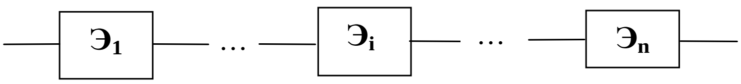

Fig. 1. Some segments of supply chain
Rys. 1. Wybrane części składowe łańcucha dostaw

Reliability of such system is understood as the reliability of its parts. If the reliability of each part of the system is the same, then the formula (5) is valid:

$$P(S) = P(Э_i)^n \tag{5}$$

where:

$P(S)$ - reliability of supply chain,

$P(Э_i)$ - reliability of each part of the chain,

n - number of elements in the supply chain.

On the assumption that the reliability of each part of the chain is equal to 0,95, which is the value of optimal correlation: expenditures–results, then the reliability of the whole system in the simple case ($n = 3$) gives $P(S) = 0{,}95^3 = 0{,}8674$ (85,74%) and in a little more complicated one ($n = 5$) $P(S) = 0{,}95^5 = 0{,}7738$ (77,38%), which is not acceptable in any case. Following, it leads to chains with maximum number of nodes, which gives the value of the reliability of the system almost 50%, the value not acceptable in practice.

It is possibly to evaluate the level of the reliability of each part of the chain $P(Э_i)$ necessary to ensure the reliability of the whole system at the level of $P(S) = 0{,}95$. This can be processed by the use of formula (6):

$$\mathbf{P}(\mathbf{Э_i}) = \sqrt[n]{\mathbf{P}(\mathbf{S})} \tag{6}$$

Then in the simple example of the supply chain, the reliability of each element $P(Э_i) = \sqrt[3]{\mathbf{0,95}}$ =0,9831, and in second example of the supply chain $P(Э_i) = \sqrt[5]{\mathbf{0,95}}$ = 0,9897. In both cases the desired level of reliability needs the increasing of the stock level, which can lead to an unprofitability of the company.

In the described situation the issue needed to be considered is to reserve the canals in the supply chain, that is to take into consideration a reserving supplier at the same level as the prime one (Fig 2).

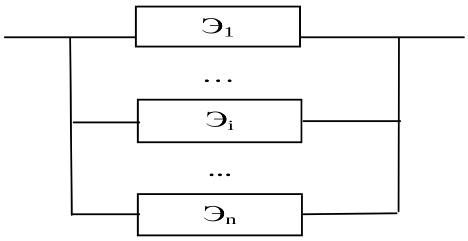

Fig. 2. The process of reserving of the elements of the supply chain
Rys. 2. Proces rezerwowania elementów łańcucha dostaw

In this situation the reliability of the supply chain is calculated as the reliability of prime and reserve canals according to formula (7).

$$\mathbf{P(З) = 1 - (1 - P(Э_i))^n} \tag{7}$$

where:

P(З) - reliability of supply chain including reserve canals,

$P(Э_i)$ - reliability of prime and reserve canals of the chain,

n - number of canals in the supply chain.

Reliability of a chain composed of:

- prime and one reserve canal is equal to: $P(З) = 1 - (1 - 0,95)^2 = 0,9975$ (99,75%),
- prime and two reserve canals is equal to: $P(З) = 1 - (1 - 0,95)^3 = 0,999875$ (99,98%),
- prime and three reserve canals is equal to: $P(З) = 1 - (1 - 0,95)^4 = 0,99999375$ (99,99%).

Based on these calculations the conclusion can be made, that the variant with prime and only one reserve canal satisfies the expectations. In the situation when each element of supply chain will have one reserve element (P(З) = 99,75%), the reliability of the simple chain (n=3) is equal to $P(S) = 0,9975^3 = 0,9925$ (99,25%) and the reliability of extended one (n=5) is $P(S) = 0,9975^5 = 0,9876$ (98,76%), which is the assumption for further extension of the supply chain. It can be seen, that even if the reliability of individual elements of the chain is lower than 95%, the reliability of the whole chain is acceptable.

It should be remarked, that above presented formulas are only valid if the special switcher between prime and reserve canal is not necessary or the reliability of this switcher is P(П) = 1. This change can be processed automatically (within a computer program) or by a logistic manager. In both these situations the not full reliability of this switcher should be taken into account. It can be especially seen in the second case presented (human factor). The basic schema of supply chain is presented at the figure 3. On the condition that every reserve canal has the same reliability, the reliability of the supply chain having a switcher, can be presented by the formula (8):

$$\mathbf{P(З) = 1 - (1 - P(Э_i)) \times \langle 1 - P(П) \times [1 - (1 - P(Э_i))^k] \rangle} \tag{8}$$

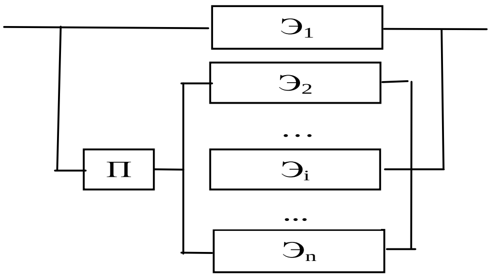

Fig. 3. The process of reserving elements of the supply chain with the switcher
Rys. 3. Proces rezerwowania elementów łańcucha dostaw obejmującego przełącznik

where:

P(З) - reliability of supply chain having reserve canals and switcher,

$P(Э_i)$ - reliability of prime and reserve canals of the chain,

P(П) - reliability of switcher,

k - number of reserve canals in the supply chain.

