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THE ASSESSMENT OF SUPPLY CHAIN EFFECTIVENESS

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Abstract:

This paper presents the problem of the assessment of the supply chains in the context of their effectiveness. In this paper the concepts of a supply chain and effectiveness were characterized. The supply chain is a structure of entities which are connected with each other by the use of material and financial flows and functional, structural, technological, economic and information dependencies. Entities such as: suppliers, final recipients, entrepreneurs, warehouse facilities, supply centers, logistics operators, carriers, etc. perform material flows from suppliers to recipients. The concept of efficiency, in general terms, refers to economic rationality and means the relationship between the achieved or expected effects and the expenditures incurred. Additionally, indicators of measuring the effectiveness of the supply chain were described. In order to assess the effectiveness of the supply chain the decision model was developed.
Optimization is crucial in decision support systems. The development of an appropriate model for mapping the behavior of a real object or system and formulating an optimization task is a necessary activity in effective management. This is even more important if we want to be competitive. Along with the development of decision support systems, as well as the development of systems for data acquisition on the system functioning, which feed optimization models in ever more detailed form, complex decision models are created that take into account many optimization criteria and require a large amount of data. It allows, however, to ensure the sustainable development of the system and simultaneous implementation of its basic tasks.
The main aim of this paper is to present the stages and assumptions of the model for assessing the effectiveness of the supply chain. The main data input, constraints of the model, the criteria functions were determined.

Key words:
decision- making model, supply chains, effectiveness

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1. Introduction

The supply chain can be defined as a group of companies such as production or distribution companies, etc., which carry out activities necessary to satisfy the demand for specific products in a relationship between the supplier – the producer or the producer - the recipient (Daganzo, 1996; Jacyna-Gołda, 2012, 2015;Szczepaśnki et al., 2017). The supply chain is a structure of entities which are connected with each other by the use of material and financial flows and functional, structural, technological, economic and information dependencies. Entities such as: suppliers, final recipients, entrepreneurs, warehouse facilities, supply centers, logistics operators, carriers, etc. perform material flows from suppliers to recipients (Wasiak & Jacyna-Gołda, 2016; Kłodawski et al., 2017). Entities operating in the supply chain through links with suppliers and the recipients are involved in various processes and activities that create value in the form of products and services delivered to final consumers. Each of the companies integrated in the supply chain is responsible for a part of the realized flows between entities (Brzeziński, 2006; Cecere, 2012; Witkowski, 2002). All participants in the supply chain are connected with each other by the flows of products, information, money, etc.

The flow of information takes place in both directions, the direction of product flow is the direction from the source of raw materials, by the producer of products, to the final recipient - the consumer, while the financial flows are carried out in the opposite direction to the flow of products (Coyle et al., 2002; Izdebski et al., 2017).

The supply chain can be treated as an existing object through synergic cooperation of individual elements, hence it can be written as an ordered three (Cempel, 2008):

$$\boldsymbol{LDS} = \boldsymbol{S}(\boldsymbol{A}, \boldsymbol{E}, \boldsymbol{R}) \qquad (1)$$

where: $\boldsymbol{LDS}$ – systemic approach to the supply chain, $\boldsymbol{A}$ – a set of supply chain elements (entities operating in the supply chain), $\boldsymbol{A} = \{A_1, A_2, \ldots A_m\}$, $\boldsymbol{E}$ – set of attributes (properties) of the supply chain elements (characteristics, properties of individual entities), $\boldsymbol{E} = \{E_1, E_2, \ldots, E_n\}$, $\boldsymbol{R}$ – a set of relations between elements and attributes of the supply chain $\boldsymbol{R} = \{R_1, R_2, \ldots, R_z\}$

The wide spectrum of interrelated relations between entities make that supply chains more and more complex, and thus more sensitive to various types of disturbances and threats from outside. The functioning of the supply chain takes place in a certain environment. The supply chain draws from it, on the one hand, various types of resources, applications for the provision of services, etc., and on the other hand, the environment assesses the supply chain due to the effectiveness of the services provided.

Schematically functioning of the supply chain in an environment in which disturbances and threats occur are presented on Fig. 1.

