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FUZZY LOGIC-DECISION-MAKING SYSTEM DEDICATED TO EVALUATION OF LOGISTICS PROJECT EFFECTIVENESS

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ABSTRACT. **Background:** Project effectiveness is synonymous with project success. It is measured or assessed in terms of the degree to which project objectives are achieved. This paper presents an approach to evaluating the effectiveness of logistics projects. The starting point is the analysis of the current state of knowledge in the area of assessing project effectiveness, including logistics projects. The purpose of the study was to identify the critical factors determining the success of logistics projects and develop a model of logistics project effectiveness.
Methods: The paper is based on the available recent scientific-theoretical research and publications and on practical studies in 25 enterprises seated in Poland. The study carried out by the authors had the form of questionnaires. The authors used a case study to validate the model of fuzzy decision-making system dedicated to estimate the level of logistics project effectiveness.
Results: Based on a literature review and research findings, the authors propose the key success factors for logistics project effectiveness. In the paper the authors propose an approach to measure the level of logistics project effectiveness using their model based on fuzzy logic. This model laid the foundations for a fuzzy decision-making system in MATLAB environmental. The paper describes the implementation of the model via a case study.
Conclusions: This approach allows for a more detailed description of logistics project effectiveness. The proposed model may be implemented by logisticians in an enterprise and/or supply chain. The approach can be useful to assess the level to which logistics project objectives are achieved - logistics project effectiveness.

Key words: project, logistics project, performance, effectiveness, efficiency, project success, fuzzy decision-making system, fuzzy logic, MATLAB software system.

INTRODUCTION

In today's highly competitive market for goods and services, the ability of project management and especially of logistics project management to plan, schedule, execute and monitor progress within strict cost, time, and performance guidelines is becoming increasingly important in order to obtain competitive priorities, such as on-time delivery and customization [Chen 2007]. More demanding customers, short product life cycles, globalization, rapid technological changes, and the need to deliver highly quality products at the right time may in fact demand break-through thinking to develop highly effective, efficient, and differentiated sets of logistics activities [Fugate, Stank 2010], including unique sets of logistics activities named logistics projects.

A logistics project can be defined as a planned set of interrelated tasks to be executed over a fixed period, limited by budget and time, which is carried out in order to improve the efficiency and effectiveness of product flows and of the associated information in companies, supply chains or spatial systems [Kisperska-Moroń, Krzyżaniak 2009]. According to another definition, a logistics project is a set of tasks characterized

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by a timeframe, costs and organization, the aim of which is to perform a singular and unique action that sets out to optimize a specific logistics process [Kasperek, Szołtysek 2008]. A logistics project is a non-routine set of task apart from other projects by time and cost, the purpose of which is to perform a singular and unique action that effects change to the logistics system of one enterprise or a supply chain within which this enterprise operates [Pisz 2011a, Pisz 2011b, Pisz 2013].

The market for goods and services is characterized by uncertainty and complexity [Anari, Rezei 2013]. These facts affect the performance of logistics projects, creating a greater risk to logistics project management [Pisz, Łapuńka 2015]. Planning and implementing projects, including logistics projects, always involves a certain level of uncertainty. This is due to the fact that these projects are often innovative and unique and it is difficult to predict the direction of implementation in uncertain situations. This uncertainty is the result of not having full access to information regarding a project type, and can be defined as the probability that the objective will not reach its planned target value [Jaffari, 200]. The internal and external conditions of project management are full of uncertainty, which stems from changing customer requirements, resource utilization, personnel mobility, economic turbulence, etc. Under such conditions, enterprises and supply chains have to manage several different logistics projects. A multi-project context is common in contemporary enterprises and supply chains. Enterprises and supply chains increasingly use multiple logistics projects in their daily work to achieve their goals. However, most logistics projects are either over budget, late or are simply not good enough and still different people claim that those projects have been successful. In that context, the effectiveness of logistics project has to be taken into account. Project effectiveness is measured or assessed in terms of the degree to which project objectives are achieved [Baccarini 1999; Belout 1998].

This paper presents an approach to evaluating the effectiveness of logistics projects. The starting point is an analysis of the current state of knowledge in the area. The authors proposed criteria for assessing the effectiveness of logistics projects based on the literature and studies in the selected 25 enterprises. Logistics project effectiveness was assessed using fuzzy logic and the authors have developed a model of fuzzy decision-making. This model laid the foundations on which to build a fuzzy decision-making system in a MATLAB environment. In this paper, implementation of the model was presented via a case study.

LITERATURE REVIEW

The knowledge of a logistics project can vary in each phase of a logistics project life cycle. In the first phase of the life cycle, knowledge is incomplete, which means that logistics projects are characterized by a high level of uncertainty during the initial stage of implementation. The knowledge of a logistics project in this phase of its life cycle is rather limited, although it grows during implementation of the project. At the end of the logistics project life cycle, knowledge is full (Fig. 1).

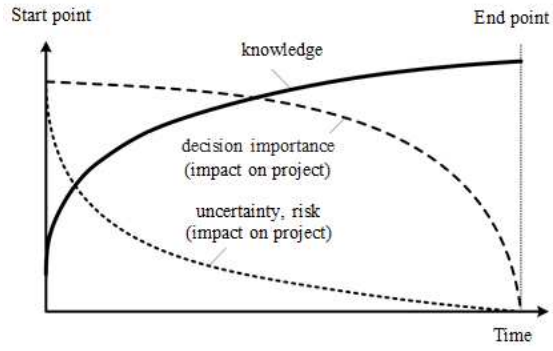

Fig. 1. Decision importance and knowledge in the logistics project life cycle
Rys. 1. Istotność decyzji i wiedzy w cyklu życia projektu logistycznego

Logistics project management consists of the following areas: time management, cost management, scope management, integration management, quality management, human resources management, communications management, risk management, procurement management. All of these areas (knowledge management of project) include procedures, methods and tools that are needed to

management these projects efficiently. The success of a single enterprise and a supply chain results from the skillful use of processes, principles, rules of conduct and resources in response to opportunities and risks that arise, including non-standard processes like logistics projects.

