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MODELLING THE SUPPLY CHAIN FOR THE COMPANY AND INDICATORS FOR ASSESSING THE EFFICIENCY OF ITS FUNCTIONING

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Abstract

The article presents selected issues concerning the modelling of the supply chain in the evaluation of the efficiency of tasks realization. In the process of determination, efficiency of the functioning of the supply chain it is necessary to determine the components of both the effects and expenditures in quantitative terms. It is assumed that the effect resulting from action taken depends on the problem under consideration, for example, the result may be the amount of the profits, savings resulting from implemented solutions or measurable improvement of the quality system, expressed e.g. percentage. While the outlay incurred for the implementation of the action is, in general, the expense of implementing this action. The article pointed out that the assessment of the efficiency can be used to decide on the choice of a decision of the many variants of solutions to the problem. In this respect, important are indicators of the efficiency both the technical, economic, quality, and organizational. In the article were also presented possible approaches to improve the efficiency of the supply chain. In the problems of assessing efficiency of functioning of systems with a complex functional structure such as supply, chains increasingly are applicable algorithms based on the so-called heuristics. Hence, in the article briefly have been characterized also chosen heuristic algorithms – genetic algorithms.

Keywords: *efficiency, supply chain efficiency indicator, supply chain efficiency*

1. Introduction

Actions aiming at improve the efficiency of realization of logistics services constitute a significant potential to increase the productivity of companies. The purchase of the product by the final customer makes a whole series of earlier events in the supply chain, resulting from orders placed to suppliers. Inventory replenishment at distributor warehouse in turn influences deliveries from a manufacturer, therefore, has an impact on the implementation of manufacturing processes and thereby supplies [5].

Rationalization of logistics processes in the company may have no less significance as the rationalization of production processes. In the literature, great importance is attributed to indicators of productivity, as many authors believe [3], [4], [11], that thanks to them it is possible to assess the reliability and flexibility of transport and the number of damaged cargo during transport. For the quantitative evaluation indicates among others such indicators as tonne-kilometres carried out, the number of items handled, the actual work time, transportation costs and the amount of transported cargo. In addition, the possibilities of growth in productivity of companies in the sphere of production are often limited or exhausted, while in the sphere of logistics and management these reserves, in general, are not used [4], [6].

Analysis of the efficiency of the supply chain should be based on gradation of its ratings from global to partial assessments concerning the general efficient use of resources of the supply chain and the individual components of the costs of implementation of logistics tasks. At the same time,

a set of basic characteristics expressing the efficiency of a particular supply chain is built upon the basis of relations between the variables that determine the efficiency of its functioning.

2. The research areas of supply chains modelling

The most important factor determining the successful management of the supply chain is the credibility and confidence in relations between the chain partners. That is why in development of each supply chain, boosting confidence among partners and the creation of efficient and reliable connections in execution of logistics tasks are key factors in achieving sustained success for companies [3], [11].

Research concerning modelling of logistics tasks in the supply chains in the evaluation of the efficiency of the functioning of these chains can be divided into three main areas of research concerning [10], [11]: technical and technological aspects of the supply chains, economic issues, including the costs of services and capital expenditures, quality, reliability and safety of realization of services.

Particular areas include number of issues arising from the specifics of the industry, various aspects and the scope of tasks performed both transport and logistics. As indicated in the literature [1], [6], the technical aspects include issues among others: rational use of means of transport, effective exploitation and their renewal, maximizing degree of utilization of means of transport, minimizing empty runs.

Among the technical and technological issues should be mentioned in particular: analysis and evaluation of effective organization of the supply chain to increase competitive advantage, the dependence of the efficiency of transport processes or logistics from infrastructure development, analysis and evaluation of the efficiency of cargo handling in logistics facilities, analysis and evaluation of the functioning of storage facilities due to the transformation resulting from the process of storage, performance test of means of transport and handling equipment used in the various supply chain cells and selection of methods for shaping efficient logistics systems.