The purpose of the supply chain is to implement logistic tasks, which include: transport services and other logistics services in a different perspective. A transport service that is a production effect of transport is determined as the performance of any transport activity for the client (Wasiak & Jacyna-Gołda, 2016). In order to realize the reported demand for services in the supply chain at the required level, the processes performed in the supply chain must be effective. The concept of efficiency, in general terms, refers to economic rationality and means the relationship between the achieved or expected effects and the expenditures incurred (Powierża, 1997; Sienkiewicz, 1987, 1994).

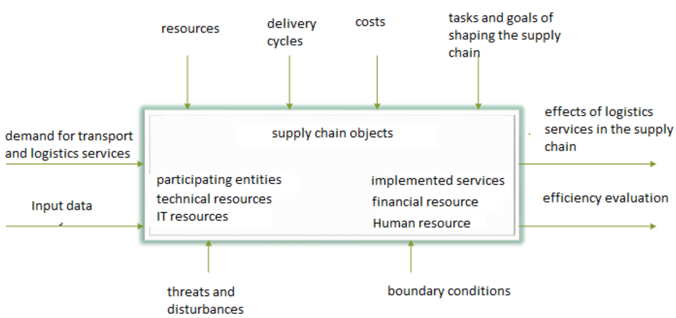

Fig. 1 The impact of the environment on the supply chain *[11]*

In order to achieve greater efficiency of a given system, one should firstly increase the effects for fixed expenses (the so-called cost principle of rational management), or while maintaining a given performance, one should increase savings in the system, e.g. by minimizing the use of resources (the so-called efficiency principle). The term of efficiency is characterized by the use of resources to realize a set number of tasks by users of the tested system. Efficiency is treated as a rational management of technical, financial, information and human resources in pursuit of the assumed goal, i.e. the implementation of logistic tasks at an acceptable level of quality. As a result, the assessment of the efficiency of the supply chain operation comes down to the assessment of parameters defining the level or scope of the chain operation (Jacyna-Gołda et al., 2017b; Wasiak et al., 2017).

Processes implemented in supply chains are connected with the implementation of a specific logistic task. Logistic tasks are understood as all transport services and other logistic services performed while moving material goods from suppliers to recipients and their storage processes. The transport and storage of material goods and thus the implementation of services in the supply chain, includes many activities that are often identified with transport and logistics processes.

The main aim of this paper is to present the problem of the assessment of the supply chains in the context of their effectiveness. Additionally, indicators of measuring the effectiveness of the supply chain were described.

2. Effectiveness of functioning the supply chain

Supply chain efficiency expresses an evaluation of its performance, and thus is a measure of the efficacy of its specific action. Assuming that a set of ***LD*** numbers for supply chains is defined as:

$$\boldsymbol{LD} = \{ld: ld = 1, 2, \ldots, LD\} \qquad (2)$$

where:
ld – supply chain number,
LD – number of analyzed supply chains,

The efficiency of the supply chain operation in the period τ can be written as a quotient of useful effects $Z(\tau, \mathrm{ld})$ and directly incurred during this period of expenditures $N(\tau, \mathrm{ld})$, i.e.:

$$\forall \mathrm{ld} \in \mathrm{LD} \;\; \Xi(\tau, \mathrm{ld}) = Z(\tau, \mathrm{ld}) / N(\tau, \mathrm{ld}) \qquad (3)$$

where:
$Z(\tau, \mathrm{ld})$ – the value of the effects obtained up to τ for the *ld*-th supply chain from the beginning of its operation,
$N(\tau, \mathrm{ld})$ – the value of expenditure incurred up to τ for the *ld*-th supply chain from the beginning of its operation.

In the time interval $(0, \tau)$ the function $N(\tau, \mathrm{ld})$ is an increasing function of time. Assuming that expenditures are a part of the resource used for the functioning of the supply chain, it is assumed that in each of the elementary time intervals $\Delta\tau$, $\Delta\tau \to 0$ their value is not less than zero. The value of the function $N(\tau, \mathrm{ld})$ at the moment τ(N(τ',ld) depending on whether the function $\eta(\tau, ld)$ is continuous or discrete, can be determined as:

$$\forall \tau' \in \mathrm{T} \;\; \forall \mathrm{ld} \in \mathrm{LD} \;\; N(\tau', \mathrm{ld}) = \int_0^{\tau'} \eta(\tau, \mathrm{ld}) \, d\tau \qquad (4)$$

$$\forall \tau' \in \mathrm{T} \;\; \forall \mathrm{ld} \in \mathrm{LD} \;\; N(\tau', \mathrm{ld}) = \sum_{k=1}^{T} \eta(\tau_k, \mathrm{ld}) \qquad (5)$$

where $\eta(\tau_k, ld)$ means the value of expenditures incurred for the *ld*-th supply chain in the time interval τ_k, where the interval with the number τ_T ends at the moment τ'.

