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FUZZY PRODUCTION MODEL OF URBAN PUBLIC PASSENGER TRANSPORT SUSTAINABLE DEVELOPMENT

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Abstract. *The structure of unclear production model of steady development of urban public passenger transport, which is based on the selection of risk factors, estimation of the character of its multilevel connections within the limits of a single transport space, has been worked out. The fuzzy production rules of forming the risks of constancy are presented from the perspective of influence on the municipal environment.*

Key words: *public passenger transport, risk, steady development.*

НЕЧЕТКАЯ ПРОДУКЦИОННАЯ МОДЕЛЬ УСТОЙЧИВОГО РАЗВИТИЯ ГОРОДСКОГО ОБЩЕСТВЕННОГО ПАССАЖИРСКОГО ТРАНСПОРТА

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Аннотация. *Предложено на основе разработанных нечетких продукционных правил в пределах выделенной многоуровневой формы представления функций городского общественного пассажирского транспорта рассматривать процесс формирования устойчивого развития городской среды через оценку рисков возникновения критических состояний его транспортно-функциональных субъектов.*

Ключевые слова: *городской пассажирский транспорт, риск, устойчивое развитие.*

НЕЧІТКА ПРОДУКЦІЙНА МОДЕЛЬ СТАЛОГО РОЗВИТКУ МІСЬКОГО ГРОМАДСЬКОГО ПАСАЖИРСЬКОГО ТРАНСПОРТУ

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Анотація. *Запропоновано на основі розроблених нечітких продукційних правил у межах виділеної багаторівневої форми подання функцій міського громадського пасажирського транспорту розглядати процес формування сталого розвитку міського середовища через оцінку ризиків виникнення критичних станів його транспортно-функціональних суб'єктів.*

Ключові слова: *міський пасажирський транспорт, ризик, сталий розвиток.*

Introduction

The urban public passenger transport (UPPT) is a major component part of the territorial structure of economy and it considerably influences the socio-economic and materially-spatial development of cities. The problem of improving the efficiency of UPPT operation presents an important economic value and does not only relate to technical and economic aspects but equally influences the social terms of develop-ment of the municipal environment (ME). The conditions of effective modern UPPT operation provide a high level of transport service quality at the sound use of resources and limitation of their negative influence on the ME. The problem of providing permanent UPPT acquires a wide interest and requires the selection of forms of its presentation, development of modern methods and approaches of its formation, creation of methodologies for estimating its efficiency and the mechanisms for its improvement.

Analysis of Publications

Recently, the task of estimating the level of constancy of the public passenger transport and the search of ways for its improvement has acquired considerable attention at forming strategic tasks of urban development [1]. The current approaches to forming the evaluation indicators of passenger transport steady development are used for making a general comparison of territorial structures (countries, cities, regions) as well as to form their rating [2]. Alternatively, their aim is an estimation of dynamics, for this purpose the change of indicators is investigated in the course of the years. In addition, the aim is to determine the degree of achievement of special purpose indexes that can be examined both as standard or threshold ones [3]. In this case it is necessary to work out a system of indexes and confirm their values that will become a guideline for the estimation.

The development of indicators and indexes of sustainable mobility, which are in the focus of modern researches, is a task that has not acquired a clear unambiguous format so far. Currently, the Organisation for Economic Co-operation and Development, the European Commission, the World Bank, the Eurostat, the European Environmental Agency and others are developing independent systems of indicators. In addition to the authorities, the problem of allocation of appropriate forms of urban transport system sustainability assessment is reflected in modern scientific works [4-7].

The establishment of a spectrum of transport sustainability assessment is implemented by creating sets of indicators that can be allocated to the relevant assessment groups:
– the causal relationships that lead to the positive or negative influence on the formation of transport sustainability;
– estimation of the change in the state of social, economic and ecological environment;
– determination of the level of influence and control of the factors which determine the regularity of transport.

Regardless of the nature of representation of the structure of indicators of sustainability, a major disadvantage of existing approaches is their focus on the evaluation of the effective parameters. In the face of uncertainty and significant external impacts evaluation of complex functional processes on the basis of effective param-

eters does not allow providing an objective presentation of clear limits of their value. Such conditions make it possible to prove the necessity of introducing the new forms of UPPT permanence representation from the position of estimating the level of criticality of their parameters in relation to internal and external subjects.

Purpose and Tasks

The aim of the work is forming the structure of fuzzy productional model of steady development of UPPT. For the achievement of the put aim it is necessary to solve next tasks:
– to distinguish the factors of risks of constancy of UPPT;
– to work out the fuzzy productional rules of forming of estimation of risks of constancy of UPPT.