In the case of economic and organizational issues, attention is paid to such problems as minimizing the cost of transition of streams of goods through the various cells of the supply chain, maximization of revenues and minimization of exploitation costs and minimization of expenditures for fixed assets. Of course, one of the determinants of effective implementation of logistics tasks is suitable potential of logistics systems in which these tasks are performed [18]. Among the main economic and organizational areas of modelling of the supply chain should be included: costs of implementation of transport tasks, unit costs of moving cargo in the supply chain and the structure of these costs, transition costs of cargo through logistics facilities, assessment of the economic efficiency of the implementation of tasks in transport and supply networks and efficiency in the use of low-emission means of transport and minimizing environmental costs resulting from the emission of harmful exhaust emissions.

The third group of research areas concerning the issues of quality, reliability and safety of services realization, in the market economy is a fundamental determinant of the functioning of enterprises. Issues of assess the quality of transport or logistics services can be seen in various aspects, although most often this analysis is carried out due to the time of delivery, security, and reliability of services realization [7]. For the assessment of the efficiency of the supply chain, most often-qualitative aspects relate to time minimization of implementation of tasks in the individual supply chain cells, ensuring timely deliveries, minimizing risk or completeness of supply.

For example, Neo et al. [15] analysed the quality of services provided by logistics operators and as key evaluation, indicators indicated the accuracy of the information, the accuracy of implementation of the picking process and timely realization of deliveries. The authors have analysed the absence of the technical performance of the warehouse and the impact of this lack on the mentioned criteria for evaluating the quality of work.

Summing up, it should be emphasized that the assessment of effectiveness of the functioning of supply chains results from the need for continued modernization (improvement) of existing supply chains. As the main reasons for the reorganization of existing systems, performing logistics tasks may be mentioned [4]. On the one hand changing customer requirements regarding the level and range of logistics services and on the other hand, changes in supply and sales market, e.g. due to migration of the population, expansion into new markets, the appearance of new sources of supply. Consequently, this leads to search for new and use of existing methods and tools for assessing efficiency of functioning of supply chains.

3. Types of indicators to assess the efficiency of supply chains

3.1. The assumptions for defining efficiency indicators

While creating, shaping, designing and reorganization of supply chains must be remembered that, their high efficiency also depends on the adaptation of their equipment (its potential) to tasks. Effective functioning of supply chains is one of the main objectives of supply chain management. To evaluate the quality and efficiency, there are indicators to determine the degree of adaptability of equipment of supply chain to perform the tasks. Evaluation indicators can be either [4], [11]: structural, when they are referred to the structure of the flows of material goods, productivity, when they are referred to the tasks performed in the system, economy, when they are referred to the cost, quality, when they are referred to the level of customer service.

In determining, the indicators to assess the efficiency should be guided by [11]:

a) adequacy, consisting of a good description of dependency and low sensitivity to changes in external factors,
b) ensuring uniformity and comparability in time and space of individual aspects,
c) capacity, according to which the indicator should contain relevant attributes of evaluation of the supply chain,
d) adaptability, assessed in terms of the interpretation of the substantive content,
e) economic dimension, which consists in determining the relationship between the effects of the use of the indicator and the cost of its calculation or obtaining.

The measurement of efficiency can have many applications, among which can be distinguished among others: the selection of means of transport to the tasks, the selection of applied technologies, increasing the efficiency of logistics processes, reducing time of implementation of tasks, reducing costs e.g. reduction in fuel consumption. To properly assess the scope of changes in the functioning of the supply chain must be analysed, different options for the implementation of logistic tasks in that chain taking into account the different variants of the configuration of a given supply chain. As the criteria for evaluating the effectiveness and efficiency of logistics processes can be used: the criterion of time of flow of materials and information, the criterion of the level of service quality, cost criterion and the criterion of operability of action.

