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Article

Planning an Intermodal Terminal for the Sustainable Transport Networks

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Abstract: Growing competition in the global market imposes the need for adequate planning of transportation processes and development of intermodal transport networks, whereby intermodal terminals play a key role. This paper proposes a methodology for prioritization of the intermodal terminal's development features, as the procedure in its planning process, leading to the design of the intermodal terminal in accordance with the needs of various stakeholders and the principles of the sustainable development. As the stakeholders often have conflicting interests and objectives, it is necessary to consider a broad set of requirements and developmental features that enable the fulfillment of the defined requirements. In order to solve the problem this paper proposes a new hybrid multi-criteria decision-making model that combines Delphi, Analytical Network Process (ANP) and Quality Function Deployment (QFD) methods in the fuzzy environment. The applicability of the proposed model is demonstrated by solving an example of planning an intermodal terminal in Belgrade.

Keywords: intermodal terminal planning; sustainable; fuzzy; Delphi; ANP; QFD

1. Introduction

Trends in the today's global market require an adequate planning of sustainable logistics processes in order to achieve successful business strategies. On the other hand, this planning is not possible without widespread and functional logistics networks, which include suppliers, manufacturers, retailers, users, logistic centers (LC), etc. LCs, as the nodes that connect all actors in the system and different modes of transport within these networks, can appear in different numbers, forms, sizes, with different functions, etc., among which the intermodal terminals particularly stand out due to their characteristics and advantages they offer.

The most visible and environmentally most damaging part of logistics is freight transport [1]; therefore, one of the most important conditions for the establishment of the sustainable logistics systems should be more intensive development of the intermodal transport. Intermodal transport is the movement of goods in one and the same loading unit or a vehicle by successive modes of transport without handling of the goods themselves when changing modes [2]. It allows energy, costs and time savings, improves the quality of services and supports sustainable development of the transport system. The main objective is the use of the various modes of transport in order to achieve higher efficiency and greater environmental sustainability [3]. This sustainability is shaped by socio-economic, demographic and environmental megatrends, i.e., major shifts in economic, social and environmental conditions that can impact people and transform societies [4]. Accordingly, intermodal transport problems considering social and environmental impacts, besides economic criteria, have gained substantial attention in recent years, in academic research (e.g., [5,6]), as well as in practice. For example, the European Union set the goals to shift 30% of the road freight transport over 300 km to other, more environmental friendly means of transport (such as rail and waterborne), by the year 2030, and more than 50% by 2050 [7]. These goals can be achieved only by more intensive development of the intermodal transport.

One of the major subsystems of the intermodal transport is intermodal terminal representing the place of storage and transshipment of intermodal transport units between the different modes of transport [8]. Intermodal terminals play a significant role in achieving socio-economic and environmental sustainability [9], and their development has an impact on improving the competitive advantage in the market [10]. Accordingly, requirements, goals and needs of different stakeholders, such as investors, owners, operators of the terminal, terminal users, authorities and residents, have to be in taken into consideration in the process of intermodal terminal planning. Their demands are often conflicting; therefore, a solution that should fit all actors involved is the goal in the planning process. Thus far, the research in the area of intermodal transport planning focused mainly on finding the optimal location for intermodal terminals (e.g., [11–13]) or how to improve operational efficiency of inland intermodal terminals [14–16]. However, the research related to solving the intermodal terminal planning problems taking into consideration variety of methods is rather scarce. Papers dealing with terminal planning are mainly focused on the intermodal transport network planning or the selection of terminal location. Therefore, the purpose of this paper is to define a methodology that comprehensively examines the different stakeholders' requirements based on which it defines and prioritizes development features leading to the design of the terminal which will be in line with the stakeholders' needs and the principles of the sustainable development. Consequently a model proposed for this study combines Delphi, ANP (Analytical Network Process) and QFD (Quality Function Deployment) methods in the fuzzy environment for solving the problem of intermodal terminal planning, i.e., for the prioritization of its development features. The model structures the problem according to the QFD principles, i.e., it forms the House of Quality (HOQ), elements of which are users' requirements and technical requirements, with the aim of establishing connections between them. Since the elements are interrelated, i.e., there are certain dependencies between them they form a network structure that can be analyzed using the ANP method. The purpose of applying the ANP method is to rank the elements and obtain their importance in order to identify those that deserve the greatest attention in the process of intermodal terminal planning. Since the strength of the elements' dependencies are being evaluated by different groups of "users" who may have different requirements, the Delphi method is incorporated into the model with the purpose of unifying the "users" assessments. The requirements are evaluated by the decision makers who often provide inaccurate, vague or ambiguous assessments due to the incomplete information or inability of their processing in the given circumstances. Therefore, the model is developed in the fuzzy environment since the fuzzy logic can effectively cope with the ambiguity of thinking and expressing the preferences by the decision makers. The applicability of the applied methods is already proven, but there are no examples in the literature of combining these three methods in the fuzzy environment. Therefore, this paper proposes a new approach that can solve complex problems and adequately consider all the relations between the requirements in an unclear and imprecise environment. The applicability of the model is demonstrated on the example of planning the intermodal terminal in Belgrade, in which the requirements of the different stakeholders are taken as the "users" requirements, while the development features of the terminal are taken as the "technical requirements". The contributions of the paper are the approach, which takes into consideration the requirements of various stakeholders and defines and prioritizes the development features according to these requirements, as well as the novel hybrid model.