Development of a Risk-System for Assessing the Sustainability of UPPT

Analysis of the consistency, completeness and interdependence of the UPPT stability risks consists in consideration of the whole risk system, the unity of which is ensured through interconnection and interaction in the process of its functioning. The functional processes that occur in the objects of subsystems of UPPT maintenance and provision and external systems ME is considered as the link which should conform to the principles of self-organization and unity of management. Risks in this system are identified with internal fluctuations that take the system out of balance. The magnitude of the output determines the amount of their assessment, and rebalancing determines the impact methods. The complexity of formalization of the consistency of risk assessment lies in the fuzziness of their submission and the hierarchy of inter-level influence. To assess the stability risks of UPPT in terms of the meta-system of ME it is possible to use the fuzzy productional model, which basically involves a network that allows actualizing various components of fuzzy models and the possibility of fuzzy inference formalization. The characteristic of risk factors is presented in table 1.

The construction of a fuzzy production network includes determining the plurality n of the risk factors $U = \{u_i\}, i = \overline{1, n}$ and the plurality m of risk indicators. Certain pluralities are included into the corresponding methodological levels of UPPT presentation and characterize its risk-system from the positions of ME.

Table 1 Risk factors of UPPT sustainability

Type	The name of the linguistic variable
Level 1 – the route network of UPPT	
u_{11}	Exceeding of demand above the suggestion
u_{12}	Lack of internal resources of UPPT enterprises
u_{13}	Physical and mental aging of transport vehicles
u_{14}	Technical failures in the process of vehicles operation
u_{15}	High innitial price of transportations
u_{16}	Complication of terms of technological operations implementation
Level 2 – the system of UPPT	
u_{21}	The decline in the quality of transport service of passengers
u_{22}	Refuse of service
u_{23}	Violation of the operating modes of vehicles
u_{24}	Decrease in the carrying capacity of UPPT
u_{25}	Reduced cost of transportation
u_{26}	The selection of individual elements of the transport infrastructure for UPPT
u_{27}	The use of additional resources of UPPT enterprises
u_{28}	The limited traffic capacity of the objects of passenger transportation infrastructure
u_{29}	Discoordination of the interaction of UPPT elements
Level 3 – the municipal transport system	
u_{31}	Decline of the level of transport service
u_{32}	Increasing the impact of transport on the environment
u_{33}	Decrease in the level of transport organization
u_{34}	Appearance of emergency situations
u_{35}	The growth of the economic effects of the transport
u_{36}	The necessity of constructing new objects of transport infrastructure
Level 4 – meta-system	
u_{41}	Social tension
u_{42}	The capacity constraints of the urban environment
u_{43}	Destabilization of the economic environment
u_{44}	The uselessness of municipal territories for residence
General level	
u_{51}	Poor life quality of the population

In the conditions of multilevel presentation of the risk-system there are transitions from risk factors to their indexes. Connection is implemented on the basis of MISO principles – structure (many entrances – one exit) and presents a cascade combination of fuzzy productional rules that implement a mapping of the input factors on the overall risk. The structure of the multilevel fuzzy production network of the risk assessment model of UPPT sustainability is shown in Fig. 1.
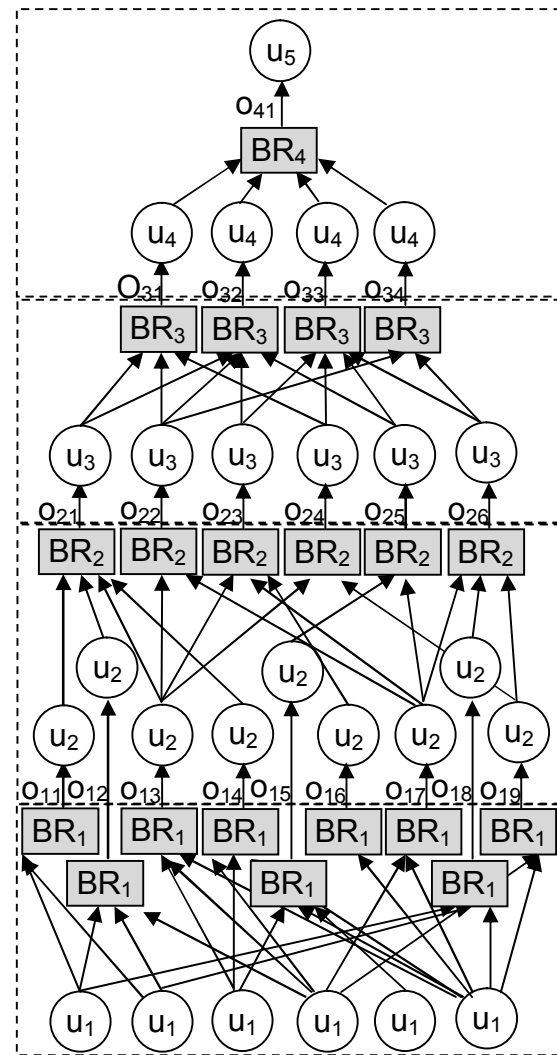