3.2. Technical indicators for assessing efficiency of the supply chain

Among the technical criteria for assessing effectiveness of the functioning of the supply chain can be identified criteria for assessing the degree of utilization of resources for the implementation of logistics services, including transport services. Among technical indicators can be distinguished among others [11]: the degree of effective work of a given equipment, means of transport, etc., degree of utilization of time of having technical resources, i.e. means of transport, loading facilities and storage facilities, the percentage share of the means of transport (equipment) in transport work performance or workload due to the involved equipment, vehicles, etc., the degree of payload or capacity utilization of means of transport that can be counted in terms of static or dynamic, the average mileage of means of transport, number of: means of transport, working hours

of means of transport and the degree of filling storage areas of warehouses or daily working time of storage facilities, etc.,

One of the basic technical criteria is the utilization indicator of fit time of technical resources to perform logistics tasks. This indicator represents quotient of working time and the total fit time. For the purpose of optimizing the technical potential of the supply chain this indicator can be determined for different types of vehicles, as well as for individual elements of the logistics chain, which have those vehicles. In such an approach is obtained detailed information about matching the technical resources of supply chain elements for the implementation of logistics tasks in the period considered. More on this topic can be found in the monograph [11].

For means of transport from the technical and technological point of view, should aim at maximizing utilization rates of their capacity and payload or mileage of used means of transport. As indicated in the works [19] e.g. in the assessment of the transport system, beyond utilization rate of the time of maintaining means of transport, also applies utilization rates of their payload and capacity and also utilization rates of their mileage [19].

Indicator of payload utilization of means of transport can be counted in terms of static or dynamic. However, for practical reasons in the supply chains in which there are implemented complex transport cycles, practical importance has only the dynamic indicator of payload utilization. According to the indications adopted in the model, assuming that are known: volume of material goods of *h*-th type transported by *st*-th type of mean of transport used in *ld*-th supply chain (in tonnes) $Q(st,ld,h)$, payload of mean of external transport of *st*-th type used in *ld*-th supply chain (in tonnes) $Ql(st,ld)$, length of connection between the cells (v, v') in the *ld*-th supply chain $\ell(ld,(v,v'))$, speeds of the mean of external transport of *st*-th type between cells (v, v') of the *ld*-supply chain $vs(st,ld,(v,v'))$ and assuming, that there are decision variables namely: $y1(ld,st,(v,v'),v'',a,b,e,h)$ time commitment of external transport of *st*-this type, which are at the disposal of v''-th element of the supply chain, in the implementation of transport tasks in *ld*-th supply chain on a connection of (v, v') for the transport of material goods of *h*-th type in relation (a, b) of the route the *e*; $zl1(ld,st,(v,v'),v'')$ the number of loaded rides of means of transport of *st*-th type, which are at the disposal of v''-th element of the supply chain on the connection (v, v') of *ld*-the supply chain and $zp1(ld,st,(v,v'),v'')$ the number of rides of means of transport of *st*-th type, which are at the disposal of v'' -th element of the supply chain without load on the connection (v,v') of *ld*-th supply chain, analytical record of this indicator has the form [11]:

$$\forall ld \in \boldsymbol{LD},\ \forall st \in \boldsymbol{STZ}(ld),$$

$$WQL(st,ld) = \sum_{a\in \boldsymbol{A}(ld)} \sum_{b\in \boldsymbol{B}(ld)} \sum_{e\in \boldsymbol{E}(ld,a,b)} \sum_{(v,v')\in \boldsymbol{EL}(ld,a,b,e)} \Big[vs\big(st,ld,(v,v')\big) \cdot \sum_{h\in \boldsymbol{H}(ld)} \sum_{v''\in \boldsymbol{V}(ld)} Q\big(st,ld,h\big)\cdot y1\big(ld,st,(v,v'),v'',a,b,e,h\big)\Big] \cdot \Bigg[\sum_{(v,v')\in \boldsymbol{L}(ld)} \sum_{v''\in \boldsymbol{V}(ld)} \Big[zl1\big(ld,st,(v,v'),v''\big)+zp1\big(ld,st,(v,v'),v''\big)\Big]\cdot \ell\big(ld,(v,v')\big)\cdot Ql\big(st,ld\big)\Bigg]^{-1} \cdot \tag{1}$$

Indicator of payload utilization is important for participants of the supply chain, since it indicates adjustment of external means of transport to material goods handled in the supply chain and a good use of means of transport in the supply chain.

