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EVALUATING LOGISTIC SYSTEMS OF BUILDING MATERIALS SUPPLY

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Abstract – There are many logistical tasks in the field of supplying construction materials, as well as financial and information flows in construction projects. All logistical processes related to the flow of resources, physical, informational, and financial, occurring between the different elements of the company's structure make up its logistical system. One of the many decisions made during the planning of a construction project is the choice of how to control the logistics system of supply. It is impossible to indicate a universal system that will optimally meet the needs of many construction projects due to the individual nature of each project. Properly selected type of logistic service and structure of logistic system allow one to reduce risk in supply chain management.
This paper proposes a multi-criteria analysis to evaluate the models of the logistic system of supply in the execution of a construction project. The Analytic Hierarchy Process AHP was used for the comparative evaluation, allowing multi-criteria pairwise comparisons of the various systems. The proposed approach allows to indicate the structure of the logistic system, ensuring continuity of construction output and also reduction of logistic costs.

Key words – civil engineering, decision making, logistic systems, project management, supply chains

JEL Classification – C44, L74

INTRODUCTION

The main tasks of logistics in the construction industry are the transfer and transport of goods, the storage and warehousing, inventory control, order processing, production planning, and waste collection and disposal. Implementing logistic processes can be organized differently in the organizational structure of the company. The analysis of physical goods flows in construction enterprises indicates their diversity resulting from the consumption of a large number of types of materials, supply, delivery, etc. Furthermore, each construction project is characterized by an individual location and transportation conditions. Consequently, neither can one typical universal logistics system be created in a construction company.

The logistics of construction projects, among others, on supplying the construction site with resources to execute construction works. Processes related to supplying, purchasing, or delivering determine undisturbed realization of construction project. Adequate materials management, efficiency of supply units, or delivery timeliness are some of the many factors influencing the efficiency of construction works execution. The main resource delivered to the construction site, in terms of quantity, mass and importance in the construction process, are building materials. Ensuring appropriate stocks of materials, in quantities and times matching the demand for them, guarantees meeting the directive dates of works realization. Therefore, it is important to choose an appropriate model of the logistic supply system to ensure continuity of construction production and reduce logistic costs.

Procurement tasks are increasingly being entrusted to external participants in the logistics chain, such as transport companies, wholesalers, and manufacturers. The choice of suppliers and even the selection of specific materials and construction elements is taken over by other participants in the construction project, such as the designer, investor, or the contract manager who manages the project on behalf of the investor. Determining the consumption of materials, the size of deliveries, and their timing is handled by site managers, cooperating wholesalers, project managers, or specialized logistics companies. Thus, there are many participants in the supply of materials. Their mutual relations are constantly changing and their specialization is increasing. This requires coordination of these activities.

A logistics system is a purposefully organized and connected set of elements such as production, procurement, transport, storage, and also the recipient, together with the relationships between these elements and between their properties. The set of logistical processes that are integrated into one another and that influence each other and are in a specific relationship with their environment forms a logistical system. It describes the manner in which the logistical processes are executed, the set of techniques for performing logistical processes and the set of means with which the logistical processes are implemented. The optimum functioning of a logistics system ensures, among other things, the appropriate flow of financial resources and information.

Due to the spatial location of logistic systems, they can be divided into macrologistic, metrologistic, and micrologistic systems. Macrologistic systems refer to the whole economy, whereas micrologistic systems to specific economic entities (companies). Metalogistic systems, which are particularly characteristic for logistics, are the micrologistic systems of companies (suppliers, manufacturers, distributors, forwarders, receivers) that cooperate with each other in logistic chains. A typical example of a metalogistic system is the supply chain.

Analysis of the structure of logistic systems allows one to distinguish several types and their classification according to the adopted criteria, which take into account the scope of the system and the varying level of its aggregation. Taking into account the number and type of supply chain hubs, in terms of logistic systems, the structures are distinguished:

– single stage (direct flow of resources),
– multi-stage (indirect resource flows),
– combined (both direct and indirect flows are possible).