The paper is organized as follows. Section 2 gives an overview of the literature on the subject. Description of the proposed hybrid model for solving the defined problem; the detailed application in steps is given in Section 3. Analysis and discussion of the results and model applicability are presented in Section 4, which is followed by the concluding remarks and directions for future research.

2. Literature Review

The following gives an overview of the research concerning the methods that form the model defined in this paper, as well as the logistics networks, LCs number and functions, intermodal transport and intermodal terminals.

2.1. Overview of the Applied Methods

For solving the described problem a new model that combines Delphi, ANP and QFD methods in the fuzzy environment is developed in this paper. The QFD method [17,18] represents a well-structured, multi-functional method which allows adequate planning, developing, designing and manufacturing of any product or service based on users' requirements and has a long history of wide application in various fields [19]. In general, the method involves creation of the HOQ, elements of which are users' requirements on one side, and technical (design, development) requirements (features) on the other [20]. The HOQ matrix is an almost universal tool that can be used for prioritizing most of the tasks in any field. The QFD method has many advantages. It is focused on customers, teamwork and documentation of all data related to the realization of the process, it is more flexible and it can be easily modified, extended or combined with other methods (unlike some other methods such as: the Taguchi method, Shainin method, Conformability analysis, Poka Yoke, etc.). Therefore, it is more suitable for achieving the appropriate level of quality in terms of users' requirements [21]. However, conventional form of the QFD method has certain limitations such as long implementation time and the use of subjective judgments and decisions. In addition, users' opinions and preferences are commonly expressed by linguistic assessments, which are often imprecise and ambiguous. As the conventional QFD method is not able to adequately interpret the ambiguity of thinking and expressing the preferences of decision-makers, one of the solutions is to integrate the fuzzy logic with the QFD method in order to increase the accuracy and objectivity. In recent years, the conventional or fuzzy QFD method is successfully applied to solve the problems in various fields (e.g., [22–24]).

The Delphi method is [25] is based on the collection of data from the participants' field of expertise with the aim of achieving the consensus through a series of questionnaires. Its main advantages are anonymity, iteration, controlled feedback, statistical group response and stability in responses among the experts on a specific issue, while the main disadvantages are that it is time-consuming, costly and has a lower questionnaire return rate [26]. In addition, the problems of imprecise, vague and ambiguous evaluations of the experts, due to incomplete information or inability of their treatment in a decision environment, are also present [27]. In order to overcome the identified disadvantages of the traditional Delphi method Murry et al. [28] proposed the extension of the method in the fuzzy environment. Since then, the fuzzy Delphi method has been used for solving various problems, either alone or in a combination with other methods (e.g., [26,27]). The fuzzy Delphi method is used in this paper because it allows integration of the decision-makers' opinions in the process of the group decision-making by obtaining the converged responses with fewer survey rounds, or even in a single round, and effectively conducts the ambiguity and uncertainty of their evaluations.

The ANP is a general form of the analytical hierarchy process (AHP) first introduced by Saaty [29]. Unlike the AHP, the ANP enables interrelationships among the decision levels and elements by forming the network structure. By adding potential interactions, interdependencies and feedbacks, the method evaluates all relationships between clusters of the network structure and elements and obtains the composite weights. This has been done through the development of a supermatrix composed of sub-matrices indicating the interactions and interdependencies between the elements. This allows the ANP method to adequately model and systematically examine the complex real-life problems. The main advantages of the ANP method are the ability to prioritize groups or clusters of elements, it considers both dependence and independence of elements, allows the judgments consistency check and facilitates weights assignment by splitting up the problem into smaller parts, while the main disadvantages are the inability to evaluate one element in isolation and identify its weaknesses and strengths and the exponential growth of the problem complexity with the increased number of elements and their interdependencies [30]. The ANP method also has a problem of experts' imprecise judgments on decision factors, which can be solved by applying fuzzy theory. The fuzzy ANP method was proposed by Mikhailov [31] and since then, it has been applied in many fields, either alone or in a combination with other methods (e.g., [26,30,32]). The fuzzy ANP is used in the paper since the elements of the problem in this paper (requirements and features) form a network structure due to their interdependencies.

There are some examples in the literature of combining the ANP and QFD methods, in a conventional form (e.g., [24,33]), or in a fuzzy environment (e.g., [34]), as well as examples of applying the fuzzy Delphi based fuzzy ANP (fuzzy DANP) method (e.g., [26]) for solving various problems. There are also examples of combining the Delphi method (e.g., [35]), as well as some other multi-criteria decision-making (MCDM) methods with the QFD in the fuzzy environment (e.g., [36]). However, there are no examples in the literature of combining the Delphi, ANP and QFD methods in the fuzzy environment, which is one of the main contributions of the paper. In relation to the above mentioned studies, the proposed model is similar to the afore mentioned in terms that it is hybrid, i.e., it combines various methods, but unlike them it combines QFD with the fuzzy Delphi based fuzzy ANP method, which allows comprehensive overview of the problem elements' dependencies and their prioritization through the unified evaluations.

