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Evolution of Performance Measurement Methods in Conditions of Uncertainty: The Implementation of Fuzzy Sets in Performance Measurement

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Abstract**—**One of the basic issues of development management is connected with performance measurement as a prerequisite for identifying the achievement of development objectives. The aim of our research is to develop an improved model of assessing a company's development results. The model should take into account the cyclical nature of development and the high degree of uncertainty in dealing with numerous management tasks. Our hypotheses may be formulated as follows: Hypothesis 1. The cycle of a company's development may be studied from the standpoint of a project cycle. To do that, methods and tools of project analysis are to be used. Hypothesis 2. The problem of the uncertainty when justifying managerial decisions within the framework of a company's development cycle can be solved through the use of the mathematical apparatus of fuzzy logic. The reasoned justification of the validity of the hypotheses made is given in the suggested article. The fuzzy logic toolkit applies to the case of technology shift within an enterprise. It is proven that some restrictions in performance measurement that are incurred to conventional methods could be eliminated by implementation of the fuzzy logic apparatus in performance measurement models.

Keywords**—**Fuzzy logic, fuzzy sets, performance measurement, project analysis.

I. Introduction

MEASURING a company's performance is one of the most pressing challenges in modern management. Traditionally, companies have been using a finance-oriented concept of assessing the performance of companies for this purpose. This concept is based on companies' financial statements. Starting from the mid-80s to early 90s of the 20th century, the finance-oriented approach has been criticized constantly. The main negative aspects of the models based on this concept can be identified as follows:

- the lack of non-financial indicators;
- the weak interdependence with strategic planning;
- strong focus on previous results;
- the short term nature;
- commitment to only part of the representation of external and internal company environment (i.e. owners and management team).

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When building a scorecard for assessing a company's performance, one should consider that a company is developing continuously. By definition, development is a process of innovative transformation of an economic system, and it is connected with permanent changes in all spheres of the company's activities. The aim of the company is to increase its performance. Therefore, performance measurement is one of the necessary preliminary stages of the evaluation of the progress and companies' development.

II. Justification of the Applicability of the Methodology of Project Analysis in Relation to the Goals of Assessing of a Company's Development Results

Assessment of the results of development is considered as a regular analytical process based on the results of monitoring of the company's activities. It includes different types of assessment: the efficiency of the company's operations, the investment decisions, and the progress in strategic goals achievement, the efficiency of resources' exploitation and other elements of the company's general potential must be estimated. This assessment is performed to analyze dynamics of indicators for the period, and it enables forecasting a company's development trends in the future. The main purpose of evaluating a company's performance is to draw conclusions about its viability and the possibility of its further development based on a comprehensive analysis, which is be performed using the scorecard that reflects the state and level of development of the subject being evaluated.

The process of a company's development is cyclical, and generally, it may be represented in the form of a diagram (Fig. 1). In fact, the project (modernization) cycles represent the wavelength of the company's development. If we refer to the concept of non-linear development of economic systems, then the S-curve describing the aggregate cycles of a company's development will be uneven, depending on the reaction rate of the modernization process. The key difference between project management and regular management lies in the fact that, during the project control, there is only one cycle at a manager's disposal which requires maximum efficiency. Therefore, in a limited time interval, designated by [1] as the inter-reconstruction period, the project cycle coincides with the next stage of a company's development.

Fig. 2 shows the projection of a project company's cycle (cycles) on a phase plane.

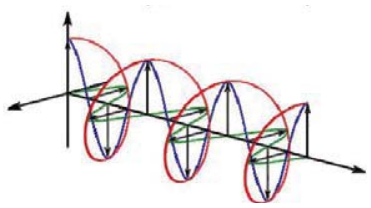

Fig. 1 The cycle of a company's development in a multidimensional space of time - efficiency (based on [2])