Single-step systems are characterized by a direct flow of resources (from the point of delivery to the point of receipt). The advantage of single-stage systems is that additional logistics processes are avoided at the point of flow failure (at the warehouse or cross-docking point). In contrast, the operation of multistage systems is based on the transfer of resources from the sending point to the receiving point, through at least one additional intermediate point. At this point, the resources are subject to handling processes (distribution, concentration, reloading) or storage. From the intermediate point, the goods go to the final recipients. The advantage of multistage systems is that the concentration point of goods is closer to the regional market, making it possible to meet the needs of customers in this market faster. The disadvantage of this type of system is the additional logistical processes at the point of concentration or distribution. In the last type of system, indirect and direct resource flows occur in parallel.

Considering the above assumptions, the following ways of supply can be distinguished in the logistic service of construction projects, which is executed by many enterprises:

– individual contractors by independent supply chains; planning of supplies, selection of suppliers, etc., is the responsibility of the contractors and their logistic services;
– the entire project, in a centralized manner, by the logistics services of the general contractor;
– by logistics organizations existing or established specifically for the project;
– mixed models of the above modes of supply.

1. Review of the literature

The proper functioning of any construction company is often disturbed by the appearance of many decision-making problems, which certainly include difficulties related to the purchase and supply of materials and resources. The question of satisfying as much as possible the expectations of construction contractors with respect to suppliers of building materials has been addressed many times by researchers [1–11]. In literature, there are attempts to evaluate logistic systems by means of, among others, cost analyses and simulations, as well as multicriteria analysis of the impact of logistic system structure on inventory management. On the other hand, the choice of system depends on the economic, physical and organizational conditions of the construction project.

Peng [12] carried out the evaluation and selection of logistics outsourcing service suppliers based on AHP. He proves that, based on the analysis of the characteristics of logistics outsourcing industry, the evaluation index system including logistics cost, logistics operation efficiency, the basic qualities of service suppliers and logistics technology level has more targeted and practicability.

Falshini et al. [13] proposed a mathematical method that combines AHP, DEA, and linear programming to support the multi-criteria evaluation of third-party logistics service providers. Thus, resulted in an efficient and effective methodology, which allows one to satisfy firm needs while considering a huge number of relevant information in a supplier selection process.

Vieira et al. [14] proposed a framework for the design of operations in distribution centres based on a joint study of three elements: distribution strategy, internal activities and the characteristics of the distribution operations. The framework was then applied to a sports fashion retail operation and was reported to enable the decision-making process regarding operations at DCs, creating scenarios for evaluation.

Aized and Srai [15] provided a conceptual planning approach to modelling a hierarchy-based Last Mile system, which is particularly useful in the planning of the routing of the system. Hierarchical modelling is implemented using the Petri net method, which is suitable to the needs of the system being a discrete event dynamical system.

Melkonyan et al. [16] applied a system dynamics simulation and a multi-criteria decision aid to assess the sustainability performance of these distribution channel options for a case study of a local food cooperative and a logistics service provider in Austria.

Huang et al. [17] developed a framework that describes the main phases of Blockchain-enabled circular supply chain management and evaluates the critical success factors of Blockchain implementation. The outcome of the AHP analysis shows that technology-related success factors, such as technical capability, technological maturity, and technological feasibility, play critical roles in circular supply chain management.

Fang and Ng [18] examined whether the development of logistics cost analysis can help determine suitable logistics strategies for a project involving the use of bulky components such as pre-cast concrete units. By representing the cost components through the cost functions, simulations were carried out to determine the logistic cost in different logistic scenarios. The simulation model identified a logistics option that results in the lowest logistics cost without affecting the construction schedule.

Muha [19] determined the scope of the optimization of individual logistics models from the point of view of how individual costs categories and processes are treated. As a result, it was found that the lack of a uniform definition or standard to unify individual logistics costs and the knowledge of logistics costs are the main factors that affect the level of difficulty in managing logistics costs.