Recently, there has been a significant change in how business is conducted, which has been particularly visible in the SME sector. Enterprises in this sector are sensitive to changes in the market for goods and services. In addition, they are prone to turbulences that arise due to economic crises. Therefore, the transformation of business conduct and the differentiation between routine tasks and tasks that are unique (projects) in a production system become necessary. Both the process approach and the project approach are important for any given enterprise that wants to maintain its market position [Artto, and Kujala, 2008]. From the perspective of logistics management, logistics project management is crucial, as its results have an impact on the effectiveness of the transformation and flow of goods and services, including their attendant information flows, from the sources of materials to the end users. Logistics project management refers to integration of all activities, both internal and external to the single enterprise and to many enterprises in supply chain.

From the research perspective, logistics project management deserves special attention. In practice, this involves carrying out unique orders - logistics projects, which require an individualized approach and a substantial amount of preparation time. Enterprises and supply chains carrying out orders of this kind are particularly vulnerable to the loss of competitiveness, since logistics project management entails the application of substantial knowledge, experience, tools, methods and techniques to planning in order to satisfy or surpass the needs and expectations of clients. This, in turn, necessitates compromises between a number of parameters, such as time, costs, clients' needs, stakeholder's requirements and expectations, and logistics project goals.

The problem of delays and cost overruns in the field of logistics projects are a common phenomenon worldwide. The process of transforming a logistics project initiative into material results is executed in a manner that can be described as chaotic: transformation diverges fundamentally from baseline plans made on commencing a project, no project management methodologies are implemented and more often than not it resembles ad hoc activities rather than a systematic set of methods which would constitute a conceptually coherent approach to project management.

It has been observed that near half of all undertaken logistics project are over cost, near 70 percent of all logistics projects are over schedule. This is confirmed by the results of studies on the state of knowledge about practices employed by Polish managers in the management of logistics projects, titled 'Logistics projects - experiences of Polish enterprises'. These studies were carried out by Logisys Ltd. as part of the Panel of Polish Logistics Managers [PPML 2011] cycle. The aim of the study, in which 142 logistics managers participated, was to answer the following questions: 'How do Polish managers manage logistics projects?' and 'What obstacles to achieving the goals set out in logistics projects do they face?' The report indicates that the enterprises surveyed carried out at least one logistics project (over 70% of enterprises in Poland), apart from their basic business activity. In the period in question (i.e. in the last three years), a significant number of enterprises (40%) carried out at least four projects. The logistics projects undertaken by entrepreneurs involved rearranging warehouse space, changing processes, expanding warehouses, introducing or changing a logistics operator. Other examples of logistics projects included 'integration of processes with other company departments in Europe', 'unification of a material index', or 'carrying out external audit and an attempt to reorganize company departments'. The report exposed weak points in the practices of logistics project management in the enterprises under study, of which those pertaining to the costing of logistics projects were deemed vital. In over 2/3 of the enterprises studied the calculations performed during the costing of a logistics project were not thorough enough, one of the consequences being budget overruns

(only 42% of the projects did not exceed the planned budget). Exceeding the expected deadline of a logistics project, more often than not by 20% compared with the original schedule, was common practice. Only 1/3 of all logistics projects were completed on time [PPML 2011].

Project management's ability in the area of logistics to schedule activities and monitor progress within strict cost, time, scope, quality and performance guidelines is becoming increasingly important to obtain competitive priorities such as on-time delivery of the right product in the correct quantity to the right consumer in good condition at an acceptable cost. Today's managers of logistics projects are working in a fast-moving, ever-changing environment. Their competencies are one of the key critical factors of a logistics project's success. Effective logistics project managers are needed for the successful completion of logistics projects [Kisperska-Moroń, Krzyżaniak 2009].

Effective management of logistics projects is crucial for the development and survival of any enterprise, especially of any supply chain. Enterprises in a supply chain which plan a new logistics project are forced to look for scientific tools that assist them in evaluating their logistics projects. The logistics project management team is responsible for producing the logistics project output. Together with their team, the logistics project manager must be constantly aware of the project goal, logistics project purpose and efficiency of the logistics project management. Effective logistics project management is the key for successful accomplishment of sophisticated projects in a single enterprise, and in several enterprises (Figure 2).

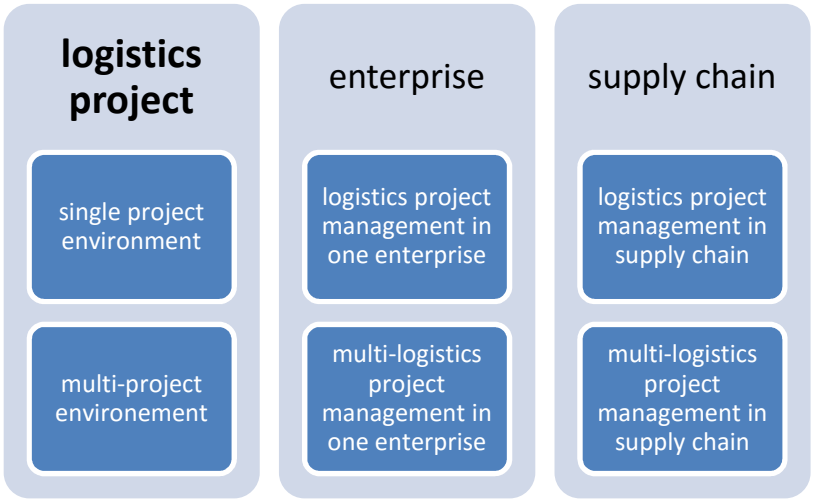

Fig. 2. Framework of logistics project management
Rys. 2. Podejście do zarządzania projektami logistycznymi

Enterprises in a business network are a part of supply chain, which is a chain of interconnected links that facilitates the movement of supplies. The chain can be short with only few links and handoffs, or it can be lengthy, extensive, and complex, with dozens of links and handoffs [Arway 2013]. This depends on the structure of the product being moved along the chain and also the requirements and limitations of the chain. Since the product design dictates multiple requirements for the supply chain, once a product design is completed, it drives the structure of the supply chain, limiting the flexibility of engineers to generate and evaluate different (and potentially more cost-effective) supply chain alternatives [Gokhan, Neddy 2010]. In practice, this means that management of such unique processes can be characterized by different levels of effectiveness and efficiency. Logistics project management can help to obtain a higher level of effectiveness in such processes.