2.2. Intermodal Terminals as Nodes in the Logistics Networks

Economic development and globalization led to a significant increase in the cargo volumes between the producers and consumers, and consequently, to the need for planning and design of logistics networks for the efficient realization of these flows. In this process, it is necessary to make a number of decisions concerning the nodes in the network (LCs), allocation of users and flows to the network participants, transport modes and means, i.e., about all the factors that affect the network flows [37]. As some of the most important elements of the network, LCs are the subject of numerous studies related to their number and location (e.g., [38]), functions (e.g., [39,40]), connection possibilities (e.g., [41]). The existing literature also recognizes ambiguity on the conceptual boundaries of logistics centres [10]. Höltgen [42], for example, tried to find a unique definition for intermodal logistics centers, since the concept varies from country to country; however, there is a common ground: it should contribute to intermodal transport, promote regional economic activity and improve land use and local goods distribution. Considering the type of goods, mode of transport, transport technology, functions and subsystems, etc., LCs can be classified as goods terminals, freight villages, inland terminals, city logistics terminals, distribution centers, freight centers, hub terminals, dry ports, inland container centers, etc. [10,43], among which the intermodal terminals are particularly significant due to their overall contribution to the logistics network operation. An intermodal terminal is not only a physical configuration of pavement and tracks, but an organization of integrated services that meets the business needs of a specific marketplace [44]. With increasing awareness of the importance and benefits of the intermodal transport increases the research interest for the same. Caris et al. [45] have classified intermodal transport research based on the following topics: political support (e.g., [46]), design of the terminal network (e.g., [47]), design of intermodal services (e.g., [48]), intermodal routing (e.g., [49]), operations of container drayage (e.g., [50]), use of innovative information and communication technologies (e.g., [51]). In addition, in the literature one can find the examples of solving the problems concerning transshipment technologies (e.g., [52]), costs analysis (e.g., [53]), transportation units (e.g., [54]), terminal location [11,12,26,55], selection of the efficient terminal types [56], evaluation of the terminal technologies [16], evaluation of the basic characteristics of the different types of intermodal terminal [10,57], evaluation of the logistics performance for freight mode choice at intermodal terminal [58], measuring the terminal performance [59], optimization of the zones for temporary container storage [60], spatial optimization of the terminal subsystems, i.e., layout optimization [61], etc. The special class of researches deals with the various problems of intermodal terminals, and intermodal transport in general, with the focus on the sustainability, e.g., loading optimization in intermodal terminal considering energy consumption [62,63], terminal location selection for development of the sustainable transport system [64], integration of various technologies in intermodal transport chains (e.g., [65,66]), container routing in a sustainable intermodal transport systems [67], etc.

3. Proposed Hybrid Model

This paper proposes a new hybrid model based on the combination of the Delphi, ANP and QFD methods in the fuzzy environment for the solution of the defined problem, i.e., for definition of the development features and their evaluation in the process of intermodal terminal planning. Model structures the problem according to the QFD method, i.e., it begins with forming the HOQ. In order to establish connections between structural elements of the HOQ and to determine the final weights of the elements the fuzzy DANP method is used. As the structural elements are evaluated by representatives of various stakeholders, fuzzy Delphi part is introduced in order to unify their evaluations. The following explains the steps of applying a hybrid model, which is with minimal adjustments universally applicable for the development and evaluation of products, services, etc. in any field. The general view of the proposed model is shown in Figure 1.

Step 1: Define the problem to be solved and identify the stakeholders interested in its solution.

Step 2: Define the problem structure, elements of which are users' requirements (stakeholders' requirements in this paper) and developmental features of the products/services (intermodal terminal in this paper).

Step 3: Form the HOQ by establishing the relations (interdependences) between the structural elements (users' requirements and development features).

Step 4: Define the fuzzy linguistic scale for evaluation. Connections between the structural elements (users' requirements and development features) and the significance of the elements are defined based on the decision-makers' opinions. Decision-makers are stakeholders' representatives and experts. Opinions of stakeholders' representatives are collected through the interviews and questionnaires, based on which the expert evaluations are formed. Evaluations are then transformed into triangular fuzzy numbers using the fuzzy scale given in Table 1.

Table 1. Linguistic terms and corresponding fuzzy values.

Linguistic Term	Abbreviations	Fuzzy Scale
None	N	(1, 1, 2)
Very Low	VL	(1, 2, 3)
Low	L	(2, 3, 4)
Fairly Low	FL	(3, 4, 5)
Medium	M	(4, 5, 6)
Fairly High	FH	(5, 6, 7)
High	H	(6, 7, 8)
Very High	VH	(7, 8, 9)
Extremely High	EH	(8, 9, 9)

Step 5: Obtain the matrices of the elements' interdependencies strengths.

Step 5.1: Obtain the pairwise comparisons of all interdependent elements in relation to all stakeholders (by the experts), transform the evaluations into triangular fuzzy numbers (using the relations given in Table 1) and unify the assessment using the fuzzy Delphi method [68]:

$$\widetilde{\delta} = (\alpha, \beta, \gamma) \tag{1}$$

$$\alpha = Min(l_h), \ \ h = 1, \ldots, o \tag{2}$$

$$\beta = \left(\prod_{h=1}^{o} m_h \right)^{1/o}, \ \ h = 1, \ldots, o \tag{3}$$

$$\gamma = Max(u_h), \ \ h = 1, \ldots, o \tag{4}$$

where α, β and γ are lower, medium and upper values of the unified fuzzy evaluation $\widetilde{\delta}$, respectively, and $\alpha \leq \beta \leq \gamma$. l_h, m_h and u_h are lower, medium and upper values of the triangular fuzzy evaluation which indicate the importance of the element in relation to the stakeholder h. o is the number of the considered stakeholders.