Shen et al. [20] examined green supply chain management to propose a fuzzy multi-criteria approach for green suppliers. They applied fuzzy set theory to translate subjective human perceptions into a solid crisp value. These linguistic preferences were combined through fuzzy TOPSIS to generate an overall performance score for each supplier.

Vaidya and Hudnurkar [21] proposed an approach to evaluate the performance of the supply chain using multiple criteria. The analytic hierarchy process was used to develop an eight step methodology for performance evaluation. Supply chain performance number was computed, suggesting the present performance status of the supply chain. The methodology also helps rank the various links according to its performance. The analysis leads in computation of supply chain performance number.

Jaskowski et al. [3] presented a mixed integer linear programming model to optimize the supplies of materials or components that are consumed irregularly. The model enables the user to determine economic order quantities for consecutive periods of construction works and to select the most economical supply channels of a particular material/component. The benefits of using the proposed approach in reducing the total inventory cost were shown.

Semenov and Jacyna [2] considered the problem of planning effective modular supply chains resistant to adverse events. Their analysis confirms the validity of forming efficient and reliable supply chains ready to match supplies to specific orders, adapt to flexible and innovative transformations, and minimize time losses and costs of restoring supply capacity in case of an emergency. The authors made a theoretical analysis of the problem and presented the author's approach to building reliable modular supply chains in the automotive industry.

This paper should help improve the understanding of managers and planners about construction logistics activities and their related costs so as to increase their bid competitiveness and/or improve the chance of success at the construction stage by minimizing the construction logistics cost.

2. MULTI-CRITERIA EVALUATION

Decision theory describes and explains the behaviour of a complex system consisting of human and information resources. A decision is considered a choice of course of action to solve a particular problem. This choice is usually based on the available information. A decision can be understood as a chain of interconnected actions, often referred to in the literature as the decision-making process. In this process, the decision maker makes a conscious choice of one of several available, considered feasible options of action. The result of the juxtaposition of the decision-maker's preferences and the various decision options is to find a subjective solution that best meets the decision criteria.

As a result of watching how people make judgments, Saaty [22-23] developed the Analytic Hierarchy Process (AHP). This method, based on verbal pairwise comparisons of options against criteria, enables the creation of a scale vector that orders the decision options from the perspective of the adopted criteria. In AHP, the problem is ordered within a hierarchical structure understood in that the overall goal that the decision maker wants to achieve is at the highest level of the hierarchy. The overall goal consists of sub-criteria that can be further parcelled out. At the lowest level of the hierarchical structure, there are the decision options.

The AHP has become one of the most widely and widely used multi-criteria decision support methods. It is used for many purposes, such as planning, selecting the best alternative, resource allocation, resolving conflicts, optimization, etc. The AHP has also been widely commented on and subjected to many attempts at improvement through the introduction of new pairwise comparison scales or the introduction of the evaluation consistency factor.

Despite its many advantages, the AHP method also has some limitations, which include [23-25]:

- limited for practical reasons to a few numbers of comparable elements at the same hierarchical level;
- assumption of full comparability of elements occurring in the hierarchical model;
- requirement of consistency of the evaluation matrix;
- difficult inclusion of dependencies between partial objective functions;
- major simplifications in modelling the actual situation, however, providing practical benefits in the form of simplified decision support procedures;
- recommendation of cooperation of an external analyst-consultant, who should also be an organizer of the decision-making process;
- the need to train people who are to apply the AHP method in the basics and practical aspects of its use.

The AHP uses linguistically formulated ratings for pairwise comparisons of decision alternatives. This raises the problem of how to assign verbally specified evaluations to Saaty's numerical scale in a way that allows for accounting for all shades of meaning in the evaluations given by decision makers [24]. Many researchers have tried to overcome this difficulty by modelling verbal ratings of decision makers using fuzzy sets. Despite numerous fuzzy extensions of the AHP, Saaty and Tran [25] indicate that the method works correctly when judgments are precise and correct, and that fuzzifying imprecise judgments does not lead to correct results. They also criticize artificial improvement of the consistency of the rating matrix by fuzzing it because improving inconsistency does not necessarily improve the validity of the outcome.