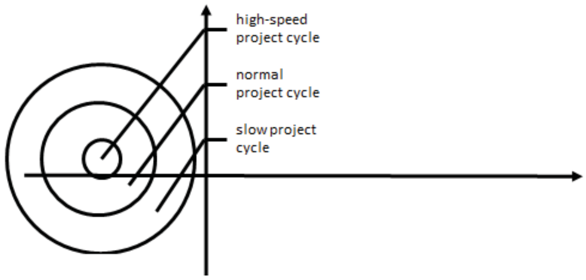

Fig. 2 The projection of a project company's cycle (cycles) on a phase plane (based on [3])

III. Methodological Approaches to the Assessment of a Company's Performance

The assessment of a company's performance should have a systematic nature. First, this requires the assessment of a company's performance from the standpoint of various stakeholders, such as companies' management teams, owners, business partners, creditors, suppliers; tax and customs services, and customers. From this point of view, it is necessary to identify the main elements of a company as a system of economic interests, and to identify the indicators associated with each group of stakeholders, according to the criterion of complete satisfaction of their interests related to the activities of a given company.

Second, there exist two basic approaches (resource-based and cost-driven) to the elaboration of a company's performance indicators. This consideration determines the need for the division of main types of resources included in the economic potential of the company into two groups: applied resources and consumed resources. In addition, it is necessary to determine the period during which the assessment should be carried out. The results of development may be assessed both in the short term and in the long term. Consequently, let us separate the approaches, which enable us to assess operational and strategic results.

The above approaches to a company's performance measurement (PM) reflect basic development trends of modern economic theory and practice in this field. Having analyzed the advantages and disadvantages of each model, we may now generalize the results.

The majority of the reviewed models claim not only to fulfill the functions of assessing performance. From the point of view of their developers, these models may be viewed as concepts of a company's management [4]. This category includes such models as the Balanced scorecard, Management and performance assessment system based on the EVA indicator (economic value added) [5]-[7], Productivity Measurement and Enhancement System (ProMES) [8], [9], Quantum Performance Measurement [10], Ernst & Young model for performance measurement [11], the Caterpillar company model [12], and the Hewlett-Packard concept [13]. Let us define the requirements to be met by any management concept.

1. A scorecard should include qualitative and quantitative characteristics of the main factors, which determine a company's performance;
2. A motivating function of the performance targets should be taken into consideration;
3. The interests of internal and external stakeholders should be taken into account;
4. A control model must ensure the interconnection of strategic and operational management levels, and the arrangement and hierarchical subordination of a company's objectives;
5. It is necessary to work out methodological support for the procedures of arriving at estimated indicators and reports. The latter should be of a standard nature, which is mandatory for all of a company's divisions, and which should be formalized in the respective internal regulations;
6. The scorecard should help to forecast future development results, form all planned target performance indicators, and carry out an analysis of performance to plan. The applied concept should support managerial decision-making by providing decision-makers with the required information that must be complete, relevant, and authentic;
7. The system of indicators must be sufficiently flexible, adaptive, allowing rapid reaction to changes in the internal and external environment of a company;
8. A mechanism should be available for taking into account risk and uncertainty, especially in the process of forecasting and long-term planning.

Let us assess how the models conform with basic requirements of management concepts (Table I).

Thus, the main drawback of the existing systems of assessing a company's performance is that it does not take into account the risks and uncertainties in the development of forecasts of a company's development, and in the assessment its prospects, and does not always allow the strategic and operational objectives of a company to be coordinated. From a practical standpoint, the three models given below seem to be the most preferable:

- BSC (Balanced scorecard in conjunction with the EVA model);
- Business Management Window
- Quantum Performance Measurement

At the same time, all models selected for management of a company's development require a further mechanism for forecasting the results of development, which could take into account quantitative and qualitative factors, as well as the risks and uncertainties associated with forecasting future events.