Step 5.2: Calculate the relative weights of the elements. Unified fuzzy evaluations of the elements form the fuzzy judgment matrix $\widetilde{\Delta}^I$:

$$\widetilde{\Delta}^I = \begin{bmatrix} \widetilde{\delta}^I{}_{11} & \widetilde{\delta}^I{}_{12} & \cdots & \widetilde{\delta}^I{}_{1n} \\ \widetilde{\delta}^I{}_{21} & \widetilde{\delta}^I{}_{22} & \cdots & \widetilde{\delta}^I{}_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ \widetilde{\delta}^I{}_{n1} & \widetilde{\delta}^I{}_{n2} & \cdots & \widetilde{\delta}^I{}_{nn} \end{bmatrix} \tag{5}$$

where $\widetilde{\delta}^I{}_{ij} = \left(\alpha_{ij}, \beta_{ij}, \gamma_{ij}\right)$ indicates the unified fuzzy value of importance of element i over element j, and i,j = 1, ..., n, where n is the number of elements.

The priority vectors for each pairwise comparison matrix have to be obtained. The priority vector can be obtained from the fuzzy matrix $\widetilde{\Delta}^I$ in various ways. This paper uses the "logarithmic fuzzy preference programming" (LFPP) [69] method which approximates the triangular fuzzy judgments $\widetilde{\delta}^I{}_{ij} = \left(\alpha_{ij}, \beta_{ij}, \gamma_{ij}\right)$ from the matrix $\widetilde{\Delta}^I$ using the equation:

$$\ln \widetilde{\delta}^I{}_{ij} \approx \left(\ln \alpha_{ij}, \ln \beta_{ij}, \ln \gamma_{ij}\right), \ i, j = 1, 2, \ldots, n \tag{6}$$

For obtaining the elements' weights (w_i) the following nonlinear priority model is proposed:

$$\begin{aligned} & Min\, J = (1-\lambda)^2 + M \cdot \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} \left(\varepsilon_{ij}^2 + \eta_{ij}^2\right) \\ & s.t. \begin{cases} x_i - x_j - \lambda \ln\left(\beta_{ij}/\alpha_{ij}\right) + \varepsilon_{ij} \geq \ln \alpha_{ij}, \ i = 1, \ldots, n-1; \ j = i+1, \ldots, n, \\ -x_i + x_j - \lambda \ln\left(\gamma_{ij}/\beta_{ij}\right) + \eta_{ij} \geq -\ln \gamma_{ij}, \ i = 1, \ldots, n-1; \ j = i+1, \ldots, n, \\ \lambda, x_i \geq 0, \ i = 1, \ldots, n, \\ \varepsilon_{ij}, \eta_{ij} \geq 0, \ i = 1, \ldots, n-1; \ j = i+1, \ldots, n, \end{cases} \end{aligned} \tag{7}$$

where $x_{i,j} = lnw_{i,j}$ for i = 1, ..., n, j = i + 1, ..., n, and M is a specified sufficiently large constant such as M = 10^3. ε_{ij} and η_{ij} for i = 1, ..., n − 1 and j = 1, ..., n are the nonnegative deviation variables introduced to avoid membership degree λ from taking a negative value. It is most desirable that the values of the deviation variables are as small as possible, and they have to meet the following inequalities:

$$\ln w_i - \ln w_j - \lambda \ln\left(\beta_{ij}/\alpha_{ij}\right) + \varepsilon_{ij} \geq \ln \alpha_{ij}, \ i = 1, \ldots, n-1; \ j = i+1, \ldots, n,$$

$$-\ln w_i + \ln w_j - \lambda \ln\left(\gamma_{ij}/\beta_{ij}\right) + \eta_{ij} \geq -\ln \gamma_{ij}, \ i = 1, \ldots, n-1; \ j = i+1, \ldots, n.$$