Cargoes, which are the subject of transport, may have different characteristics resulting from the individual characteristics of the cargo. Similarly, as the indicator of payload utilization of means of transport is calculated **indicator of capacity utilization of means of transport**. This indicator is significant, because in many cases we have to deal with lightweight loads, but with

relatively large volume. For the purpose of formulating the indicators, assuming that are known capacity of mean of external transport of *st*-th type used in *ld*-th supply chain (in m^3) $Qp(st,ld)$, spatial rate for *h*-th type of material goods in *ld*-th supply chain $\gamma l(ld,h)$, the following designations has been adopted [11]:

$$\forall ld \in \boldsymbol{LD},\ \forall st \in \boldsymbol{STZ}(ld),$$
$$WQP(st,ld) = \sum_{a\in\boldsymbol{A}(ld)}\sum_{b\in\boldsymbol{B}(ld)}\sum_{e\in\boldsymbol{E}(ld,a,b)}\sum_{(v,v')\in\boldsymbol{EL}(ld,a,b,e)}\Big[vs\big(st,ld,(v,v')\big)\cdot$$
$$\cdot\sum_{h\in\boldsymbol{H}(ld)}\sum_{v''\in\boldsymbol{V}(ld)}Q(st,ld,h)\cdot y1\big(ld,st,(v,v'),v'',a,b,e,h\big)\gamma l(ld,h)\Big]\cdot \tag{2}$$
$$\cdot\left[\sum_{(v,v')\in\boldsymbol{L}(ld)}\sum_{v''\in\boldsymbol{V}(ld)}\Big[zl1\big(ld,st,(v,v'),v''\big)+zp1\big(ld,st,(v,v'),v''\big)\Big]\cdot\ell\big(ld,(v,v')\big)\cdot Qp(st,ld)\right]^{-1}.$$

3.3. Economic indicators of supply chain efficiency

An important group of indicators to assess the efficiency of the functioning of each system are economic indicators. Among the economic indicators can be distinguished indicators that are used to determine the value of carried transport work determining the productivity of means of transport and other resources, or the configuration of the supply chain. In general, economic indicators are given as measures of absolute or relative. The main economic indicators in the evaluation of the functioning of the supply chain can be distinguished among others:

a) absolute measures: the total cost of implementation of tasks, services, etc., annual operating costs, the total cost of transport, the value of means of transport, cost of storage,
b) relative: the share of transport costs in total costs, transport costs per unit of freight, maintenance costs of means of transport for a month, a year, the cost of the transition of unit of material through the warehouse facility etc..

Most fully, evaluation of efficiency of functioning of supply chain in terms of economic reflects the **indicator of the total cost of implementation of logistics tasks**. Assuming that are known cost of using by means of external transport of st-th type the road connection between the cells (*v, v'*) of *ld*-th supply chain $kd(st,ld,(v,v'))$, incurred per unit of working time operating cost of mean of external transport of *st*-th type used by the *v*-th element of *ld*-th supply chain $kh(ld,v,st)$, incurred on the distance unit operating cost of mean of external transport of *st*-th type used by the *v*-th element of *ld*-th supply chain $kl(ld,v,st)$, related to the labour time unit operating cost of mean of internal transport of *st*-th type by the *v*-th element of *ld*-th supply chain $kw(ld,v,st)$ and the time of commitment of means of internal transport of *st*-th type in the implementation of logistic tasks in the *v*-of cell of *ld*-th supply chain is marked as $y2(ld,st,v,h)$, the value of such an indicator can be determined by dependence [11]:

$$\forall ld \in \boldsymbol{LD},\qquad WKC\big(ld\big) = K\big(ld\big)\cdot x\big(ld\big)+$$
$$+\sum_{st\in\boldsymbol{STZ}(ld)}\sum_{(v,v')\in\boldsymbol{LF}(ld)}\sum_{v''\in\boldsymbol{V}(ld)}\Big[\big(zl1\big(ld,st,(v,v'),v''\big)+zp1\big(ld,st,(v,v'),v''\big)\big)\cdot\big(kd\big(st,ld,(v,v')\big)+$$
$$+\ell\big(ld,(v,v')\big)\cdot kl\big(ld,v'',st\big)+\frac{\ell\big(ld,(v,v')\big)}{vs\big(st,ld,(v,v')\big)}\cdot kh\big(ld,v'',st\big)\Big)\Big]+$$
$$+\sum_{v\in\boldsymbol{V}(ld)}\sum_{st\in\boldsymbol{STWV}(v,ld)}\left[kw(ld,v,st)\cdot\sum_{h\in\boldsymbol{H}(ld)}y2\big(ld,st,v,h\big)\right]. \tag{4}$$

Of course, efficient supply chain is the one that provides the same effects, i.e. implementation of the agreed logistics tasks at lower expenditures. Thus, the total cost indicator should be minimized.

3.4. Qualitative and social indicators of supply chain efficiency

A very important group of indicators to assess efficiency of functioning of supply chain, especially in the era of market economy and sustainable development of the various systems are qualitative and social indicators. Among the qualitative indicators should be mentioned, among others [11]: loss of time of delivery, duration of logistics tasks, the reliability of implementation of logistics tasks, the risk of lack of delivery measured by the probability of failure of delivery, unit duration of logistic services divided into individual supply chain cells and number of failures of means of transport.

The functioning of the supply chain is determined by actions of all its elements. All the elements (cells) of the chain must fulfil their separate performance expectations. This means that the elements in the chain may be considered as a system reliability of the entire series. Unreliability of one or more elements reflected in unreliability of the entire supply chain. Conversely reliability of individual elements of the supply chain, makes it can meet the performance expectations in all markets in their environment. Thus, for the entire supply chain, assuming that it has a serial structure, and are known reliability index of the connection between the cells (v, v') in the ld-th supply chain $nl(ld,(v,v'))$, reliability index of the v-th cell of the ld-th supply chain $nv(ld,v)$, and defines a binary decision variable that takes the value 1 when for the implementation of the flow of material goods has been selected ld-th supply chain $x(ld)$, its reliability in the structural sense can be determined as follows [11]:

$$\forall ld \in \boldsymbol{LD}, \quad WNS(ld) = x(ld) \cdot \prod_{(v,v') \in \boldsymbol{L}(ld)} nl(ld,(v,v')) \cdot \prod_{v \in \boldsymbol{V}(ld)} nv(ld,v)). \tag{5}$$

The reliability of the supply chain can also be seen against the transportation and storage sequences implemented in the supply chain or from the point of view of realized transport tasks. In this aspect must also be considered indicators of reliability of means of transport and loading equipment and categories of human labour. One of the most important indicators for assessing implementation of logistics tasks in the supply chain from the point of view of reliability are weighted losses of working time of vehicles on the routes. These losses arise due to conflict situations occurring during transport [11].

4. Practical application of indicators for assessing the efficiency of supply chains

The diagnosis of major decision-making problems occurring in the supply chain and propose appropriate decision-making procedures leading to optimal decision should contribute to the rationalization of logistic tasks and consequently to improve the functioning of the entire chain. Efficient supply chain management is possible when [3], [11]:

c) supply chain is perceived as a whole organization,
d) delivery is a common objective of all participants in the chain, and strategic decisions regarding supply have an impact on costs and market share,
e) problems are solved in a comprehensive manner,
f) it takes into account the economically viable reserves, reducing them to the most necessary size,
g) integration chain participants are based on the use of modern information technology and widely understood cooperation.