However, the function $Z(\tau, \mathrm{ld})$ of obtained effects, in the analyzed time interval, can take both positive and negative values. Similarly to the expenditure function, the value of the function $Z(\tau, \mathrm{ld})$ at the moment τ' can be determined on the basis of the values of elementary functions $\mu(\tau, ld)$ depending on whether they are continuous or discrete functions:

$$\forall \tau' \in T \;\; \forall \mathrm{ld} \in LD \;\; Z(\tau', \mathrm{ld}) = \int_0^{\tau'} \mu(\tau, \mathrm{ld}) \, d\tau \qquad (6)$$

$$\forall \tau' \in \mathrm{T} \;\; \forall \mathrm{ld} \in \mathrm{LD} \;\; Z(\tau', \mathrm{ld}) = \sum_{k=1}^{T} \mu(\tau_k, \mathrm{ld}) \qquad (7)$$

To assess the quality and efficiency of the supply chain the following indicators can distinguish:

- technical indicators, e.g.: the degree of effective operation of a given device, means of transport, etc., the degree of using the load capacity of means of transport, the share of a given means of transport (equipment) in the performed transport

work, the degree of use of internal transport devices, e.g. in storage facilities, number of means of transport, number of working hours of means of transport, mileage of vehicles, daily work time of storage facilities, efficiency of the reloading systems, maximizing the use of vehicles,
- economic indicators, e.g.: the cost of the service provided, annual operating costs, transport costs, depreciation costs of means of transport, personnel costs of the transport department, the cost of storage,
- qualitative indicators, e.g.: loss of delivery time, time of logistics tasks, reliability of logistics tasks, the risk of not realizing deliveries, number of transport equipment failures,
- environmental indicators , e.g.: minimizing the emission of harmful exhaust gases, minimizing congestion in the supply chain.

The following criteria can be used as criteria for assessing the efficiency and effectiveness of logistic processes: the criterion of time of material and information flow, the criterion of the level of service quality, the criterion of costs and the criterion of operational efficiency.

Striving to improve the efficiency of supply chains requires the use of optimization methods based on mathematical models. The use of mathematical methods when looking for optimal solutions usually allows for significant savings, i.e. increased efficiency of the tested system. Finding the best solution to a given problem is possible using optimization methods in an algorithmic way, analytically or numerically, they allow you to search for optimal solutions without having to analyze all possible variants.

3. The decision model for assessing the effectiveness of the supply chain

3.1. The main assumption

The process of constructing mathematical models, including the decision supply chain model, is the selection of an acceptable substitute, taking into account the mathematical-logical relations that will enable experimenting with them taking into account different boundary conditions. The stages of building the decision model for assessing the effectiveness of the supply chain, Fig. 2.:

1) Identification - it consists in in generating from the existing fragment of reality all of its elements that are necessary to build a model. This stage concerns the development of assumptions and determining the elements of the model.
2) Development of the conceptual model - it consists in the transformation of a set of assumptions, obtained as a result of identification, into the form of a conceptual model. This stage is aimed at establishing the relationship between the identified elements and establishing a system of features necessary for its description.
3) Formalization of the model - involves the construction of analytical structures. This stage basically boils down to the construction of a mathematical model, which allows the formulation of optimization tasks, and then through the use of appropriate algorithms, the creation of computer applications as a tool to support decision making.
4) Algorithm - it consists in actions aimed at transforming the formal model into the structure of the so-called object condition generator.
5) Computer implementation - it is based on converting the algorithmic model into an IT form. The procedure and the final form of the model depend on the class of the object, the system, the purpose of modeling, existing possibilities in the scope of access to software and hardware IT resources.
6) Model verification - it involves assessing the model's adaptation to the solved problem.
7) Adaptation- implementation of the model consists in carrying out suitably programmed experiments for different decision situations, including various functional and system configurations as well as various technological parameters, etc. Adaptation allows to determine the scope, conditions of applicability and the possibility of using the model.