TABLE I
COMPARATIVE CHARACTERISTICS OF THE EXISTING CONCEPTS OF MEASURING A COMPANY'S PERFORMANCE

	The ability to link strategic and operational planning	Motivation	Due consideration of stakeholders' interests	Well-defined scorecard that includes qualitative and quantitative indicators	The possibility of standardizating planning and reporting documents	The possibility of forecasting and advanced planning	Support for management decisions	Flexibility	Consideration of risk and uncertainty	Overall conclusion
Balanced scorecard	Mostly strategic control	Average level of motivation	The axis owners-managers only	None	Standardization is possible in principle	Involves forecasting	Only strategic ones	Yes	Does not take into account	Practically, it is necessary to combine with models of operational management
Management and performance assessment system based on the EVA indicator	Mostly operative	Provides incentives for managers	The axis owners-managers only	One basic EVA indicator, in the absence of clear calculation model	Standardization is possible in principle	Forecasting is possible in terms of one indicator	Only in relation to EVA	Lacks	Takes into account through the cost of capital	It is necessary to combine with balanced scorecard (BSC) for practical use
Productivity Measurement and Enhancement System (ProMES)	Allows for strategic and operational objectives	Provides incentives for managers and, partially, the staff	The axis the owners-managers only	Involves the development of well-defined scorecard that comprises mainly quantitative characteristics	Standardization is possible in principle	Limited	Provides support for management decisions	Yes	Does not take into account	Requires additional forecasting mechanism
Performance Pyramid	Allows for strategic and operational objectives	Provides incentives for managers and, partially, for the staff	The axis owners-managers only	Involves the development of well-defined scorecard that comprises mainly quantitative characteristics	Standardization is possible in principle	Limited	Provides support for management decisions	Yes	Does not take into account	Requires additional forecasting mechanism
Quantum Performance Measurement	Allows for the strategic and operational objectives	Provides incentives for managers and, partially, for the staff	The axis owners-managers only	Involves the development of well-defined scorecard that comprises mainly quantitative characteristics	Standardization is possible in principle	Provision is made for forecasting	Provides support for management decisions	Yes	Does not take into account	Requires additional mechanism for considering risk and uncertainty
Ernst & Young system of Measurement of achievements	Mostly operational control	Provides incentives for managers and, partially, for the staff	The axis of the owners-managers only	Involves the development of well-defined scorecard that comprises mainly quantitative characteristics	Standardization is possible in principle	Limited	Provides for support for management decisions	No	Does not take into account	It is necessary to combine with the balanced scorecard (BSC) for practical use
Caterpillar	Mostly operational control	Provides incentives for managers and, partially, for the staff	The axis of the owners-managers only	Involves the development of well-defined scorecard that comprises mainly quantitative characteristics	Standardization is possible in principle	Involves forecasting	Provides for support for management decisions	No	Does not take into account	Requires formation of additional forecasting mechanism and additional mechanism for considering risk and uncertainty
The Hewlett Packard concept of internal market	Takes account of the strategic and operational objectives	Provides incentives for managers and, partially, for the staff	The axis owners-managers only	Involves the development of well-defined scorecard that comprises mainly quantitative characteristics	Standardization is possible in principle	Involves forecasting	Provides support for management decisions (mainly strategic)	No	Does not take into account	Requires additional mechanism of considering risk and uncertainty
Business Management Window	Takes account of strategic and operational objectives	Provides incentives for managers and, partially, for the staff partially	The axis of the owners-managers only	Involves the development of well-defined scorecard that comprises mainly quantitative characteristics	Standardization is possible in principle	Involves forecasting	Provides support for management decisions (mainly strategic)	No	Takes into account partially	Requires additional forecasting mechanism for considering risk

None of the models considered have sufficient flexibility. Performance targets established within the framework of these models are strictly determined. As practice shows, during the development process, exactly predetermined performance targets can hardly ever be achieved. Will it be necessary to give up the development as abortive if the development parameters are not achieved? Is it possible to think that the development goal has been reached if a group of target performance criteria are not all met? From a theoretical point of view, using strict logic, we must consider any incomplete performance of the plan as a failure. However, in practice, at the stage of the comprehensive assessment of the development process, with due regard for the synergistic effect, some deviation of actual parameters from target values is considered to be valid and acceptable.

There are situations frequently encountered in managerial control tasks, when the initial conditions of a task are not clearly defined. These situations reflect a lack of awareness on the part of a decision-maker.