To study decision-making processes in supply chains use various tools, e.g. optimization methods, mathematical programming, simulation methods, methods of stochastic dynamic

programming and the theory of mass service. When raising the efficiency of the supply chain is basically used two approaches: quantitative formal and informal quality that are, in general, a set of rules for the assessment of the operation from the experience of researchers (Fig. 1).

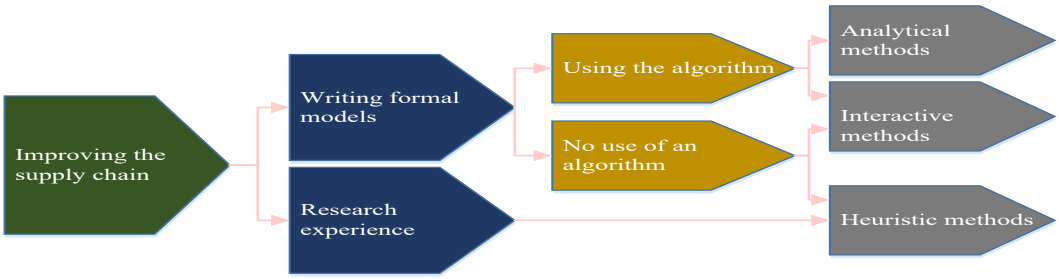

Fig. 1. Possible approaches to improve the efficiency of the supply chain [11]

When formalized approach, modelling decision situation in mathematical language is a record of the boundary conditions and evaluation criteria in a formal way of using the apparatus of mathematical modelling. The boundary conditions are described by appropriate equations or inequalities determine the set of feasible solutions. In these equations, there are certain fixed size data and treated as quantities that should be set (decision variables). In general, there are also the conditions regarding for example the nature or type of variable (e.g. binarity etc.).

In the problems of assessing the effectiveness of the systems of complex functional structure such as supply, chains increasingly apply algorithms based on the so-called heuristics [8], [9]. Heuristic algorithms can be classified in many ways. One way of classification is the division of heuristics loan prospector and heuristics population, that is, respectively, with one embodiment of the current, and with a number of current solutions. Another important division concerns the division on heuristics, deterministic and random, that is, depending on the use of pseudo-random number generator to determine or improve solutions. For metaheuristics include, among others local search, greedy algorithms, ant or genetic algorithms [12], [9].

A different class of algorithms are the genetic algorithms that take into account the observations of natural biological mechanisms of evolution are subject i.e. on the principles of natural selection and heredity. They are characterized by high-speed operation even with a large number of decision variables [16], [13]. To improve and analysis of the processes of cargo flows can also be used models derived from the theory of mass service [6], [18], [14]. However, due to the complexity of logistics systems, these models have limited applicability.

In the literature, one can find many approaches to the problem of improving the logistics processes based on simulation tests (e.g. [2], [17]). In the study of processes occurring in the system with simulation method, there are three processes running parallel at the time: modelling and simulation of examined process, experimenting – observation of the values of determined sizes of the simulated process, inference about values of characteristics we are interested in. Conducting simulation experiments, the results of their observation provides data for statistical inference about the values of characteristics that we are interested in.

5. Summary

A holistic approach to the problem is to include not only the technical and technological considerations of the functioning of supply chains in terms of the organization of logistics service of companies but also the limitations and criteria relevant to particular interests of different participants in the decision making process. A very important issue in supply chain modelling is the selection of methods and tools for assessment of the supply chain including elements relevant to assess the efficiency of realized tasks.

Quite important in the assessment of the efficiency of the supply chain is the analysis of the factors influencing the risk and reliability of the effective functioning of supply chain in the

context of the realized tasks. With this important are properly identified boundary conditions taking into account technical, economic, technological and quality limitations.

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