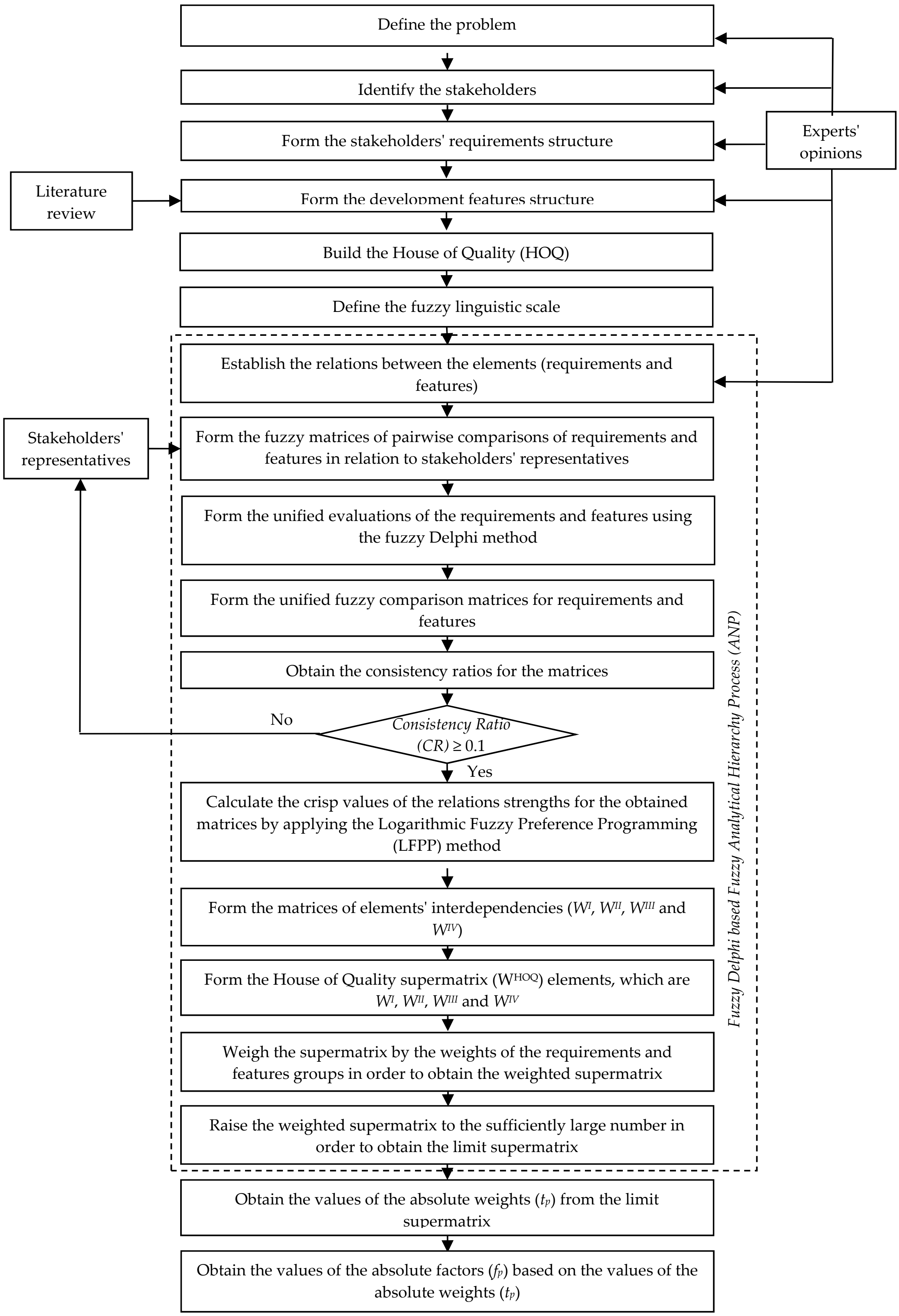

Figure 1. The proposed hybrid MCDM model.

Let $x_i^*(i = 1, \ldots, n)$ be the optimal solution to model (7). The normalized priorities for fuzzy pairwise comparison matrix $\widetilde{\Delta}^I = \left(\widetilde{\delta}^I{}_{ij}\right)_{n \times n}$ can then be obtained as:

$$w_i^* = \exp\left(x_i^*\right) / \sum_{j=1}^{n} \exp\left(x_j^*\right),\ i = 1, \ldots, n, \tag{8}$$

where exp() is the exponential function, namely $\exp\left(x_{i,j}^*\right) = e^{x_{i,j}^*}$ for i = 1, ..., n, j = i + 1, ..., n. This method results in crisp normalized weights.

In order to control the result of the method, the Consistency Ratio (CR) for each matrix is calculated as follows [29]:

$$CR = CI/RI \tag{9}$$

where CI is the Consistency Index and is calculated as follows:

$$CI = (\lambda_{\max} - n)/(n - 1) \tag{10}$$

$\lambda_{\max}$ is the Perron root or principal eigenvalue of the matrix $\widetilde{\Delta}^I$. RI is the Random Index whose values for matrices of various sizes can be seen in [29]. The comparisons are acceptable only if the CR values are less than 0.10.

Step 6: Form the HOQ supermatrix (W^{HOQ}) elements of which are the matrices of the elements' interdependencies:

$$W^{HOQ} = \begin{matrix} \\ Stakeholders'\ requirements\ (\mathrm{Req.}) \\ Development\ features\ (Fea.) \end{matrix} \begin{matrix} \mathrm{Req.} & Fea. \\ \left(\begin{matrix} W^I & W^{IV} \\ W^{III} & W^{II} \end{matrix} \right) \end{matrix} \tag{11}$$

Step 7: Obtain the weighted supermatrix. This matrix is obtained by multiplying the matrix W^{HOQ} with the weights of the requirements and development features categories. Categories are established by classifying the requirements and development features according to their economic and social affiliations. As the different categories are of different importance for the stakeholders, they are evaluated and priority vectors are obtained in the same way as for the elements' weights, the procedure of which is already described in the step 5.2.

Step 8: Obtain the limit supermatrix. Raising the supermatrix to the power $2p$ + 1, where p is a sufficiently large number, the matrix is converging, i.e., the row values of the matrix are converging to the same values for every column of the matrix [70]. Obtained matrix is called the limit supermatrix.

Step 9: Obtain the absolute weights (t_p) and absolute factors (f_p) of the development features. Converged values by the developmental features (obtained in the limit supermatrix) adopt as the absolute weights of the development features, and then calculate the absolute factors using the following equation:

$$f_p = t_p / \sum_{p=1}^{m} t_p,\ p = 1, \ldots, m \tag{12}$$

Step 10: Rank the developmental features according to the decreasing values of the absolute factors (f_p).