A comprehensive analysis of the supply chain assessment should therefore cover both technical aspects (inter alia, line transport infrastructure and point, availability of transport), economic, organizational or quality but also aspects of security, reliability of supply, environmental and social (Wasiak & Jacyna-Gołda, 2016; Jacyna et al., 2017; Jacyna-Gołda & Lewczuk, 2017). In each from these areas, there are decision problems covering a wide range of factors that should be considered when choosing how to implement logistics processes in the supply chain. The basic decisions regarding the assessment of the efficiency of the supply chain operation are mainly related to Michlowicz, 2015):
- efficient use of supply chain resources in both cost and technical,
- minimizing the total cost of material flow while maintaining the required level of service,

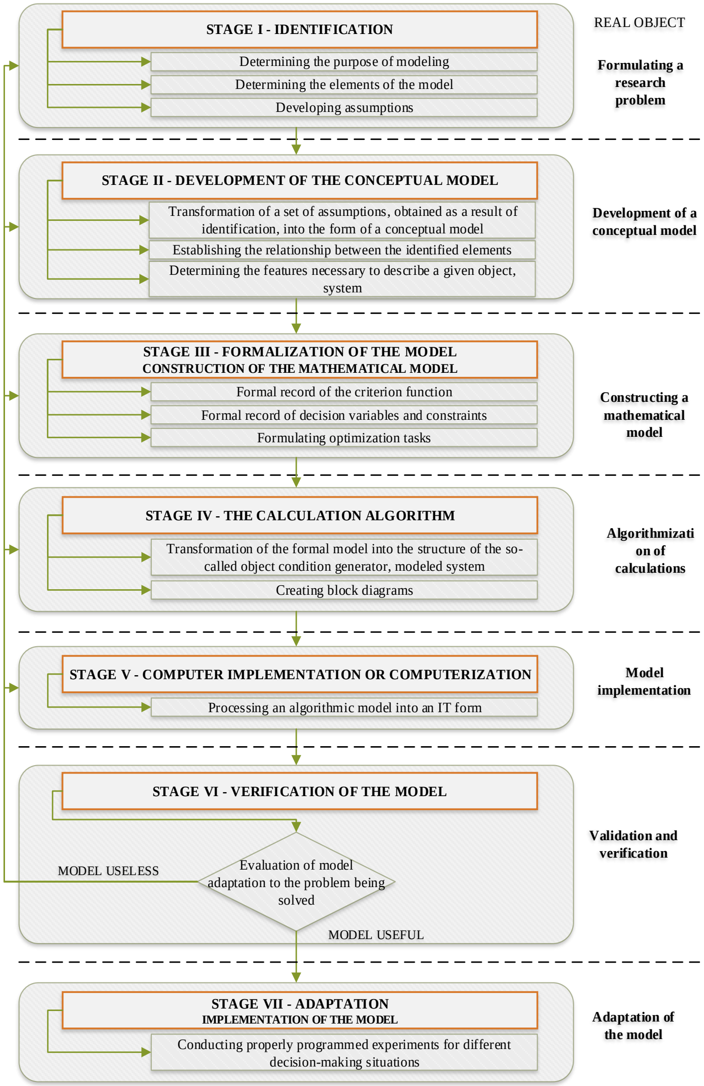

Fig. 2. The stages of building the decision model for assessing the effectiveness of the supply chain

- minimizing the time of order fulfillment at the assumed flow costs level,
- efficient use of the load capacity of means of transport while minimizing time
and delivery costs,
- analysis and evaluation of the effectiveness of alternative solutions for technical and organizational equipment of the supply chain (potential) and its individual links,
- effective selection of supply chain potential for submitted tasks (eg means of transport in the sphere of supply and distribution),
- ensuring the highest possible reliability, frequency and flexibility of deliveries with the assumed level of flow costs,
- effective planning of changes in the configuration of the supply chain (searching for locations for warehouse facilities, logistics centers, etc.),

- optimization of stock levels along the supply chain with flexible adaptation to the preferences of individual market segments in the scope of delivery service.

Various tools are used to analyze decision processes in supply chains, e.g. optimization methods, mathematical programming, simulation methods, stochastic methods, dynamic programming or mass service theory. In real decision-making problems, the decision maker often has to evaluate variant solutions not because of one but from the point of view of different criteria (Roy, 1990; Jacyna-Gołda et al., 2017a; Jacyna et al., 2014).