The information that is used may be subjective, and it is encountered in people's language, as a large number of uncertainties, such as “much”, “low”, “about”, which have no equivalents in the language of mathematics. Therefore, the description of this information by means of traditional mathematics significantly coarsens a mathematical model. Thus, for further application of mathematical methods aimed at analyzing and studying the systems that are becoming increasingly sophisticated, it was necessary to create new mathematical apparatus, allowing for formal description of fuzzy concepts being handled by men when describing their desires, goals, and the perception of the system. Such apparatus is the constant theory of fuzzy sets established by L. Zadeh, whose first fundamental work was published back in 1965 [14].

Over the past thirty years, this new trend has been developing rapidly, and hundreds of papers have been written dedicated to theoretical and applied aspects of the theory of fuzzy sets. Since 1965, three key stages of the development of fuzzy sets concepts could be revealed. First, the main principles of fuzzy sets and approaches to their practical implementation were described ([14]-[17]); then the practical implications were developed and the efficiency of fuzzy logics was confirmed ([18]-[20]). Finally, the rapid expansion of the fuzzy logics to various fields has started ([21]-[24]).

One of the most important trends of the new theory was the problem of decision-making in fuzzy conditions, and the criteria which led to the emergence of a new direction in mathematical programming, particularly, fuzzy mathematical programming (FMP).

The more a company is studied, the newer sources of uncertainty are revealed. Decomposition of the original analysis model, usually rough and approximate, is associated with an increasing shortage of quantitative and qualitative initial data. The problems of uncertainty that cannot be described with the help of mathematical logic are especially clearly manifested in the attempt to model the changes inherent in a company’s development. The apparatus of fuzzy sets theory makes it possible to model the economic dynamics of a company with the assessments and expectations of the person who makes managerial decisions on the selection of the option for the development of the economic processes. Consequently, the model that allows development results to be effectively forecast should be based on the principles of fuzzy logic, the application of which makes it possible to set performance targets as fuzzy sets with fuzzy boundaries and take into account qualitative parameters as linguistic variables. Thus, if we complement a quantum measurement model of activities results with a forecasting system based on fuzzy logic principles, a company’s development management model will look like that shown in Fig. 3.

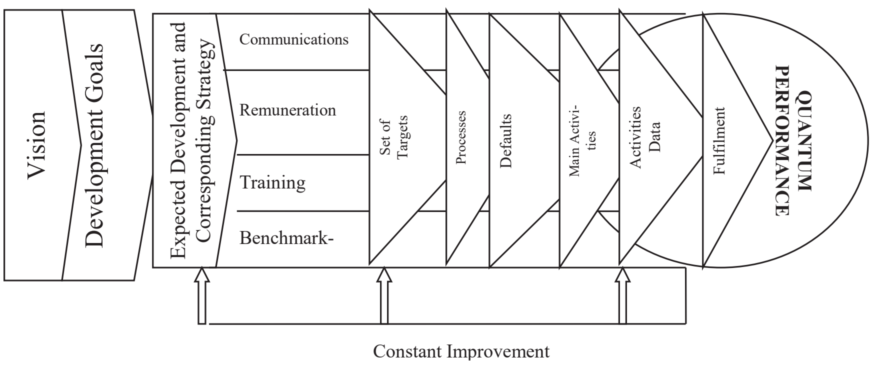

Fig. 3 The quantum measurement model of the results of a company’s activities with integrated fuzzy set approach mechanism

IV. An Application of the Fuzzy Set Approach for Proper Evaluation of the Efficiency of Transition From the IT-Systems to Cloud Computing

Let us consider a decision-making process of the development model of a company’s information system based on the example of justification of the viability of making the transition to cloud computing. The example is based on the JTI corporation, Russian branch. Giving up standard technologies in favour of cloud computing provides the following benefits for the business, from both technological and managerial standpoints:

- cost-saving at all levels of the IT departments associated with the implementation, customization, support, and update of the system;
- focusing on key activities;
- scalability and flexibility of the solution;
- relative simplicity of integration (migration) and operation;
- quality improvement of the services provided;
- automation level improvement;
- portability of the technology;
- optimization of IT infrastructure resources.