4. Planning of the Intermodal Terminal in Belgrade

Application of the proposed hybrid model for LC planning is demonstrated by planning the intermodal terminal in Belgrade, Serbia. The adoption and establishment of intermodal terminal in Belgrade is the most important initiative for the development of intermodal transport, and logistics in general, in Serbia and the region [1]. The problem is structured as a QFD problem in which the "users" requirements are actually defined as the requirements of various stakeholders' members (Investors, owners and operators—Inv., Users—Use., and Authorities and residents—Aut.) which have different and often conflicting objectives and requirements [71–73]. Investors, owners and operators of the terminal have the objective to build a terminal, run it and provide the services at a level that meets the users' requirements and respects the specific demands of the authorities and residents, with as little initial investment, operating and other expenses as possible, in order to achieve the greatest possible profit. Terminal users (shippers, logistics service providers, transport operators, etc.) aim to get as adequate and quality service as possible, at an affordable price. Main objectives of the authorities and residents are economic development and job creation, while improving the environmental protection, safety and health protection.

4.1. Stakeholders' Requirements

The requirements in the process of planning the intermodal terminal in Belgrade are defined according to the literature review on the objectives of the stakeholders [55,71–73] and experience of the authors of this paper on the projects related to the intermodal transportation (IMOD-X [74], Facilitating Intermodal Transport in Serbia [75], Feasibility study for Logistic Centre and Intermodal Terminal Vršac [76]). There are a total of 21 requirements, classified into four categories: economic (Ec), environmental (En), infrastructural (In) and service quality (Qu) requirements are defined.

The first category of the stakeholders' requirements consists of the economic requirements.

Ec_1—Contribution to the economic development: when planning the terminal, one must take into account its impact on the development of local, regional and national economy. All stakeholders, although with a different level of importance, benefit from the positive impact of the terminal to the economy.

Ec_2—Small investments for the terminal construction: terminal construction requires significant resources therefore the aim is to have these investments as small as possible. Logically, this requirement is the most important for investors.

Ec_3—Low land price: price of the land on which it is planned the construction of the terminal depends on various factors and may be a very important item in the planning and construction of the terminal. It is important for investors that this price is as low as possible.

Ec_4—Low operating costs: operating costs include the costs of all activities and processes that occur within the terminal. It is important for investors, operators and owners that they are as low as possible, which enables them to maximize their profit. On the other hand, low operating costs affect the price of the services; therefore, they are also important for the users.

Ec_5—Low labor costs: the same as in the case of operating costs, it is essential for the investors, owners, operators and users that these costs are as low as possible.

The second category consists of the environmental requirements.

En_1—Fitting into surroundings: visual fitting of the terminal facilities into the surroundings is certainly most important for the authorities and residents, but investors and owners have to take care about this issue as well if they want to achieve the status of a socially responsible company.

En_2—Low vibrations and noise emissions: vibration and noise occurring as a result of the traffic flows to and from the terminal, as well as inside the terminal, must be at the lowest possible level. As for most requirements of this category, the highest attention for this requirement is paid by the residents and authorities, but should not be ignored by the other stakeholders.

En_3—Low gas emissions and energy consumption: the same as in the case of vibration and noise, the aim here is to obtain the lowest possible level of emissions and consumption of the non-renewable energy. The effects of achieving this requirement are twofold. On a local scale they improve the atmospheric conditions in the areas affected by the freight vehicles, and on a global scale they reduce the carbon footprint, initiate more intensive use of the renewable energy and promote the sustainable development in general. However, this requirement gains additional attention if a much broader range of negative effects is taken into account and the fact that it has no local character (as it is the case with the vibration and noise, effects of which are noticeable only at their source).

En_4—Low traffic congestion: traffic congestion as a result of the increased number of freight vehicles on the network, and especially on the links directly connecting the terminal, due to more intensive freight and transport flows generated by putting the terminal into operation, should be as low as possible. This requirement ensures the sustainable development of the transport networks and it is quite important to all stakeholders because its failure can generate a number of negative effects.

En_5—Fewer incidents: situations that may lead to the adverse effects on the environment and human life and health, either in traffic or in the terminal itself, must be kept to a minimum.

En_6—Resilience of the terminal: the terminal and its subsystems, operators, activities, users etc., should be able to withstand, react and recover from disruptive events (e.g., natural disasters, epidemics, cyber-threats, etc.) in order to diminish the damage to property and equipment and massive interruptions in providing the services. The third category of the requirements consists of infrastructural requirements.

In_1—The possibility of building and expansion: a very important requirement in the process of terminal planning, especially for investors, is the possibility of building on the location and the potential for future expansions in order to provide required capacity. This is largely dictated by the land-use defined by the various plans and strategies, as well as by geographic, topographic, geological characteristics and the existing objects on the site.

In_2—The existence of adequate facilities and equipment: it is essential that the terminal has adequate facilities and equipment, in terms of capacity, operational characteristics and capability to process a given level of demand in compliance with quality standards and regulation, in order to achieve high quality process implementation. This requirement is important for users, investors, owners and operators of the terminal.

In_3—The use of various transport modes: positive effects of the intermodal transportation significantly rise by increasing the number of different transport modes that can be used. As the intermodal transportation is crucial for achieving sustainable transport development, and therefore beneficial for all stakeholders, this requirement is very important for each of them.

In_4—Location availability: undisturbed and good access to a terminal location is very important for the smooth flows realization and terminal operations. The request is particularly important for the investors, owners, operators and users.

In_5—Adequate utility supply: regular and uninterrupted supply of water, electricity, gas and other consumables is necessary in order to ensure proper terminal operation, activities implementation and stay of people within the terminal. The request is significant for users, as well as for investors, owners and operators.

The fourth category of the requirements consists of service quality requirements.