3.2. . The data input

For physical implementation of logistics processes in the supply chain, such elements are necessary as:

- users, i.e. clients (sender, recipients, enterprises, logistic facilities) and logistics operators,
- transport infrastructure, including road, railway, water and cargo handling points, along with specific characteristics,
- external transport means and handling devices as well as storage devices with their characteristics,
- human resources and their characteristics,
- organizational system ensuring proper use of supply chain equipment,
- available technologies for the implementation of logistics tasks
- information system.

The aim of the supply chain is optimal - in the sense of the adopted criteria - to provide logistic services, reported by enterprises or other serviced entities. Therefore, for their implementation it is necessary that a given supply chain possesses a defined structure, determined parameters of particular elements of the structure, a set volume of logistic services (tasks), fixed equipment, organization and specific performance indicators to assess the correct functioning of the supply chain.

Assuming that the mapping of the structure of the determined (*ld*-th) supply chain is marked with the symbol $\boldsymbol{G}$ (*ld*), the set of transport and storage used in this supply chain - the symbol $\boldsymbol{ST}$ (*ld*), the set of human resources used in it - the symbol $\boldsymbol{KL}$ (*ld*) , a set of characteristics defined on the elements of the structure of this supply chain and on transport and human resources involved in it - $\boldsymbol{F}$ (*ld*) symbol, volume of logistics services demand - ***ULD*** symbol, supply chain organization - $\boldsymbol{O}$ (ld) symbol, set of indicators of effectiveness measurement operation of supply chains - ***WLD*** symbol, the model of supply chain efficiency assessment (***MOELD***) can be written as an ordered structure, the form:

$$\boldsymbol{MOELD} = \langle \boldsymbol{G}(ld), \boldsymbol{ST}(ld), \boldsymbol{KL}(ld), \boldsymbol{F}(ld), \mathbf{ULD}, \boldsymbol{O}(ld), \boldsymbol{WLD}: ld \in \boldsymbol{LD} \rangle$$

The analysis of the functioning of the actual supply chains shows that the individual links of the *ld*-th supply chain can perform various functions, e.g. they can be manufacturing companies reporting the demand for logistics services in the scope of production services (e.g. supply, distribution), logistic objects (e.g. warehouses , logistics or distribution centers) processing of loads, raw materials, etc., suppliers of raw materials for production, operators servicing enterprises (implementing logistic services). In order to define the decision model for assessing the effectiveness of the supply chain the following point elements must be determined:

- set of company numbers requesting logistics services,
- set of numbers of operators performing logistic services in supply chains,
- set of logistic object numbers (warehouses, logistics centers, distribution centers, etc.) which constitute cargo processing areas in supply chains,
- set of the numbers of suppliers or recipients constituting place of sending raw materials in the sphere of supply or the place of collection of finished products in the sphere of distribution.

Additionally, in order to define the decision model for assessing the effectiveness of the supply chain, the following elements must be determined:

- a set of types of transport means and storage devices that can be used to perform logistic tasks in the logistics network,
- the set of all types of human work categories necessary to perform tasks in the logistics network,
- the length of the link between point elements,
- a set of types of material goods serviced in the *ld*-th supply chain,
- permissible time of logistic implementation in connection with the displacement of material goods in the *ld*-th chain,
- the number of vehicles of each type,
- operating costs of external transport means,
- capacity of the external transport means.

1.2 Decision variables, constraints

The decision types of seven types need to be defined:

- variables regarding the selection of the supply chain: for the purpose of defining a variable concerning the selection of the supply chain to realize the assumed flows of material goods, it was assumed that on the ***LD*** set of supply chain numbers, *x* is mapped carrying out elements of this set into elements of the set {0, 1}, i.e.:

$$x: \boldsymbol{LD} \longrightarrow \{0, 1\}$$

however, if *x* (*ld*) = 1, the *ld*-th supply chain was selected to realize the flow of cargo, otherwise *x* (*ld*) = 0.