With the list of benefits from the use of cloud technology, we have two alternative ways of analysis that can be implemented as the basis of fuzzy analysis:

1) To consider each of the following benefits as the factor influencing the final indicator – the profitability of the project. In this case, the above-stated positive effects are the input parameters, while the profitability of the project is the output parameter. The main advantage of this analysis will be the speed of implementing it, as well as a clear determination of the cause-and-effect relationships (described by fuzzy algorithm analysis). However, there is one disadvantage - the approach gives a more subjective and approximate evaluation, because any expert needs to make a preliminary assessment of the effects based on a defined scale (for example, to evaluate the scalability of new technology based on a 10-point rating scale), and that will reflect the expert's personal attitude to the subject of the analysis.
2) To consider every effect independently, and to create a fuzzy handling mechanism for each one, and only then to combine them into one input parameter for a new fuzzy analysis of the final result - the profitability of the project as a whole. From the standpoint of fuzzy logic machines, this means creating the following algorithm:

a) to select one of the effects of the project implementation and to analyze it: to define the factors influencing its success; to define links; to create a fuzzy handling mechanism and to evaluate the effect by means of fuzzy logic (Fig. 4 as: Ci → Bi);
b) to repeat the procedure for each effect. Thus, we must get the i-e number of fuzzy logic mechanisms, each having its own set of input parameters (Ci) and output parameter (Bi), that benefit from the implementation of the project;
c) to consider the claimed effects of implementation of the project as the input parameters for new fuzzy logic mechanisms that provide the evaluation and expression of the metrics of interest at the output (profitability, margin, cash flow value, etc.) (Fig. 4 as: Bi → R).

The following advantages of such an evaluation approach are worth noting: it minimizes subjective evaluation to the greatest possible extent; each step of the analysis gives us the possibility to create a local fuzzy analysis machine which is independent of others. Therefore, each such mechanism has its own set of parameters that it uses, and its own output parameter, which is the input parameter for the final fuzzy logic machine (Fig. 5). The obvious disadvantage of such a model is that during the analysis it will require a large number of resources, including analytical resources, the demand for which will grow in geometric progression: the larger the number of the identified effects and the factors affecting them, the more fuzzy-mechanisms will have to be created, and the more complicated structure they will have.

The next step in the creation of the fuzzy logic model is the study of linguistic and fuzzy variables. These are the key concepts of fuzzy logic theory, and their definition allows us to move from crisp values to fuzzy ones, from a binary language to a semantic one. For each of the given input and output parameters, we define a linguistic variable, and then the associated membership function. However, before creating them, it is worth noting the input specific features under the project. The project which we analyze using fuzzy logic is an innovative one, and it describes innovation in the field of information technology, consequently, it is characterized by the parameters, for the evaluation of which it is difficult or impossible to find analogues. Moreover, some of these parameters are difficult to evaluate based on any scale. Thus, we see the problem – the proposed assessment parameters that will be used as input parameters for the model can either be evaluated based on a predetermined scale of metrics (in this case, such an evaluation will be subjective and rather stochastic) or characterized by qualitative evaluation. That is one of the major problems that arise when we consider the innovation projects, and that, with varying degrees of success, are solved by the use of one or other evaluation models.

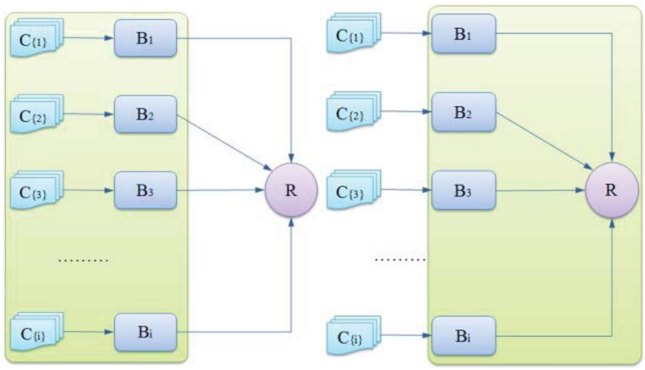

Fig. 4 Arrangement of fuzzy logic machines for evaluating the benefits of project implementation. ab where C_i - factors influencing identified effects (advantages); B_i – project implementation advantages, as determined by experts; R – cumulative result of implementation of the project