Fig. 1. The multilevel fuzzy production network of the risk assessment model of UPPT sustainability

The estimation of the level of parameters of the risk system is conducted by means of linguistic variables that can be presented as great numbers of terms. The terms are presented by three variants, for risk factors: L – is low accordance, P – is partial accordance and C – is complete accordance. The selection of risk factors and their indexes is conducted on the basis of analysis of the structure of internal and external UPPT connections within the limits of ME. The estimation of risk indexes is conducted by means of three terms: LER – low expectation of risk, MER – the middle level of risk expectation and HER – is the high expectation of risk, CER – the critical condition of the expected risk that according to their value correspond to the terms of risk of a higher level of UPPT presentation.

To form the estimations and fuzzy productional rules of a model they use analytical forms of presentation of intercommunications of the UPPT risk model. For each methodological level they develop their own database of BR rules that define the status of risk indicators based on the analysis of factors and risk indicators. Fuzzy production rules are divided into two groups. The first group reflects the acceptable level of the risk value at which the level of negative exposure does not exceed the average level and under the appropriate conditions of manufacturing processes can be compensated by internal UPPT resource reserves. The second group of formed rules reflects a state in which there is a transition in the zone of unacceptable risks. This condition leads to leaving it outside of the acceptable level of service-resource settings. The fuzzy production rules of forming the risk assessment of UPPT sustainability are shown in table 2.

Table 2 Fuzzy production rules of forming of risk assessment of sustainability of UPPT

Base	Risk	The indicator of risk			
		LER	MER	HER	CER
Level 1 – the route network of UPPT					
BR_{11}	o_{11}	$u_{11}=Lu_{12}=P$	$u_{11}=Pu_{12}=P$	$u_{11}=Cu_{12}=P$	$u_{11}=Cu_{12}=C$
BR_{12}	o_{12}	$u_{11}=Lu_{12}=Pu_{14}=L$	$u_{11}=P(u_{12}=Pu_{14}=P)$	$u_{11}=Cu_{12}=Pu_{14}=P$	$u_{11}=Cu_{12}=Cu_{14}=C$
BR_{13}	o_{13}	$u_{13}=Pu_{14}=Lu_{16}=L$	$u_{13}=Pu_{14}=Pu_{16}=L$	$u_{13}=C(u_{14}=Cu_{16}==C)$	$u_{13}=Cu_{14}=Cu_{16}=C$
BR_{14}	o_{14}	$u_{13}=Pu_{14}=Lu_{16}=L$	$u_{13}=Cu_{14}=Pu_{16}=L$	$(u_{13}=Cu_{14}=C)u_{16}==C$	$u_{13}=Cu_{14}=Cu_{16}=C$
BR_{15}	o_{15}	$u_{13}=Lu_{15}=Lu_{16}=L$	$u_{13}=Pu_{15}=Pu_{16}=P$	$u_{13}=Cu_{15}=Pu_{16}=C$	$u_{13}=Cu_{15}=Cu_{16}=C$
BR_{16}	o_{16}	$u_{15}=Lu_{16}=L$	$u_{15}=Pu_{16}=P$	$u_{15}=Pu_{16}=C$	$u_{15}=Cu_{16}=C$
BR_{17}	o_{17}	$u_{12}=Lu_{16}=L$	$u_{12}=Pu_{16}=P$	$u_{12}=Cu_{16}=P$	$u_{12}=Cu_{16}=C$
BR_{18}	o_{18}	$u_{11}=Lu_{16}=L$	$u_{11}=Pu_{16}=P$	$u_{11}=Cu_{16}=P$	$u_{11}=Cu_{16}=C$
BR_{19}	o_{19}	$u_{14}=Lu_{16}=L$	$u_{14}=Pu_{16}=P$	$u_{14}=Cu_{16}=P$	$u_{14}=Cu_{16}=C$
Level 2 – the system of UPPT					
BR_{21}	o_{21}	$u_{21}=Lu_{22}=Lu_{23}=Pu_{24}=P$	$u_{21}=Lu_{22}=Pu_{23}=Cu_{24}=P$	$u_{22}=P(u_{21}=Pu_{23}=Cu_{24}=C)$	$u_{22}=Cu_{21}=C(u_{23}=Cu_{24}=C)$
BR_{22}	o_{22}	$u_{23}=Lu_{27}=L$	$u_{23}=Pu_{27}=P$	$u_{23}=Cu_{27}=P$	$u_{23}=Cu_{27}=C$
BR_{23}	o_{23}	$u_{23}=Lu_{26}=Lu_{27}=L$	$u_{23}=Pu_{26}=Lu_{27}=P$	$u_{23}=Cu_{26}=Pu_{27}=C$	$u_{23}=Cu_{26}=Cu_{27}=C$
BR_{24}	o_{24}	$u_{23}=Lu_{28}=Lu_{29}=L$	$u_{23}=Lu_{28}=Pu_{29}=P$	$u_{23}=Pu_{28}=Cu_{29}=C$	$u_{23}=Cu_{28}=Cu_{29}=C$
BR_{25}	o_{25}	$u_{25}=Lu_{27}=L$	$u_{25}=Lu_{27}=P$	$u_{25}=Pu_{27}=C$	$u_{25}=Cu_{27}=C$
BR_{26}	o_{26}	$u_{27}=Lu_{28}=Lu_{29}=L$	$u_{27}=Pu_{28}=Lu_{29}=P$	$u_{27}=Cu_{28}=Pu_{29}=C$	$u_{27}=C(u_{28}=Cu_{29}==C)$
Level 3 – the municipal transport system					
BR_{31}	o_{31}	$u_{31}=Lu_{32}=Lu_{34}=L$	$u_{31}=Pu_{32}=Pu_{34}=P$	$u_{31}=Pu_{32}=Cu_{34}=P$	$u_{31}=Cu_{32}=Cu_{34}=C$
BR_{32}	o_{32}	$u_{32}=Lu_{33}=Lu_{35}=L$	$u_{32}=Pu_{33}=Pu_{35}=P$	$u_{32}=Pu_{33}=Cu_{35}=P$	$u_{32}=Cu_{33}=Cu_{35}=C$
BR_{33}	o_{33}	$u_{33}=Lu_{34}=Lu_{35}==Lu_{36}=L$	$u_{33}=Pu_{34}=Pu_{35}==Pu_{36}=P$	$u_{33}=Cu_{34}=Pu_{35}==Pu_{36}=C$	$u_{33}=Cu_{34}=Cu_{35}==Cu_{36}=C$
BR_{34}	o_{34}	$u_{32}=Lu_{36}=L$	$u_{32}=Pu_{36}=P$	$u_{32}=Pu_{36}=C$	$u_{32}=C\vee u_{36}=C$
Level 4 – meta-system					
BR_{41}	o_{41}	$u_{41}=Lu_{42}=Lu_{43}==Lu_{44}=L$	$u_{41}=Pu_{42}=Pu_{43}==Pu_{44}=P$	$u_{41}=Cu_{42}=Cu_{43}==Pu_{44}=C$	$(u_{41}=Cu_{42}=Cu_{43}==C)u_{44}=C$