A low level of logistics project effectiveness must be addressed and, to the

extent possible, resolved. A high level of logistics project effectiveness can be achieved through more effective logistics project management and education of logistics project managers.

Many researchers and practitioners consider performance, effectiveness, and success as synonyms [Belout 1998], which means that effectiveness is a synonym of success. It can be treated as the degree to which objectives are achieved [Belout, 1998; Baccarini 1999]. Success is corresponding to the effectiveness and the efficiency of the project and Brudney and England claim that efficiency is broadly understood as the maximization of output for a given level of input or resources. Effectiveness is aimed at achieving goals or objectives [Belout 1998]. Usually, success and effectiveness were related to three principal criteria: time, cost, quality. Various aspects of success were assessed: project efficiency (measured by the project management triangle), the project's impact on the client (measured by client satisfaction level), organization success (measured by the actual impact of project outcomes on the organization), as well as future-proofing (measuring how well project outcomes were aligned with the strategic goals of a company) [Mir, Pinnington 2014]. Nevertheless, to date success has in principle been measured by business results. Today, we can note an evolution of project success concepts.

So far, social or ecological values have not been deemed to constitute a fundamental aspect of project success [Floricel et. al. 2014]. This changes diametrically with the introduction of the so-called triple bottom line (TBL), an approach that balances economy, environment and society, embodying the idea of sustainable development. The aim of TBL is to support business solutions which are simultaneously socially responsible, environmentally friendly and economically valuable. The environmental and social outcomes are treated on an equal footing with the financial outcomes. The three together make up shared value. In this respect, the concept of creating shared value (CSV), proposed in 2011 by M. Porter and M. Kramer in Harvard Business Review [Porter, Kramer 2011], is of great significance.

AN APPROACH TO MEASURING THE LEVEL OF LOGISTICS PROJECT EFFECTIVENESS

The concept of logistics project effectiveness is a controversial concept and can be treated as a synonym of logistics project success. Evaluation of logistics project effectiveness should produce information on outcomes and should shed light on the influence of the project, enterprise performance and/or supply chain effectiveness. It should be a multi-determined measure [Mustapha, Naoum,1998].

The present authors tried to study logistics project success factors and to measure logistics project success using a practical example. They identified the key success factors - criteria that influence the effectiveness of logistics projects. These success factors were prepared based on a literature review and questionnaires. The study carried out by the authors took the form of questionnaires. It was carried out between July 2014 and October 2014 in production, production and service, service enterprises, transportation-freight forwarding-logistics business enterprises seated in Poland. Over 80 questionnaires were distributed to enterprises and valid responses were received from 25 enterprises. The overall response rate for the study was approximately 31 per cent. Table 1 presents basic information concerning the enterprises included in the study. The respondent enterprises are divided into micro, small, medium and large enterprises, and production, service, production and service, transportation-freight forwarding-logistics industries.

Twenty-five responses were received where all the questions were answered. Data were obtained from logistics project managers using questionnaires comprising multiple-choice questions and one open question. The first part of the questionnaire included questions classifying enterprises in terms of employment rate and enterprise type. The central part of the study focused on issues concerning measurement of logistics project success factors. The master list of success factors of logistics project is shown in Table 1. The respondents were asked to identify the success

factors that are relevant to their enterprises. This list contains the success factors of logistics projects to be considered for logistics project effectiveness. In addition, they were asked to add any other success factors of a logistics project that they believed are relevant but not listed in the questionnaire.

Table 1. Basic information concerning the enterprises included in the study of logistics project success factors
Tabela 1. Podstawowe informacje dotyczące przedsiębiorstw biorących udział w badaniu krytycznych czynników sukcesu projektów logistycznych

Type of enterprise	Production *n*	Service *n*	Production and service *n*	Transportation-freight forwarding-logistics *n*	Total *n*
Micro-sized enterprise	0	1	1	1	3
Small-sized enterprise	2	2	2	2	8
Medium-sized enterprise	2	2	2	3	9
Large-sized enterprices	2	1	1	1	5
	6	6	6	7	25

Table 2. The proposed questionnaire on success factors of logistics projects
Tabela 2. Kwestionariusz ankiety dotyczący czynników sukcesu projektów logistycznych

Logistics project success factor	Relevant	
meeting logistics project schedule	yes	no
staying within budget	yes	no
meeting quality standards	yes	no
delay in payment	yes	no
penalties	yes	no
customer satisfaction	yes	no
end-user satisfaction	yes	no
logistics project team satisfaction	yes	no
logistics project manager satisfaction	yes	no
supplier satisfaction	yes	no
meeting technical performance	yes	no
meeting operational performance	yes	no
labor productivity	yes	no
quality of materials	yes	no
late delivery of materials	yes	no
delivery on time	yes	no
materials damage	yes	no
delay in inspection and testing	yes	no
communication and coordination	yes	no
errors and delays	yes	no
solving logistic problems	yes	no
created new market	yes	no
reducing logistics cost	yes	no
reducing supply chain logistics cost	yes	no
increased market share	yes	no
created new product line	yes	no
development new supply chain	yes	no
development new technology	yes	no