In order to evaluate the elements located on particular levels of the hierarchical structure, a matrix of comparisons (evaluations) is created whose degree is equal to the number of elements being compared. On the other hand, by the vector of priorities are expressed the evaluations of analysed criteria and variants due to the superior goal. The components of the vector determine the degree to which the elements of the lower level possess the feature defined at the higher level. The elements analysed in the hierarchical model are then ordered according to the size of the calculated priority vectors in order of importance. The higher the value of the priority vector, the more important the element is.

Although pairwise comparisons are made by experts with knowledge of the field, they can also make errors in assigning scores. The reliability of the results is checked by calculating the index and the consequence coefficient. To eliminate inconsistencies, the consequence coefficient CR is calculated according to the relationship [22]:

$$CR = \frac{CI}{RI} \times 100\% \quad (1)$$

where: RI is a random index, depends on the degree of the matrix n, taking values from 0÷1.45, while CI is a consequence index determined from the relationship:

$$CI = \frac{(\lambda_{max} - n)}{(n-1)} \quad (2)$$

where: λ_{max} is the maximum eigenvalue of the matrix.

If the CI value does not exceed 0.1, it means that the experts' evaluations are consistent. The principle of logical consistency has two important meanings. The first is related to the grouping of similar items according to their homogeneity. The second meaning concerns the principle of transitivity of assessments, i.e., the strength of the relationship between the elements being compared. The value of the logical consequence coefficient should not exceed 10%; if it is higher, the formulation of the questions should be checked when performing pairwise comparisons [23].

The primary advantages of the AHP method that determined its use to solve the problem posed in this paper include [23-25]:

- the method provides a simple, easy to understand, and flexible model for a wide range of multi-criteria problems;

- it allows for improvement in the way the problem is stated and for improving evaluations by repeating the process;
- it reflects the natural tendency of the mind to sort the elements of a system and place them at different levels;
- it integrates deductive thinking and a systems approach in solving complex problems;
- it introduces a rating scale for non-measurable elements and a prioritization method;
- it considers the relative priorities of factors in the system and enables experts to select the best alternative based on the objective.

3. AN EXAMPLE OF EVALUATION OF SELECTED SCM SYSTEMS IN CIVIL ENGINEERING

The article presents the concept of a method for evaluating three models of the logistic system of supplying finishing works products on the example of the construction of a multi-storey office building. In the first model (LC), the logistic service is provided by the logistic centre, which also supplies other construction sites. It is a perfectly equipped, supplied and computerized unit, managed by an external company. The warehouses of the logistic centre are located outside the investment area, on the outskirts of the city. At the construction site, there is a management point, belonging to the centre, to which the contractors send their orders. The point collects orders and enters them into the internal system of the logistics centre. The warehouse staff prepare and properly describe orders directed to specific contractors and then send the transport by collective car. The logistics centre has a schedule of works executed on the construction site, which it has the possibility to supplement the stock of inventory on an ongoing basis so as to have at its disposal at all times the materials that may be needed on the construction site.

The second model (GC) is modelled on a multi-stage system. Logistics support is provided by the general contractor of the construction project. Subcontractors send information about the need for a given material to the general contractor logistics department at specific times prior to scheduled delivery. From there, the order is directed to the appropriate suppliers. Transports are sent on specific days and directed to the designated unloading zone, located on the construction site. On site, deliveries are checked by the general contractor for completeness and compliance with the order, and then directed to the target recipients.