- variables related to the selection of technological routes for individual relations of moving goods distinguished in a given supply chain: it was assumed that on the Cartesian product of set: {ld}, ***A*** (*ld*) source numbers, ***B*** (*ld*) exit numbers, $\mathbf{E}(ld,a,b)$ route numbers and $\mathbf{H}(ld)$ numbers of types of material goods serviced supply chains, x1 carries elements of these products into elements of the set {0, 1}, i.e.:

$$\forall\ ld \in \boldsymbol{LD}\ \forall\ a \in \boldsymbol{A}(ld)\ \forall\ b \in \boldsymbol{B}(ld)\ x1(ld,a,b): \boldsymbol{E}(ld,a,b) \times \boldsymbol{H}(ld) \longrightarrow \{0, 1\},$$

however, if *x*1(*ld*, *a*, *b*, *e*, *h*) = 1 then the e-th route was chosen for the realization of flows of material goods of the *h*-th type in the *ld* -th supply chain in relation (*a*, *b*), otherwise *x*1(*ld*, *a*, *b*, *e*, *h*) = 0.

-variables regarding the time of engagement of technical means and human resources were defined by introducing mapping *y*1, *y*2, *y*3, *y*4 and *y*5, which carry elements of Cartesian products of the sets into elements of a set of non-negative real numbers, as follows (, ***V***(*ld*) - a set of link numbers appearing in the *ld*-th supply chain, ***L***(*ld*) - a set of all relations occurring between the links of the *ld*-th supply chain, ***STZ***(*ld*) - a set of types of transport used in the *ld*-th supply chain, ***STW***(*ld*) - a set of types of internal transport used in the *ld*-th supply chain,):

$$\forall\ ld \in \boldsymbol{LD}\ \forall\ a \in \boldsymbol{A}(ld)\ \forall\ b \in \boldsymbol{B}(ld)$$
$$y1: \boldsymbol{STZ}(ld) \times \boldsymbol{L}(ld) \times \boldsymbol{V}(ld) \times \boldsymbol{E}(ld,a,b) \times \boldsymbol{H}(ld) \longrightarrow \Re^{+} \cup \{0\},$$

*y*1(*ld*, *st*, (*v*, *v*'), *v*'', *a*, *b*, e, *h*) $\in \Re^{+} \cup \{0\}$ has an interpretation of the time of involvement of the external transport means of st-th type that are at the disposal of *v*''- th element of the supply chain, in the implementation of transport tasks in the *ld*-th supply chain on the connection (*v*, *v* ') for transport of material goods of the *h*-th type according to the *e*- th route in the relation (*a*, *b*).

$$\forall\ ld \in \boldsymbol{LD}\ \ y2: \{ld\} \times \boldsymbol{STW}(ld) \times \boldsymbol{V}(ld) \times \boldsymbol{H}(ld) \longrightarrow \Re^{+} \cup \{0\},$$

*y*2(*ld*, *st*, *v*, *h*) $\in \Re^{+} \cup \{0\}$ has an interpretation of the time of involvement of the internal transport type of *st*-th type in the implementation of logistic tasks in the *v*-th link *ld*-th supply chain.

$$\forall\ ld \in \boldsymbol{LD}\ \ y3: \{ld\} \times \boldsymbol{STW}(ld) \times \boldsymbol{V}(ld) \times \boldsymbol{H}(ld) \longrightarrow \Re^{+} \cup \{0\},$$

*y*3(*ld*, *st*, *v*, *h*) $\in \Re^{+} \cup \{0\}$ has an interpretation of the time of engaging storage devices of *st*-th type in the implementation of logistic tasks related to the handling of material goods of the *h*-th type in the *v*-th link of the *ld*-th supply chain.

$$\forall\ ld \in \boldsymbol{LD}\ y4: \{ld\} \times \boldsymbol{KL}(ld) \times \boldsymbol{STZ}(ld) \times \boldsymbol{L}(ld) \times \boldsymbol{V}(ld) \times \boldsymbol{H}(ld) \longrightarrow \Re^{+} \cup \{0\},$$

*y*4(*ld*, *kl*, *st*, (*v*, *v*'), *v*'', *h*) $\in \Re^{+} \cup \{0\}$ has an interpretation of the total working time of employees of the *kl*-th category of human work who are at the disposal of *v* '' - this element of the supply chain in connection with the performance of transport tasks in the *ld*-th supply chain on the connection (*v*, *v* ') with a *st*-type vehicle for transport of material goods of *h*-th type.

$$\forall\ ld \in \boldsymbol{LD}\ y5: \{ld\} \times \boldsymbol{KL}(ld) \times \boldsymbol{STW}(ld) \times \boldsymbol{V}(ld) \times \boldsymbol{H}(ld) \longrightarrow \Re^{+} \cup \{0\},$$

*y*5(*ld*, *kl*, *st*, *v*, *h*) $\in \Re^{+} \cup \{0\}$ has an interpretation of the total working time of employees of the *kl*-this category of human work in connection with the implementation of logistic tasks related to the handling of material goods of h -th type in the v- th link of the ld-th supply chain by the internal transport means of st-th type.