Statistical analysis suggested that the effectiveness of a logistics project is mostly associated with the project schedule and cost budget as an objective measurement of the a project's effectiveness. The study findings show that all logistics project managers covered by the study indicated these success criteria. Meeting logistics project schedule and staying within budget are the key criteria of a logistics project. The analysis shows that the

effectiveness of a logistics project is also related to many other criteria such as: reducing logistics cost (88% of respondents), meeting quality standards (95% of respondents), stakeholders' satisfaction (83% of respondents), especially end-user satisfaction (89% of respondents), logistics project manager satisfaction (78% of respondents), logistics project team satisfaction (73% of respondents), and supplier satisfaction (58% of respondents). Meeting operational performance and technical performance is relevant to 76% and 72% of logistics project managers, respectively. These results showed that creating new market (82% of respondents), increasing market share (88% of respondents) and creating new product lines (75% of respondents) are very important for logistics project managers. The logistics project covered by the study indicated that solving logistic problems is relevant for logistics project implementation. Ninety-five logistics project managers identified this factor of logistics project effectiveness. Developing a new supply chain and new technology are key project success factors for 84% and 78% of respondents, respectively. Some of the logistics project managers covered by the study indicated that the number of penalties (78% of respondents), delivery on time (79% of respondents), materials damage (68% of respondents), labor productivity (67% of respondents), delay in payment (65% of respondents), errors and delay (73% of respondents), delay in inspection and testing (62% of respondents) is relevant for logistics project effectiveness. Communication and coordination is a key success factor for nineteen of the logistics project managers.

The success factors of a logistics project may constitute basic indicators for the analysis and assessment of effects resulting from the logistics projects.

EVALUATION OF LOGISTICS PROJECT EFFECTIVENESS

It is necessary to use the appropriate tool to assess the effectiveness of logistics projects. One tool of this type is a performance measurement system (PMS), which in the literature has been defined as a set of measures used to quantify efficiency and effectiveness. A properly designed and functioning system for measuring and evaluating the effectiveness of logistics projects should indicate what is important in achieving the objectives of the logistics project. Measuring the effectiveness of logistics projects should be based on financial and non-financial indicators.

The approach to evaluating logistics project effectiveness proposed here is based on using Balance Scorecard and fuzzy logic. This proposes using a dedicated system that can measure and evaluate the effectiveness of logistics projects implementation. The system uses this type of fuzzy logic, which enables the modeling of certain and uncertain data. The objective is to combine the criteria into a single measure that can indicate the effectiveness of the logistics project. These criteria can be divided in a few groups. The authors claim that the Balanced Scorecard approach can be used in solving the problem. The idea of the Balanced Scorecard can be adopted to measure the effectiveness of a logistics project. The proposed set of criteria of logistics project effectiveness are listed in Figure 3. All criteria that are considered in the process of evaluating the effectiveness are determined by experts, especially logistics project managers based on the real value and on their knowledge of logistics project data. These data are gathered by logistics project managers and their team and important data are defined using linguistics terms.

The criteria listed in Figure 3 can be used to measure the effectiveness of a logistics project. These criteria may be useful to combine into one measure to get an overall judgment of how well the logistics project was managed and executed. These factors can be clustered into four factors. The effectiveness of logistics project can be measured in terms of financial, stakeholder, process, learning and growth. The authors propose to use the Balanced Scorecard concept.

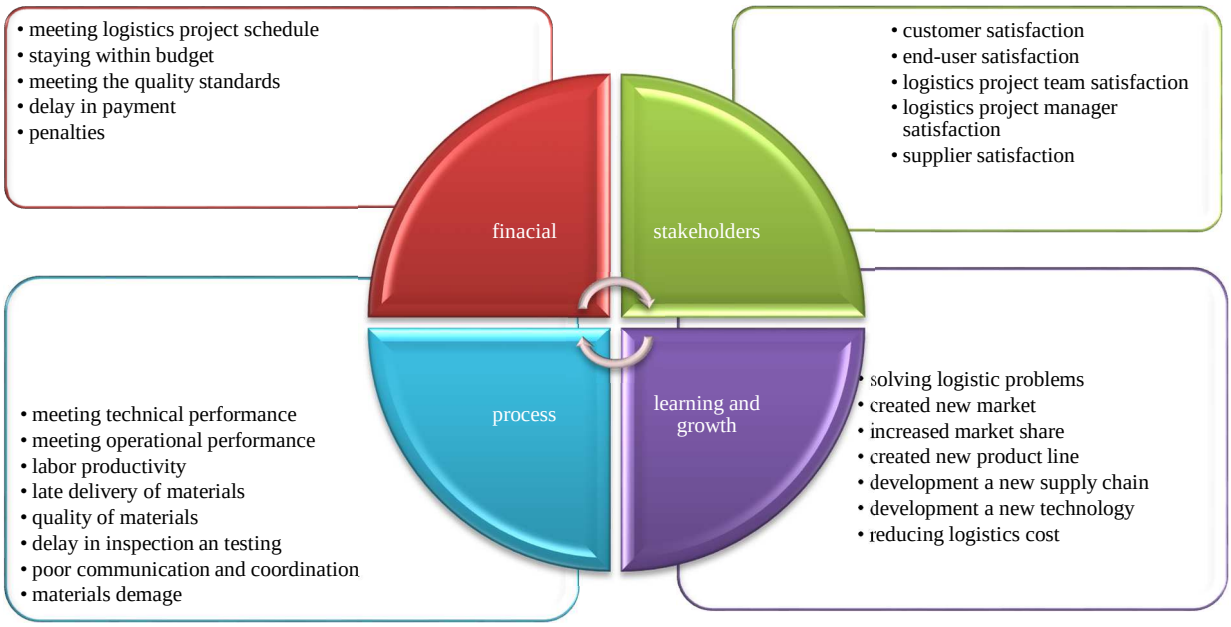

Fig. 3. The key criteria of logistics project effectiveness
Rys. 3. Kryteria pomiaru efektywności projektów logistycznych

The Balanced Scorecard provides a formalized mechanism to achieve a balance between non-financial and financial results across short-term and long-term horizons [Brewer, Speh, 2000]. The Balanced Scorecard distinguishes four main perspectives [Kaplan, Norton, 1992]: customer, internal, financial, innovation and learning. Using the Balanced Scorecard, the effectiveness of a logistics project may be defined as the goal which is achieved in the area of these four perspectives. Logistics project managers need to create their own version of the Balanced Scorecard and concentrate on the most critical measurements of logistics projects [Pisz, 2013; Pisz, Kolasa-Więcek, 2013].