Qu_1—Efficient activities realization: it is very important to achieve a higher quality of service with the rational use of various resources (time, money, human). The request is important for investors, owners, operators and users.

Qu_2—Service flexibility: ability to adapt in a reasonable period of time to the new requirements or changes in the requirements, which may arise as a result of various influences and at the initiative of different stakeholder members, is very important for the service quality. Like most of the requirements in this category, it is particularly important for the users.

Qu_3—Reliability: successful implementation of services according to the defined and imposed requirements, in terms of time, place, structure, etc., and the ability to meet the distribution requirements in all likely scenarios (following the concept of the recovery robustness [77]) is of key importance for the service quality. This requirement is primarily important for the users.

Qu_4—Availability: the service must be available to a wide range of users at the time the same is needed. This is also important for the terminal operators whose goal is to have as many users of the terminal services as possible.

Qu_5—VAL services: value added logistics services significantly affect the service quality as they offer opportunities to the customers that they otherwise would not have expected, while for the operators they create the possibility for generating the additional income.

Qu_6—Safety and security of goods, means, and people: the care about life and health of the people, technical condition of the vehicles and other assets, the quality of goods, etc., is very important for all stakeholders.

4.2. Development Features of the Intermodal Terminal

In order to transfer the stakeholders' requests onto the terminal design, development features of the intermodal terminal are defined in accordance with Zečević [43], as well as through a panel of experts participating in a variety of projects such as IMOD-X [74], Facilitating Intermodal Transport in Serbia [75], Feasibility study for Logistic Centre and Intermodal Terminal Vršac [76]. The features are classified into three categories: political and economic (Po), technological (Th) and technical (Tn).

The first category consists of political and economic features.

Po_1—Connection with other terminals in the network: inclusion of the terminal in the logistics network generates numerous effects such as attracting the larger volumes of freight and transport flows, offering the greater range and quality of services (e.g., door to door services), reducing the costs and time of transport, better supply chain management, etc.

Po_2—Subsidies: local, regional and national authorities can offer certain subsidies to facilitate the construction and operation of the terminal, thus creating a favorable climate and conditions for the successful development of the terminal.

Po_3—Adequate tax policy: tax policy can significantly affect the construction and operation of the terminal; therefore, it is important to be carefully planned and defined.

Po_4—Adoption of strategies and plans: it is very important to define and adopt the strategies and development plans that serve as a framework for decision-making and implementation of the activities according to the imposed objectives.

The second category consists of technological features.

Th_1—Wide range of intermodal terminal services and functions: definition and development of a large number of intermodal terminal functions and offering of a wide range of services for different types of goods (including some special goods such as hazardous materials, live animals, etc.), attracts more users and volumes of freight and transport flows, enables higher revenues, creates more jobs and directly contributes to the economic development.

Th_2—Application of modern technologies: modern technologies that imply automation and software solutions for monitoring, controlling and managing various processes related to the intermodal terminal enables more efficient and better implementation of all activities, environmental protection, increased security, etc.

Th_3—Adequate planning of facilities and premises: adequate planning and design reduces investment and operating costs, reduces negative impacts of the terminal and processes within it on the environment, increases the service quality and enables the possibility of a phased development and expansion of the terminal according to the future demands and needs.

Th_4—Use of appropriate equipment: equipment, i.e., hardware in the most general sense (vehicles, tools, fixtures, devices etc.) in all subsystems of the terminal must be in accordance with the requirements and defined standards and procedures in order to ensure the adequate implementation of all activities.

Th_5—Hiring qualified workforce: in order to properly encircle all technological processes, it is necessary to hire a skilled workforce that is able to maximize the use of technology, equipment and facilities of the terminal.

The third category of intermodal terminal development features consists of technical features.

Tn_1—Adequate location selection: adequate terminal location which represents a compromise solution in terms of various criteria groups, such as: land use (property, available space, various plans etc.), connectivity (with various networks and transport modes, potential flows generators/demand attractors etc.), environmental impact (protected and residential areas etc.), economic and social criteria (costs, employment etc.), physical criteria (geography, geology, topology etc.) and utilities (water supply, sewage, electricity etc.), are one of the most important factors for the successful terminal operation. Therefore, this decision must be carefully made and requires extensive analysis.

Tn_2—Development of the infrastructure for the various transport modes: as intermodal transport involves the use of various transport modes, infrastructure of which is usually not at the same level of development, it is necessary to make efforts in the construction of new and improvement of the existing infrastructure for all transport modes, by which the terminal can be connected, in order to improve the availability of the terminal, increase the efficiency of the freight and transport flows and facilitate the inclusion of the terminal in the logistics network.

Tn_3—Interconnection of various transport modes: this feature is correlated with the previous one and involves the necessary steps and application of various technical and technological solutions for effective connection and successful functioning of the various transport modes within the terminal, i.e., effective change of transport modes and application of various intermodal transport technologies.

Tn_4—Development of adequate utility infrastructure: the terminal must have adequate connections and stable supply of electricity, water, gas, etc. and it is necessary to conduct actions on building new and maintaining the existing infrastructure.

Tn_5—Adoption and compliance with procedures and standards: to ensure successful and safe operation of the terminal and quality implementation of all activities and services, it is necessary to define and comply with the certain procedures and standards.