Within the framework of the theory of fuzzy sets and its application, we offer the following approach: to eliminate the requirement of input parameters with a set crisp value. It is traditionally considered that the mechanism of fuzzy logic receives a set number of parameters with set crisp values as an input, and it is subsequently subject to further fuzzification, i.e. a correlation of crisp value with semantic term value. We suggest the following approach to overcome this limitation:

thus, at the input, the mechanism will be able to accept the parameters determined quantitatively (crisp evaluation) and qualitatively (fuzzy evaluation). Consequently, the control of input parameters will be more complicated, because it will be necessary to determine not only the factor itself, fuzzy variable and linguistic variable, but also to make a correction for the value that has been assigned to the factor, either quantitative or qualitative. On the other hand, of even greater importance is the fact that we get universal flexibility not limited to the need to measure this parameter (a scale will be needed in the process of the creating membership functions for the variable, but this task is much easier than assigning a crisp parameter that is difficult to evaluate).

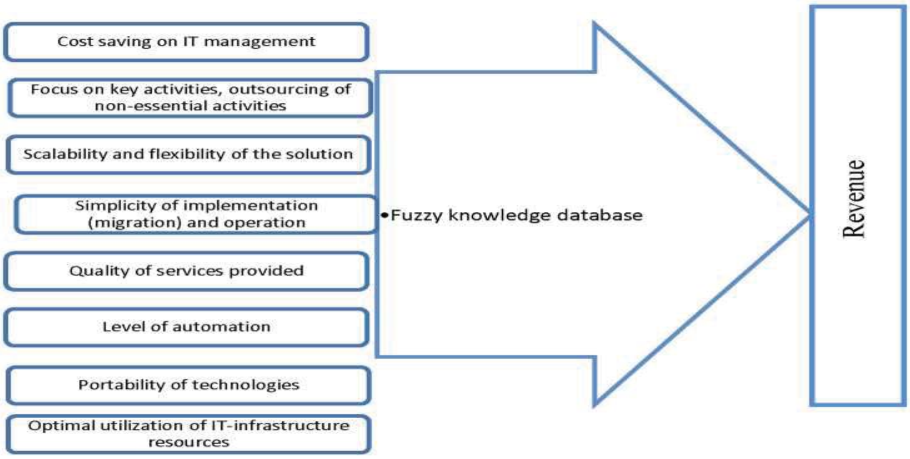

Fig. 5 Fuzzy logic model for efficiency evaluation for the transition to cloud computing

Such flexibility allows any expert to define the input pattern on his/her own, depending on the value, meaning, complexity, and the specificity of the assessment of input features. Thus, the fuzzy logic model provides the value of the total revenue that a company will receive if the project is implemented. In order to determine the revenue, which a company will receive at each stage of project implementation, we distribute its total value equivalently into shares. Thus, the implementation of the project takes 10 quarters followed by the 2 quarters of the beginning of a new system's operation (start, intensive support, and elimination of critical mistakes, more accurate definition of specifications and operational conditions etc.). It is clear that such stages as planning, definition of system requirements, configuration, testing, and new solution deployment in different regions generate no revenue, since the system, in fact, is not in efficient operation. Naturally, a company does not receive economic benefits from it. The system launch (the 1st quarter of 2013) may be considered as the beginning of the system's work for the achievement of business objectives, i.e. the beginning of assessment of the revenue received from it. Thereby, we have 10 quarters, during which we design and configure the solutions, the revenue during which will be equal to zero, and 2 quarters after the system start up, which begin to yield positive economic results. In addition, we extend the time horizon of the analysis and directly consider not only the time of project implementation, but also the following 5 years (20 quarters) as the most effective from the point of view of system operation. Thus, we are able to analyse not only the scheme of revenue receipts and expenditures associated with the project implementation, but also a number of other economic indicators, the calculation of which would have been objectively impossible, if we had confined ourselves exclusively to the period of realization of the project (e.g. payback period, profitability index etc.). This is because IT-projects, especially those ones that offer the implementation/modernization of a complex system, require commitment of considerable resources, while their efficiency (not only economic) is being introduced over quite a long period of time, and this should be analysed in order to get comprehensive and overall assessment. Therefore, we shall use our fuzzy data manipulation apparatus only in the course of these 5 years, during which the operation of a new system of business analytics, migrated to the cloud platform, forms the flows of means (revenues). Unfortunately, it is impossible to graphically show the finite surface, which is formed based on the geometry of the membership functions and the established judgments from the rule base, since it has to be built in 12 and 9-dimensional space, respectively (the number of input and output parameters). This cannot be done on a two-dimensional subspace. However, this does not make the work of apparatus based on working with the fuzzy sets less efficient or illustrative. The best data representation in this case will be tabular presentation (Table II).