Questions like the following may arise when evaluating logistics project effectiveness: When does a logistics project have low, medium, or high effectiveness? The decision-maker should solve these kinds of problems. This is a vague problem and it can be solved by introducing fuzzy logic. This is a problem-solving technique introduced by Zadeh (1965) and can solve imprecise and vague problems. Using fuzzy logic, fuzzy sets may be defined on vague linguistic terms such as very high effectiveness, low impact, medium delay. Fuzzy logic copies human decision-making using levels of possibility in a number of uncertain categories.

According to Zadeh's principles, every variable x can be expressed verbally with a value (linguistic term) $L(x)$, which is associated with fuzzy set A. The values of linguistic variables are both qualitatively and quantitatively by a fuzzy set. In fuzzy set theory, the values from the universe of variables are members of fuzzy sets, taking into account the grade of membership expressed as a function $\mu_A(x)$, so that [Rudnik, Pisz, 2014]:

$$\mu_A : x \rightarrow [0,1], \qquad (1)$$

where:
0 - lack of membership of the value x in fuzzy set A,
1- full membership of the value x in fuzzy set A,
(0,1) - partial membership of the value x in fuzzy set A.

The representation of fuzzy sets can be done in many ways, for example, triangular, trapezoidal or Gaussian [Santos, Camargo

2010]. The context will determine what is the best among the existing ones. In this paper we use representation by triangular fuzzy sets.

A fuzzy-logic decision-making system is a useful tool that can be used to handle such problem. This kind of system can be implemented using the MATLAB software. Generally, a fuzzy-logic decision-making system consists of four main components: a fuzzifications interface, a knowledge base, decision-making logic, and a defuzzification interface (Figure 4) [Dweiri, Kablan, 2006].

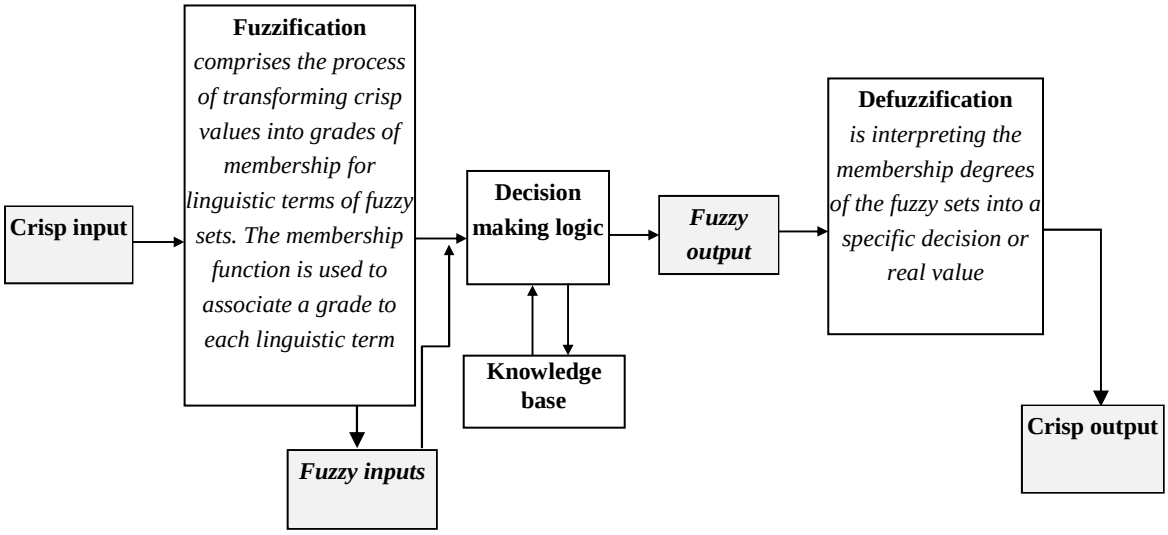

Fig. 4. The idea of fuzzy-logic decision-making system dedicated to measuring the effectiveness of a logistics project
Rys. 4. Idea rozmytego systemu podejmowania decyzji dedykowanego ocenie skuteczności projektu logistycznego

In the next section the proposed fuzzy decision-making system will be illustrated. This approach to measuring logistics project effectiveness will be described via a case study.

CASE STUDY

Let us assume an example of a logistics project P1, which is building a new warehouse. The project was executed by the developer and it was found that the project is 120% over budget and is also 145% behind schedule. There were some problems with suppliers - the deliveries of materials were completed not on time and the quality of materials was low. As a consequence, the enterprise was forced to pay penalties to the contractor. Moreover, the logistics project team had bad relations with the logistics project manager, who lacked professional and technical competences. Monitoring the logistics project was not sufficient either and there were delays in inspection and testing. The result was that the end-user of the project was not satisfied and the owner of the logistics project is disappointed.

The decision-maker wants to obtain the precise information about the effectiveness of the undertaken logistics project. He is interested in building a decision-making system that can evaluate the effectiveness of the project. The decision-maker needs all the necessary input to determine the logistics project effectiveness to obtain the right answer. Based on the expert's experience and data gathered during the execution of logistics project, the authors proposed using fuzzy logic to solve this kind of problem. A fuzzy-logic decision-making system was developed and implemented in the MATLAB environment and the fuzzy logic toolbox of the Matlab program was used to calculate logistics project effectiveness.