The third model (DD) is an example of a one-stage system and provides for individual procurement: subcontractors and general contractor are supplied with building materials by their own logistic services. Orders are placed directly with suppliers (wholesalers, manufacturers) and then delivered to specific recipients by means of transport of these suppliers. The unloading takes place at places designated and organized by the general contractor of the project.

The project is being realized downtown on a very limited construction site. The work to be executed by 10 subcontractors must be finished before the 5 month deadline. The cost of the materials that must be delivered is very high, which generates a high degree of risk in relation to the compensation of financial resources to buy building materials.

A multi-criteria decision-making problem is considered, in which three decision alternatives of a supply logistics system are evaluated with respect to the following criteria:

- Just-in-time order processing.
- Timeliness deliveries.
- The possibility of fulfilling emergency orders.
- Warehousing infrastructure costs (the creation of storage sites and their service).
- The number of reloadings (in terms of material wastage and reloading costs).
- Crediting of contractors' expenses
- The degree of orders offsetting.
- The possibility of discounts.
- Insourcing of logistic services.
- Environmental protection.

Relations with suppliers indicate preference for those who defer the payment deadline as much as possible and for tightening cooperation with proven suppliers, concluding long-term contracts, especially for the supply of materials used at each construction site. Such cooperation facilitates negotiations of commercial conditions and obliges the company to purchase from a given supplier. On the other hand, suppliers are required to prioritize orders. Most supplies are realized in the Just-in-Time system. However, there are materials purchased abroad or atypical, which determine the possibility of continuing work on the construction site. In such cases, the order is sent well in advance and a storage place is prepared at the construction site.

Taking into account the conditions of completion of the construction project and the preferences of the decision maker, the most important criteria were the insourcing of logistic services, the possibility of just-in-time deliveries, the possibility of fulfilling emergency orders and the timeliness of the deliveries, taking into account the limited warehouse capacity, delays that may generate additional costs, and the high ratio of financial resources and completion time.

Table 1. Pairwise comparisons of options for criteria

	Just-in-time order processing	Timeliness deliveries	Emergency orders	Warehousing infrastructure costs	The number of reloadings	Crediting expenses	The degree of orders offsetting	The possibility of discounts	Insourcing of logistic services	Environmental protection
Just-in-time order processing	1	2	3	5	5	2	4	3	0.5	7
Timeliness deliveries	0.5	1	2	5	5	3	4	6	1	7
Emergency orders	0.333	0.5	1	6	9	2	7	3	1	5
Warehousing infrastructure costs	0.2	0.2	0.167	1	3	0.333	2	1	0.25	1
The number of reloadings	0.2	0.2	0.111	0.333	1	0.333	1	1	0.2	2
Crediting expenses	0.5	0.333	0.5	3	3	1	4	4	1	4
The degree of orders offsetting	0.25	0.25	0.143	0.5	1	0.25	1	2	0.2	3
The possibility of discounts	0.333	0.167	0.333	1	1	0.25	0.5	1	0.167	2
Insourcing of logistic services	2	1	1	4	5	1	5	6	1	5
Environmental protection	0.143	0.143	0.2	1	0.5	0.25	0.333	0.5	0.2	1

The degree of order offsetting, the possibility of discounts, and the possibility of crediting expanses were assumed as secondary criteria due to the possibility of changing the investor's decision as to the materials used, and the possible necessity to use products conducive to accelerated project execution.

Costs related to storage infrastructure, environmental protection, and the number of reloadings were considered the least important criteria.

To facilitate the processing of the data obtained from the expert group, publicly available AHP-based decision analysis software was used, for example *SpiceLogic Analytic Hierarchy Process Software*.

The rating of the decision variants against the criteria is presented in Table 2.