It can be noticed, that the number of canals (prime and reserve) in the supply chain is n = k + 1. The different variants of reserving of nodes of the supply chain and corresponding parameters are presented in the table 3.

Table 3. Variants of reserving of nodes of supply chain
Tabela 3. Warianty rezerwacji elementów łańcucha dostaw

Parameters		chain without reserving	chain with reserving	
number of canals (n)		1	2	3
number of reserve canals (k)		0	1	2
reliability of canals $P(Э_i)$		95,00%	95,00%	95,00%
reliability of chain without switcher		95,00%; u = 1,65	99,75%; u = 2,81	99,99%; u = 3,5
reliability of chain with switcher	P(П) = 95,00%	-	99,51%; u = 2,58	99,73%; u = 2,78
	P(П) = 90,00%	-	99,27%; u = 2,44	99,48%; u = 2,57
	P(П) = 50,00%	-	97,37%; u = 1,94	97,49%; u = 1,96

To this point, the variants discussed in this paper, were about so called hot reserving of canals. The independence of reserve canals on the prime canal is characteristic for such variants. In practice it means that prime and reserve canals function in a parallel way.

The situation becomes more complicated, when reserve canals used to replace the prime not functioning canal, are treated to be completely reliable. It occurs in the situation when they do not use their resources till the moment of the switching (this situation is called cold reserving). In second variant reserve canals scheduled to replace a prime canal can have lower reliability and therefore these reserve canals work with lower functionality than the prime one (so called lighter reserving).

Generally, in the situation when the prime canal ($Э_1$) is out of function, the system with cold reserving is changed to first reserve canal ($Э_2$), when this reserve canal is out of order, it is switched to second reserve canal ($Э_3$). Till the moment of its switching on, the reserve canal does not work and after this moment the changing of the canal is impossible. So the following variant is possible for the system (S_i):

S_1 – prime canal $Э_1$ works,

S_2 – reserve canal $Э_2$ works,

S_3 – reserve canal $Э_3$ works,

S_4 – no canal works.

The succession of switching in the system with the light reserving is similar to the previous one, only the number of available variants is higher because the level of the replacement ability of canals is taken into account in the process of switching.

Let $Э_1$ means the prime canal, $Э_2$, $Э_3$ and $Э_4$ – reserve canals. The prime canal submits the flow of refusals (λ_1). Till its switching on, each reserve canal submits the flow of refusals ($\lambda_2 \ll \lambda_1$), the intensity of which grows rapidly when the reserve canal is switched on ($\lambda`_2 \gg \lambda_2$; $\lambda`_2 \approx \lambda_1$). The process of switching the canals is similar to the process in the case of cold reserving. To describe the situation in the system (S_{iy}) the following conditions should be given:

$i = 1$ if prime canal works,

$i = 0$ if prime canal does not work,

y number of valid (ready to work) reserve canals.

The following variants of system are available:

S_{13} – prime canal works, all three reserve canals ready to be switched on,

S_{12} – prime canal works, two reserve canals ready to be switched on, one reserve canal out of order,

S_{11} – prime canal works, one reserve canal ready to be switched on, two reserve canals out of order,

S_{10} – prime canal works, all three reserve canals out of order,

S_{03}– prime canal does not work, one reserve canal switched on and works, two other reserve canals ready to be switched on,

S_{02}– prime canal does not work, one reserve canal switched on and works, one other reserve canal ready to be switched on, and other reserve one out of order,

S_{01}– prime canal does not work, one reserve canal switched on and works, two other reserve canals out of order,

S_{00}– all canals out of order.

The reliability of the system P(S) is equal to the sum of probabilities when the whole system works properly:

$$\mathbf{P(S) = P(S_{13}) + P(S_{12}) + P(S_{11}) + P(S_{10}) + P(S_{03}) + P(S_{02}) + P(S_{01})} \tag{10}$$

As a matter of fact the complexity of the process is not in a modeling of the type of reserving of the logistic system of supply chains but in the idenfication of available models in the given situation of a considered company, in the real environment in which the examined supply chain exits.

STUDIUM WYBRANYCH ZAGADNIEŃ NIEZAWODNOŚCI ŁAŃCUCHA DOSTAW W PRZEDSIĘBIORSTWIE HANDLOWYM

STRESZCZENIE. W pracy przedstawiono zagadnienia niezawodności działania łańcucha dostaw, jako całości w zależności od niezawodności funkcjonowania jego poszczególnych elementów. Poddano dyskusji problemy różnych wariantów przełączania kanałów (głównego i rezerwowych) w obrębie łańcucha dostaw.

Słowa kluczowe: łańcuch dostaw, rezerwowanie kanałów łańcucha dostaw, niezawodność poziomu obsługi, przełączanie kanałów łańcucha dostaw.

STUDIE DES AUGEWÄHLTEN PROBLEMEN DER LIEFERKETTE-ZUVERLÄSSIGKEIT IN HANDELSUNTERNEHMEN

ZUSAMMENFASSUNG. Die Arbeit präsentiert die Probleme der Zuverlässigkeit der Lieferkette als Ganzes in die Abhängigkeit von der Zuverlässigkeit ihrer Elemente. Verschiedene Varianten für die Reservierung von Kanälen (Haupt- und Ersatz-Kanälen) und Probleme verbunden mit ihrer Umstellung, wurden diskutiert.

Codewörter: Lieferkette, Reservierung von Kanälen, die Zuverlässigkeit des Service-Level, Schalten von Kanälen in der Lieferkette

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