In addition, due to the need to consider the entire transport cycles, the model also includes decision variables regarding the number of courses without the cargo. On the Cartesian products of sets: {ld}, ***STZ*** (ld), ***V*** (ld), ***L*** (ld), the mapping $zp1$ was applied, which carry elements of these products into elements of a set of natural numbers, i.e.:

$$\forall\ ld \in \boldsymbol{LD}\ zp1:\ \{ld\} \times \boldsymbol{STZ}(ld) \times \boldsymbol{L}(ld) \times \boldsymbol{V}(ld) \longrightarrow \mathcal{N},$$

$zp1(ld, st, (v, v'), v'') \in \mathcal{N}$ has an interpretation of the number of courses of the st-th means that are at the disposal of v'' - th element of the supply chain in the connection (v, v') of the ld-th supply chain without cargo.

One of the main limitations is the limit that guarantee the realization of logistics tasks in the selected supply chain. It means that from among the supply chains defined in a given logistics network, exactly one must be chosen for the implementation of the set tasks. The next limitation is the allocation of technical and human resources for the implementation of logistic tasks according to established technologies and for the selected structure of the supply chain.
An important problem due to the efficiency of using resources to implement logistics tasks in the supply chain is to plan transport cycles. These cycles must start and end in the links that are the holders of individual means of transport, and individual sections of a given transport cycle must start and end in the same elements of the supply chain. Further restrictions apply to the transport and storage potential of supply chains.
The total working time of the vehicle, load devices, or employees, cannot be greater than their available working time, which results from the number of these technical means or the number of employees employed and their long-term working time indicators (it results from service and repairs, downtime or in the case of employees - holidays and sick leaves).
The last limit concerns ensuring that the time of logistics services will be accepted by the participants of the supply chain. It means that for each relation a suitable technological route must be selected and technical means must be selected that will ensure that the logistic service will be implemented within this relationship within no longer than expected by the participants in the supply chain.

3.5. Indicators and criteria for assessing the effectiveness of supply chain

Tasks implemented by the supply chain are logistics services including, among others: transport of raw materials, materials, semi-finished products, finished products, etc., storage, distribution and completion. The problem is to provide such service to enterprises in the sphere of supply as well as production in order to achieve the highest possible efficiency of the supply chain. Efficiency applies not only to minimizing the cost or time of logistics processes, but also to maximizing the use of means of transport or minimizing risk when servicing enterprises. In the present model the technical, economical and qualitative criteria were defined.
Among the technical criteria for assessing the effectiveness of the supply chain operation, one can distinguish criteria regarding the assessment of the degree of use of system resources for the provision of logistic services, including transport services.
One of the basic technical criteria is the use of time available for technical resources to implement logistic tasks. This indicator is the quotient of working time and total available time. In order to optimize the technical potential of the supply chain, this indicator can be determined for particular types of means, as well as for individual elements of the logistics chain, which have these means at their disposal. The utilization rates of the time of possession of technical resources, i.e. means of transport $WTP(ld, v, st)$, $WTW($ld,v,st$)$ loading equipment and WTW(ld,v,st$)$ storage facilities, are presented as follows:

$$\forall ld \in \boldsymbol{LD},\ \forall v \in \boldsymbol{V}(ld),\ \forall st \in \boldsymbol{STZV}(v, ld)$$

$$WTP(ld, v, st) = \frac{\displaystyle\sum_{(v'', v''') \in \boldsymbol{L}(ld)} \left[\frac{\ell(ld, (v'', v''')) \cdot \begin{pmatrix} zl1(ld, st, (v'', v'''), v) + \\ zp1(ld, st, (v'', v'''), v) \end{pmatrix}}{vs(st, ld, (v'', v'''))} \right]}{TDsp(ld, v, st) \cdot Nsp(ld, v, st)}$$