Table 2. Priority Trade-offs

Criteria		Weight	Priorities		
			LC	GC	DD
1	Just-in-time order processing	0.20	0.57	0.29	0.14
2	Timeliness deliveries	0.18	0.40	0.40	0.20
3	The possibility to fulfil emergency orders	0.16	0.57	0.29	0.14
4	Warehousing infrastructure costs	0.04	0.71	0.14	0.14
5	The number of reloadings	0.03	0.06	0.47	0.47
6	Crediting of contractors’ expenses	0.11	0.07	0.50	0.43
7	The degree of orders offsetting	0.04	0.80	0.10	0.10
8	The possibility of discounts	0.05	0.73	0.15	0.12
9	Insourcing of logistic services	0.17	0.80	0.11	0.09
10	Environmental protection	0.02	0.69	0.17	0.14

As a result of the findings, an assessment of the utility of the variants and the priorities of the criteria was obtained. As a result of the analysis, it turned out that the optimal variant in the analysed example is the system in which the logistic service is provided by the logistic centre (Fig. 1.). Figure 2 presents the final evaluations of each variant in the analysed example with a division into particular levels of criteria, and Figure 3 shows the weights of the criteria used in the analysis. As can be seen, the criterion that determined the choice of the LC variant was the possibility of order fulfilment in just-in-time system.

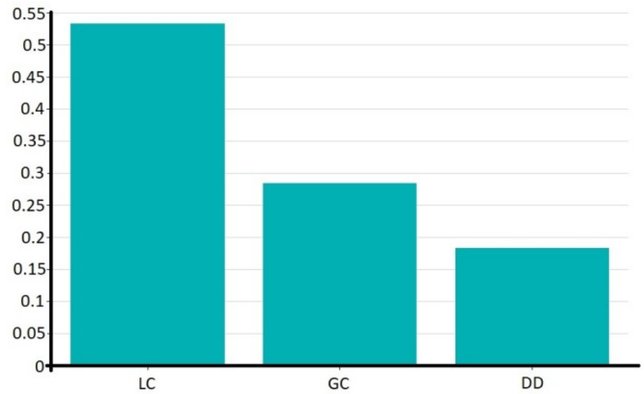

Fig. 1. Evaluation of the usefulness of each variant

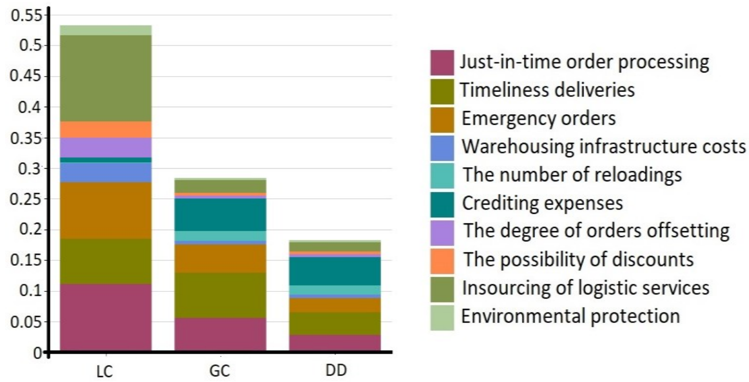

Fig. 2. Final evaluations of each variant divided by criteria

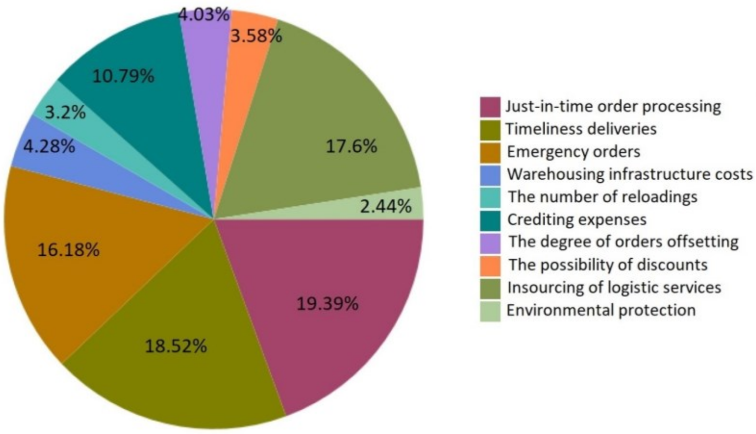

Fig. 3. Diagram of the weights of the individual criteria

A graphical method was used to represent the logistics systems of supply on a radar chart, where the strengths and weaknesses of each system are clearly shown. Figure 4 compares the results for the three selected systems. The values on the graph increase along the radius, taking the value 0 at the centre of the circle and the value 1 at the circle. Connecting the points reflecting the scores given to each system results in a geometric model that characterizes the logistics system of supply. The ideal state is a circular model.