TABLE II
OUTPUT PARAMETERS

Set of fuzzy values	Type of a membership function	Input features
low	Z-function	[4; 40]
medium	triangular	[20; 60; 75]
high	S-function	[65; 100]

The name of a linguistic variable: **"the optimality of IT-infrastructure resources utilization"**
Set of precise values: [0; 100]
Number of the basic term-set elements: 3

A membership function is shown graphically in Fig. 6.

So, we have completed the construction of the valuation model of effects (in this context – benefits) of the implementation of the project, which provides data on the planned levels of annual revenue. Now, if we input the parameters' values in qualitative or quantitative terms, which correspond to their status during each interval of time, we will get the following results (in this case, we do not consider the first two years from the beginning of the development of the solution, for its development and implementation do not generate positive cash flows. On the contrary, it is an extremely costly period, which may be considered as the period of spending the capital investments) (Table III).

Accordingly, the fuzzy input information was processed. This information was defined by a set of quantitative and qualitative parameters, which are included in the quantum model, and it was processed within the framework of a developed model. The output information obtained transmits fuzzy output parameters into financial indicators, based on which any weighted management decision may be taken

TABLE III
PLANNED RECEIPTS AFTER PUTTING THE PROJECT INTO PRODUCTIVE OPERATION

Year	Planned receipts, millions of US dollars
2013	6,024.24
2014	7,930.13
2015	7,523.50
2016	7,572.39
2017	7,115.81

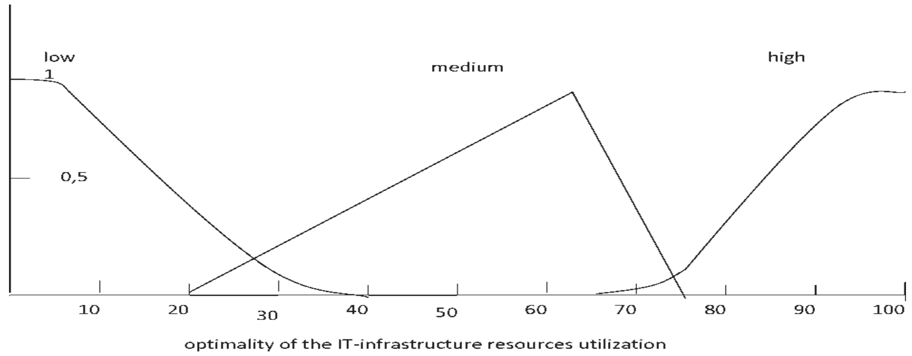

Fig. 6 Membership functions for an output variable "optimality of the IT-infrastructure resources utilization".

V. CONCLUSION

In order to demonstrate the practical application and the peculiarities of carrying out performance measurement in fuzzy output information conditions, we reviewed the example of one of such projects, specifically the assessment and economic justification of implementation of a cloud computing method. As a result, the feasibility of a complex model, which considers the assessment of a company's development results from a variety of angles, taking into account fuzzy data, has been justified. For this part of risk measurement and calculation of financial indicators, we embedded the mechanism of fuzzy logic into the model, which allowed us to ensure the objectivity of assessment, as well as finding out the values of a number of parameters. In the application of a new mathematical apparatus, some restrictions, which cannot be eliminated by conventional methods, but must be factored into the analysis, have been lifted.

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