where: ***STZV***(v,ld) - a set of types of means of transport used in the ld-th supply chain by the v-th element of this chain $\ell(ld,(v,v'))$ - length of connection between cells (*v, v* ') of the *ld*-th supply chain, *zl*1(*ld*,*st*,(*v*,*v*'),*v*'') - the number of journeys of loaded means of transport of the *st*-th type, which are at the disposal of *v* " - this element of the supply chain after the connection (*v, v* ') of the *ld*-th supply chain, *vs*(*st*,*ld*,(*v*,*v'*)) - the speed of the external transport mode of this type between the links (*v, v* ') of the *ld*-th supply chain, *TDsp*(*ld*,*v*,*st*) - average holding time in the records of the external transport of this type by the *v*-th element of the *ld*-th supply chain, *Nsp*(*ld*,*v*,*st*) - the number of external transport vehicles of the *st*-th type available in *v*- th link of the *ld*-th supply chain.

$$\forall ld \in \mathbf{LD} \;\; \forall v \in \mathbf{V}(ld) \;\; \forall st \in \mathbf{STWV}(v,ld)$$
$$WTW(ld,v,st) = \frac{\sum_{h \in \mathbf{H}(ld)} y2(ld,st,v,h)}{TDsl(ld,v,st)\cdot Nsl(ld,v,st)}$$

where
STWV(*v*,*ld*) - a set of types of internal transport used in the *ld*-th supply chain by the *v*-th element of this chain, *y*2(*ld*,*st*,*v*,*h*) - time of engagement of means of internal transport of this type in the implementation of logistic tasks in the *v*-th link of the *ld*-th supply chain, *TDsl*(*ld*,*v*,*st*) - average holding time in the records of the internal transport type of this type by the *v*-th element of the *ld*-th supply chain, *Nsl*(*ld*,*v*,*st*) - number of means of internal transport of the type available for *v*-th link of the *ld*-th supply chain.

$$\forall ld \in \mathbf{LD} \;\; \forall v \in \mathbf{V}(ld) \;\; \forall st \in \mathbf{STMV}(v,ld)$$
$$WTM(ld,v,st) = \frac{\sum_{h \in \mathbf{H}(ld)} y3(ld,st,v,h)}{TDsm(ld,v,st)\cdot Nsm(ld,v,st)}$$

where
*y*3(*ld*,*st*,*v*,*h*) - time of engaging st-*th* storage facilities in the implementation of logistic tasks related to the handling of material goods in the *v*-th link of the *ld*-th supply chain, *TDsm*(*ld*,*v*,*st*) - the average time to hold in the record of *st*-th storage equipment by the *v*-th element of the *ld*-th supply chain, *Nsm*(*ld*,*v*,*st*) - the number of *st*-th storage devices that are at the disposal of the *v*-th links of the - *ld* th supply chain.
Among the economic criteria, one can distinguish criteria that are used to determine the value of transport performance determining the productivity of means of transport and other resources, or the configuration of the supply chain. The indicator of the total cost of logistics tasks implementation can be used to assess effectiveness. An efficient supply chain is one that provides the same results, i.e. the implementation of established logistics tasks at a lower cost. Thus, the total cost index should be minimized.
All elements of the supply chain must meet their separate performance expectations. This means that elements in the chain can be treated as a reliability system of the entire series. The unreliability of one or more elements translates into unreliability of the entire supply chain. Among the qualitative criteria one can distinguish the supply chain reliability indicator. Reliability of the supply chain can also be considered from the point of view of transport tasks being performed. In this aspect, the reliability indicators of means of transport and loading devices and the category of human work must be additionally taken into account. Thanks to this, by assigning the resources of the highest reliability to the implementation of appropriate, in terms of reliability, technological lines, a guarantee of effective implementation of logistic tasks in the supply chain is obtained. One of the most important indicators to assess the implementation of logistic tasks in supply chains from the point of view of reliability are weighted losses of working time of vehicles on connections. These losses arise as a result of conflict situations occurring during transport.

4. Conclusion

The variety of services and the specificity of supply chains have meant that individual participants of these chains, especially decision makers, organizers and logistic operators have started to look for tools to optimize and test the effectiveness of implemented solutions. Due to market needs, these tools must take into account technical, economic (financial), quality as well as environmental (social) aspects. The implemented solutions should be evaluated due to their effectiveness and in terms of introducing changes based on best practices, i.e. systems with the highest efficiency ratios. In order to assess the effectiveness of supply chains, the model for assessing the effectiveness of the supply chain was presented. The efficiency of supply chains is assessed using the adopted indicators.

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