A sensitivity analysis was conducted that attempts to answer the question of how the results will change if the inputs change. One of the primary inputs is the weights of each criterion. Figure 5 shows an example of a sensitivity analysis for the insourcing of logistic services criterion. Regardless of the importance of this criterion, both the order of the variants and their final evaluation do not change significantly.

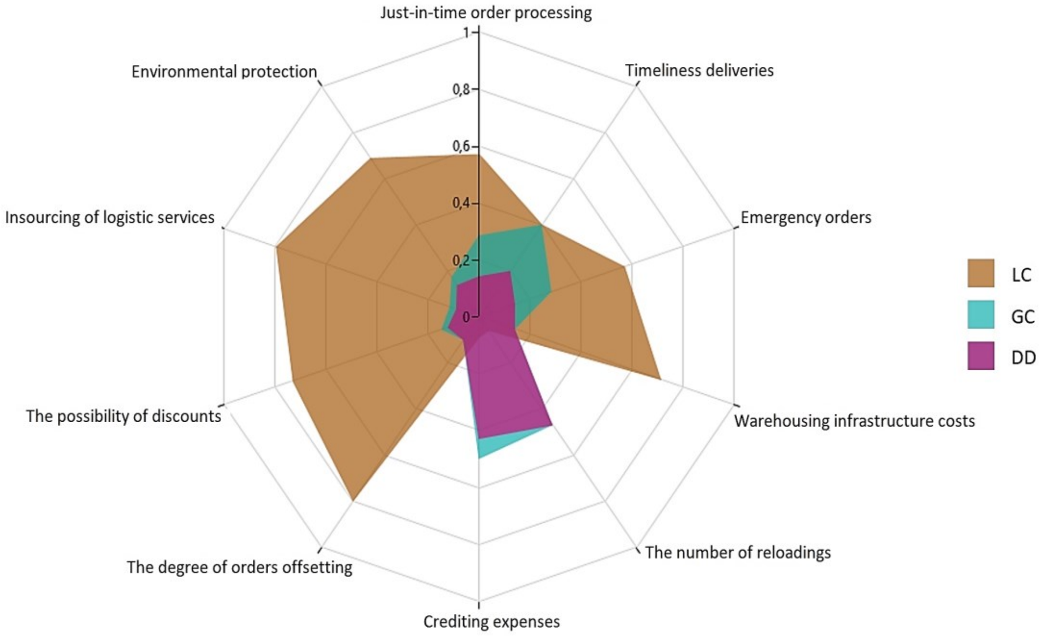

Fig. 4. Radar diagram with comparison of variants

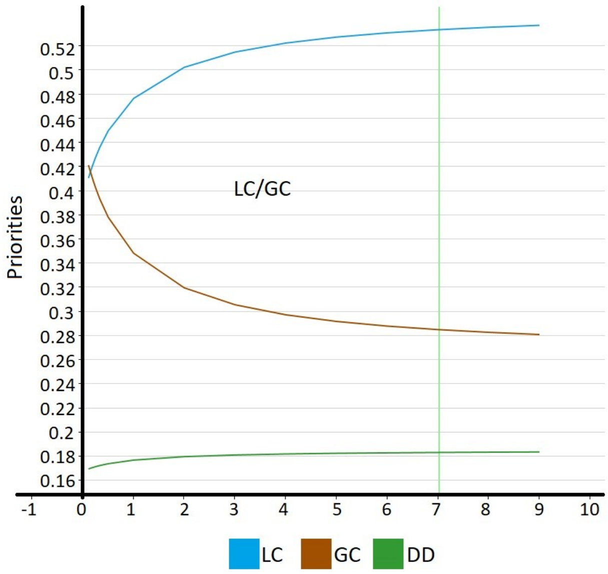

Fig. 5. Sensivity analysis for 'Insourcing of logistic services' criterion

CONCLUSIONS

The proper functioning of any construction company is often disrupted by the emergence of many decision-making problems, which certainly include the difficulties associated with the purchase and supply of construction materials and raw materials.

This paper presents a unique approach for supply chain performance evaluation considering multiple criteria, with a flexibility to modify and analyse using the available data sets. The vector of weights obtained from the AHP calculations indicates that the use of a central warehouse as a properly configured and adapted unit for the construction project allows effective supply chain management.

The analysis does not fully solve the decision problem, which is the selection of logistic systems, because it does not concern the supply of the entire construction project, but only its part, the finishing works.

Properly selected type of logistic service and structure of logistic system can reduce risk in supply chain management. The method proposed in the paper can become the core of a decision support system to solve decision problems in project management. The author sees the need for further development of the topic raised in the article. It would be necessary to carry out an analysis which should concern not only a single case but the organization of a broader construction supply process in general. It is also reasonable to conduct further analyses that examine the influence of the type of construction products supplied on the choice of logistic system. A particularly interesting direction to expand the discussed issue also seems to be to conduct an actual study of logistics systems of supply on the Polish market and compare them before and after the COVID-19 pandemic.