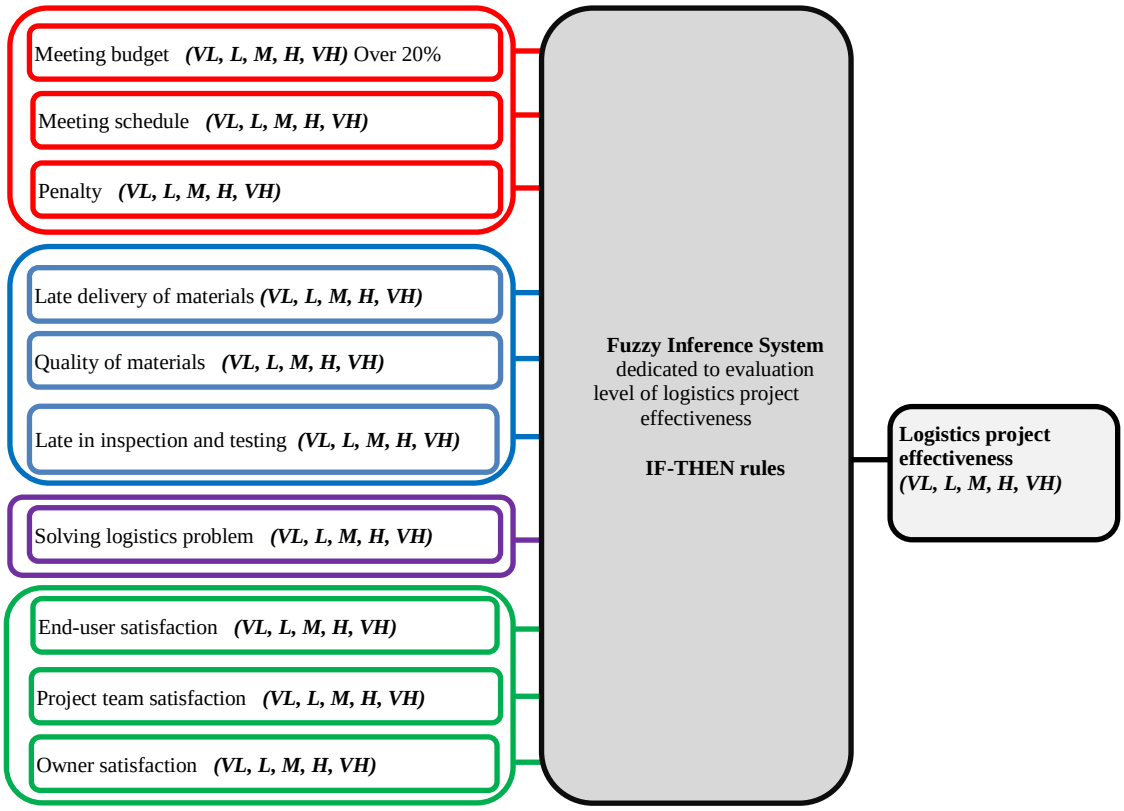

Fig. 5. The Fuzzy Inference System dedicated to evaluate the level of logistics project effectiveness
Rys. 5. Rozmyty system wnioskujący dedykowany ocenie poziomu skuteczności realizacji projektu logistycznego

The idea of a Fuzzy Inference System is presented in Figure 5. The four components of this system can be seen from Fig. 5 and will be explained as follows:

1. The fuzzification interface.

A model was established with 10 inputs and 1 output variable. The inputs and output variables were identified by experts. The input variables and output variable were fuzzified based on experts' subjective judgment, knowledge and experience. These experts used triangular and trapezoidal membership functions to describe input and output values. The experts proposed a 5-level scale for input variables. Represented by triangular and trapezoidal membership functions, these areas are, respectively: very low, low, medium, high, very high. Figure 6 presents an input variable of meeting the budget and meeting costs, respectively. The output parameters are represented on the unit universe [0,1] with triangular and trapezoidal membership functions describing the linguistic variable, i.e. the level of logistics project effectiveness: very low, low, medium, high, very high (Fig. 7).

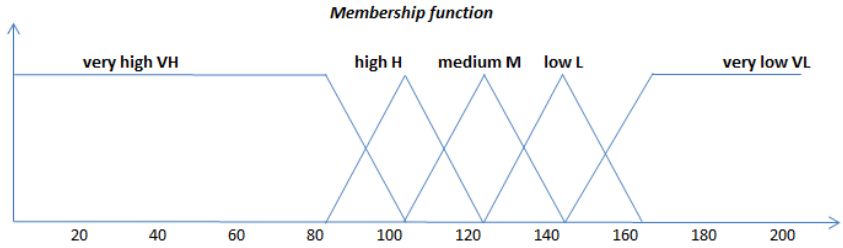

Fig. 6. An example of input variables' membership function
Rys. 6. Funkcja przynależności przykładowej zmiennej wejściowej

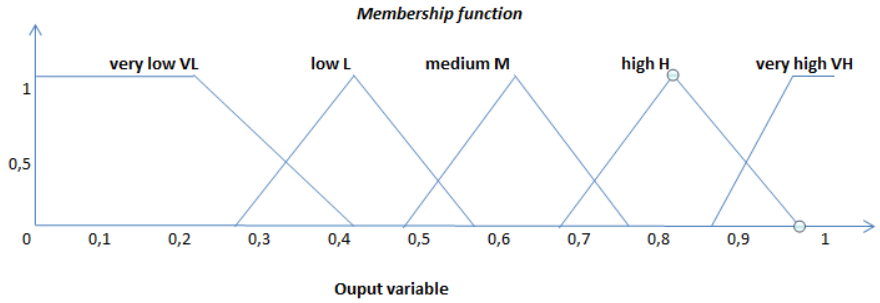

Fig. 7. Output variable membership function
Rys. 7. Funkcja przynależności zmiennej wyjściowej

2. The knowledge base

The effectiveness of a logistics project is determined from the aggregation of sets of fuzzy rules. The impact of given criteria on the effectiveness of logistics project is evaluated using a set of fuzzy IF-THEN rules. These rules are based on experts' subjective judgment, knowledge and experience. The rules were designed to take into account all possible situations.