The inter-level transition between the risk factors and their indicators in the given model are implemented by mapping the linguistic variables

$$o_{ki} = u_{(k+1)i}, i = \overline{1,n}, \qquad (1)$$

where k is the methodological level of UPPT performance.

Critical assessment of the indicator of the level of risk k regardless of the condition factors of the level $(k+1)$ involves the provision of assessment of risk indicators at a critical level.

The presented fuzzy productional model makes it possible to provide a wide range of risk factors accounting and to integrate their quality and quantitative descriptions in the estimation of UPPT constancy. The presented fuzzy productional model includes 6 risks of the first methodological level (the route network of UPPT) factors, 9 – of the second one (the system of UPPT), 6 – of the third one (MTS) and 4 – of the fourth one (ME). A model is implemented on the basis of rules that provide the possibility of implementing the linguistic analysis of the risk of UPPT constancy in conditions of the inter-level transition. Certain rules make it possi-

ble to estimate the priorities of risks (low, middle, high, critical) and to determine the character of their influence on the state of the ME. The procedure of fuzzification of factors and indexes of the risk of UPPT constancy is conducted on the basis of determining the functions of belonging of great numbers of terms of entrance and exit values and needs implementation of researches in the area of forming their criticality in relation to the purpose of the ME metasystem.

Conclusion

The presented fuzzy production model of risk assessment of UPPT sustainability is based on the implementation of the procedures for determining the rules of the state of transition of the internal and external level. The necessary condition for the implementation of this procedure is the selection of membership functions of fuzzy sets which characterize the risk factors. The presented terms for their estimation have three-level forms that require the selection of limits of determination of their belongings. The task of determination of limits of belonging of fuzzy sets consists in the selection of the kind and the character of function and parametrization of its key transit points. In a general view of terms they use piecewise linear functions of belonging for the offered form. The factor, which determines the degree of belonging of an element to the appropriate term, is the level of reserves of resource capabilities.

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