Other commonly used methods found in the literature are usually some improvements of the AHP method, created as a consequence of discovering its limitations in specific practical applications. However, it is usually related to extension of the decision-making model and implementation of additional constraints, which may make it difficult to carry out a quick analysis.

However, it seems that the application of the presented method to solving decision problems, which are encountered every day by both managers and construction engineers, is better than using strictly intuitive solutions. Due to its simplicity, flexibility in adaptation and high efficiency in analysing and solving decision-making problems, Saaty's classic method is very useful in determining priorities in project management.

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OCENA SYSTEMÓW LOGISTYCZNYCH ZAOPATRZENIA W WYROBY BUDOWLANE

Istnieje wiele zadań logistycznych w sferze zaopatrzenia w wyroby budowlane oraz w obszarze przepływów środków finansowych i informacji w przedsięwzięciach związanych z realizacją robót budowlanych. Wszystkie procesy logistyczne związane z przepływem zasobów fizycznych, informacyjnych i finansowych, zachodzące pomiędzy poszczególnymi elementami struktury przedsiębiorstwa składają się na jego system logistyczny. Jedną z wielu decyzji podejmowanych w trakcie planowania przedsięwzięcia budowlanego jest wybór sposobu sterowania systemem logistycznym zaopatrzenia. Nie można wskazać uniwersalnego systemu, który będzie w optymalny sposób zaspokajał potrzeby wielu zamierzeń budowlanych, ze względu na indywidualny charakter każdego przedsięwzięcia. Odpowiednio dobrany typ obsługi logistycznej i struktura systemu logistycznego pozwala ograniczyć ryzyko w zarządzaniu łańcuchem dostaw.
W artykule zaproponowano analizę wielokryterialną do oceny modeli systemu logistycznego zaopatrzenia przy realizacji przedsięwzięcia budowlanego. Do oceny porównawczej zastosowano hierarchiczny proces decyzyjny AHP, umożliwiający wielokryterialne porównania parami poszczególnych systemów. Zaproponowane podejście pozwala na wskazanie struktury systemu logistycznego, zapewniającej ciągłość produkcji budowlanej a także redukcję kosztów logistycznych.

Słowa kluczowe: inżynieria lądowa, łańcuchy dostaw, podejmowanie decyzji, systemy logistyczne, zarządzanie projektami

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