Examples of fuzzy rules from the knowledge base are as follows:
IF meeting budget is very low THEN effectiveness is very low
IF meeting budget is low THEN effectiveness is low
IF meeting budget is medium THEN effectiveness is medium
IF meeting budget is high THEN effectiveness is high
IF meeting budget is very high THEN effectiveness is very high
IF meeting schedule is very low THEN effectiveness is very low
IF meeting schedule is low THEN effectiveness is low
IF meeting schedule is medium THEN effectiveness is medium
IF meeting schedule is high THEN effectiveness is high
IF meeting schedule is very high THEN effectiveness is very high
IF meeting end-user satisfaction is very low THEN effectiveness is very low
IF meeting end-user satisfaction is low THEN effectiveness is low
IF meeting end-user satisfaction is medium THEN effectiveness is medium
IF meeting end-user satisfaction is high THEN effectiveness is high
IF meeting end-user satisfaction is very high THEN effectiveness is very high
IF penalty is very low THEN effectiveness is very high
IF penalty is low THEN effectiveness is high
IF penalty is medium THEN effectiveness is medium
IF penalty is high THEN effectiveness is low
IF penalty is very high THEN effectiveness is very low
IF late delivery of materials is very low THEN effectiveness is very high
IF late delivery of materials is low THEN effectiveness is high
IF late delivery of materials is medium THEN effectiveness is medium
IF late delivery of materials is high THEN effectiveness is low
IF late delivery of materials is very high THEN effectiveness is very low
IF quality of materials is very low THEN effectiveness is very low
IF quality of materials is low THEN effectiveness is low
IF quality of materials is medium THEN effectiveness is medium
IF quality of materials is high THEN effectiveness is high
IF quality of materials is very high THEN effectiveness is very high

The experts assumed that all criteria of given groups have the same impact on the level of logistics project effectiveness. In practice,

we can observe that some of the perspectives can have a different impact on effectiveness.

3. The decision-making logic

The evaluation of a fuzzy rule is based on computing the truth value of its antecedent and applying it to its consequent. This results in assigning one fuzzy subset to each output variable true. In Min Inteferencing, where parts of fuzzy rules are labelled with AND logical operation, the fuzzy AND is obtained as the minimum of the membership values of the input variables' membership values. The level of logistics project effectiveness is determined by performing a fuzzy union of the resultant magnitude fuzzy sets [Nasa, Yadav, 2012].

4. The defuzzification interface

The last component is defuzzification. The output variable is defuzzified to get a crisp value. It converts a fuzzy control action into a nonfuzzy control action. The fuzzy result of the output variable - effectiveness of logistics project is composed and defuzzified using one chosen method - the Center of Area COA according to the following formula [Dweiri, Kablan 2006]:

$$y^* = \frac{\sum_{i=1}^{m} y_i \cdot \mu_i}{\sum_{i=1}^{m} \mu_i}$$

where:

m – a number of discrete values of output variable,
y_i – *i-th* value of output variable,
μ_i – value of obtained membership function for i-th value of output variable.

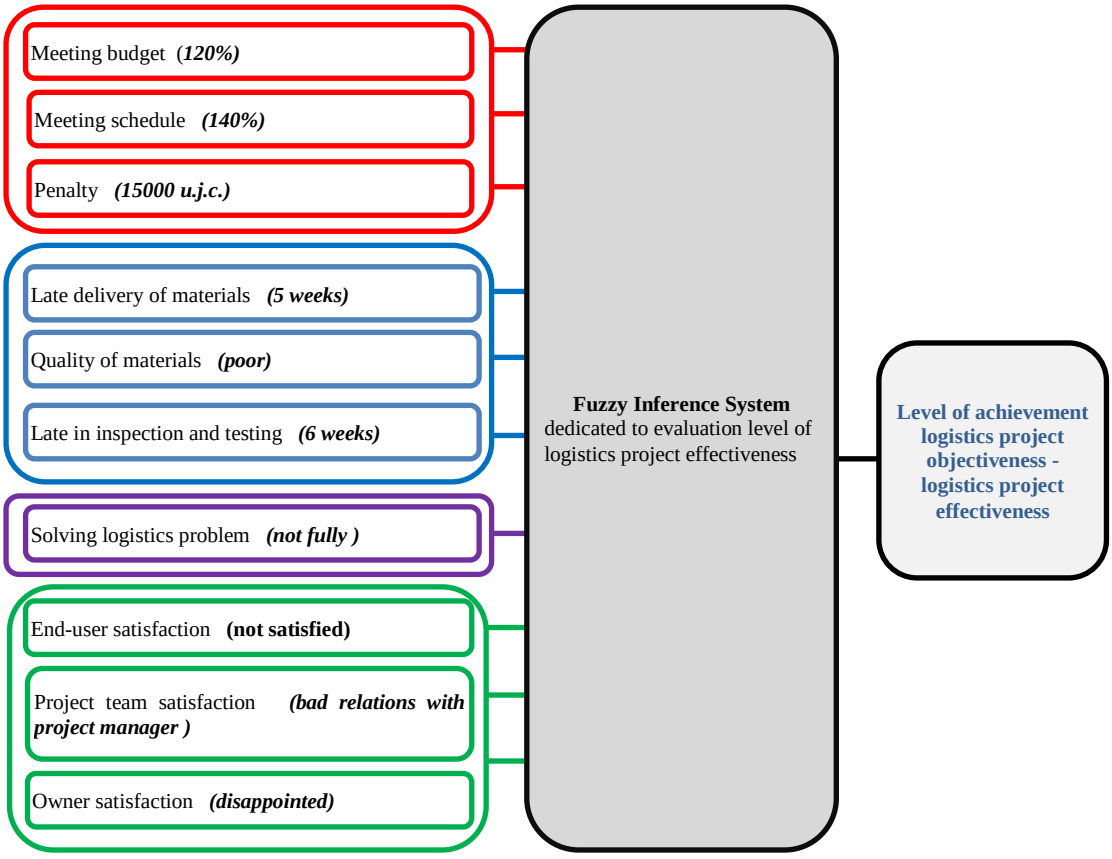

Fig. 8. Input variables of the Fuzzy Inference System
Rys. 8. Definicja zmiennych wejściowych Rozmytego Systemu Wnioskującego

The steps described above are needed to obtain the right information about the effectiveness of the logistics project. The construction of a fuzzy-logic decision-making system is complete and is the result of inferencing and defuzzification. The authors entered information about the logistics project into the developed Fuzzy Inference System designed to evaluate logistics project effectiveness (Fig. 8).

The resulting value of a given logistics project's effectiveness is 0.65. This is a relatively low level of achievement of the logistics project management's internal objectives. The output is a crucial value for logistics project stakeholders and can be treated as an indicator of the level to which logistics project objectives are achieved. The results of effectiveness evaluation indicate the strengths and weaknesses of a given project management. These kinds of information should be used in planning new similar logistics projects, for example, it is a useful value for selecting a logistics project manager, their team, suppliers and materials, etc.

SUMMARY

Effective management of logistics projects is crucial for the development and survival of any enterprise, especially of any supply chain. Enterprises gathered in a supply chain which plan new logistics project are forced to look for a scientific tool that assists them in evaluating their logistics projects. The logistics project management team is responsible for producing the logistics project output. The logistics project managers and their teams must be constantly aware of the project's goal, logistics project purpose and efficiency of the logistics project management. Effective logistics project management is the key for successful accomplishment of sophisticated projects in a single enterprise, and in several enterprises.

The paper presents an approach to the evaluation of the logistics projects effectiveness. This approach allows for a more detailed description of the uncertainty in assessing the effectiveness of logistics projects. Fuzzy logic copies human decision-making using levels of possibility in a number of uncertain categories. The fuzzy decision-making system proposed here can combine the measurement of different success factors into one measurement to obtain a final value of logistics project effectiveness. Based on the approach in this research, a software tool has been developed. The authors have designed and implemented a model using a fuzzy module in the MATLAB system. The accuracy of this system has been verified using a selected enterprise. This computer application supports the decision-maker in the final evaluation of the logistics project's effectiveness. The knowledge gained through this system is a valuable source of information for logistics project stakeholders. Evaluating logistics project effectiveness serves to provide logistics project managers with information about the level to which a logistics project's objectives are achieved.

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ROZMYTY SYSTEM PODEJMOWANIA DECYZJI DEDYKOWANY OCENIE SKUTECZNOŚCI REALIZACJI PROJEKTÓW LOGISTYCZNYCH

STRESZCZENIE. **Wstęp:** Efektywność projektu jest często utożsamiana z sukcesem projektu. Praca podejmuje zagadnienia związane z pomiarem i oceną skuteczności projektów, w tym przypadku projektów logistycznych. Autorzy dokonali analizy literatury tematu. Wyodrębnili kluczowe mierniki sukcesu projektów logistycznych. Na bazie przeprowadzonych badań zbudowano model skuteczności projektów logistycznych, który następnie zaimplementowano w systemie MATLAB.
Metody: Praca została przygotowana w oparciu o dostępne badania zarówno teoretyczne, jak i praktyczne. Przeprowadzono badania ankietowe w 25 przedsiębiorstwach w Polsce. Wykorzystano studium przypadku celem ilustracji podjętego problemu.
Rezultaty: Przygotowano zestaw mierników umożliwiających dokonanie oceny stopnia skuteczności realizacji celów projektów. Przygotowano model umożliwiający pomiar i ocenę skuteczności działań projektowych, który wykorzystuje logikę rozmytą. Opracowany model został zaimplementowany w systemie MATLAB.
Wnioski: Proponowane podejście umożliwia opis problemu pomiaru i oceny skuteczności realizacji projektów logistycznych. Zaproponowane podejście może zostać wykorzystane przez logistyków, menedżerów projektów w ocenie skuteczności działań podejmowanych przez nich projektów logistycznych..

Słowa kluczowe: projekt, projekt logistyczny, efektywność, skuteczność, sprawność, sukces projektu, rozmyty system podejmowania decyzji, logika rozmyta, komputerowy system MATLAB.

EIN FUZZY-SYSTEM ZUM ENTSCHEIDUNGSTREFFEN BEZOGEN AUF DIE BEWERTUNG VON EFFIZIENZ BEI DER AUSFÜHRUNG VON LOGISTIK-PROJEKTEN

ZUSAMMENFASSUNG. Einführung: Die Projekt-Effizienz wird oft mit dem Erfolg eines Projektes gleichgestellt. Die vorliegende Arbeit spricht die Fragestellungen, die mit der Bemessung und der Bewertung der Projekt-Effizienz, nämlich im besagten Falle der Effizienz bei logistischen Projekten, verbunden sind, an. Die Autoren haben die Gegenstandliteratur einer Analyse unterzogen. Ferner wurden von ihnen die schlüsselhaften Indikatoren und Maßstäbe eines Erfolgs innerhalb von logistischen Projekten ausgewählt. Anhand der durchgeführten Forschungen wurde für die logistischen Projekte ein Effizienz-Modell, das man demzufolge ins MATLAB-System implementierte, aufgestellt.
Methoden: Das Forschungsvorhaben wurde in Anlehnung an die verfügbaren, sowohl die theoretischen als auch die praktischen Erforschungen durchgeführt. Dazu wurden in 25 polnischen Unternehmen entsprechende Umfrage-Untersuchungen vorgenommen. Dabei hat man zwecks der Projizierung des betreffenden Problems eine Fallstudie in Anspruch genommen.
Ergebnisse: Es wurde ein Satz von Indikatoren, die die Bewertung der Effizienz innerhalb der logistischen Projekte ermöglichen, bereitgestellt. Des Weiteren wurde ein die Fuzzy-Logik beanspruchendes Modell für die Bemessung und Bewertung der Effizienz von Projekt-Vorhaben aufgestellt. Das ermittelte Modell wurde ins MATLAB-System implementiert.
Fazit: Die vorgeschlagene Vorgehensweise ermöglicht die Projizierung der Problemstellung der Bemessung und Bewertung der Effizienz bei der Ausführung bestimmter Logistik-Projekte. Die dargestellte Lösung kann von Logistikern als Projekt-Managern bei der Bewertung des Effizienz-Grades bei den von ihnen unternommenen Logistik-Projekten in Anspruch genommen werden.

Codewörter: Projekt, Logistik-Projekt, Effektivität, Effizienz, Fertigkeit, Projekt-Erfolg, Fuzzy-System zum Entscheidungstreffen, Fuzzy-Logik, rechnerunterstütztes MATLAB-System.

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