4.3. Application of the Proposed Model for Intermodal Terminal Planning

This paper solves the problem of planning the intermodal terminal in Belgrade, for solving of which various stakeholders, listed above, are interested (Step 1). The stakeholders' requirements, described in more detail in Section 4.1 (Step 2), and the intermodal terminal development features defined according to the requirements and described in the Section 4.2 (Step 2), represent the structural elements of the problem. The problem is defined and set up as a QFD problem, i.e., the HOQ, given in Figure 2, is formed by establishing the interconnections between the elements, (Step 3). The direction of the arrow points to the requirement or the feature being under influence of some other requirement or the feature.

The defined problem, with the established interrelations between the elements that form a network structure, is further being solved as an ANP problem, i.e., by applying the fuzzy DANP method. For the comparisons of the interrelated elements, the linguistic scale is used, which can be converted into the fuzzy scale by applying the relations given in Table 1 (Step 4).

The aim of the next step is to obtain the matrices W^I, W^{II}, W^{III} and W^{IV} by applying the described methodology (Step 5). The matrix is formed by the priority vectors, which indicate the strengths of the interdependencies between the stakeholders' requirements, those who belong to the same category as well as between those who belong to the different categories. These priority vectors are obtained by applying the fuzzy DANP method, and the procedure is demonstrated for the case of determining the priority vector of economic demands in relation to the requirement "Contribution to the economic development" (Ec_1). First, it is necessary to make a comparison of all interdependent elements by the stakeholders' representatives (Table 2), using the linguistic evaluations which can be converted into the fuzzy numbers by applying the scale given in Table 1.

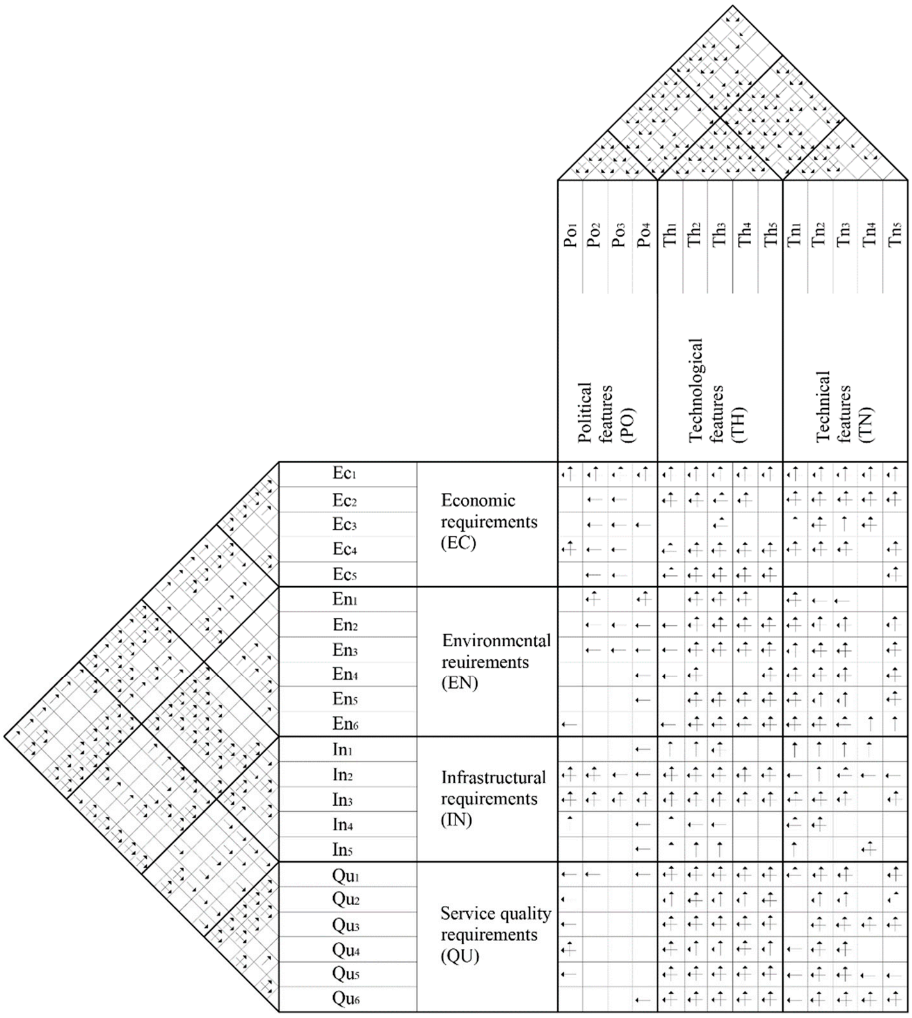

Figure 2. House of Quality for the intermodal transport terminal planning.

Table 2. Pairwise comparisons of Ec requirements in relation to requirement Ec_1

	Ec_2			**Ec_3**			**Ec_4**			**Ec_5**		
	Inv.	**Use.**	**Aut.**	**Inv.**	**Use.**	**Aut.**	**Inv.**	**Use.**	**Aut.**	**Inv.**	**Use.**	**Aut.**
Ec_2				VL	VL	N	L		VL	L		VL
Ec_3							VL		VL	N		VL
Ec_4		VL			L					N	N	N
Ec_5												

By applying Equations (1)–(4) (Step 5.1), unified evaluations of the requirements are obtained, i.e., the fuzzy judgment matrix given in Table 3 is obtained. Other relations are established in the same manner.

Table 3. Unified evaluations of the pairwise comparison of Ec in relation to Ec_1.

	Ec_2	**Ec_3**	**Ec_4**	**Ec_5**
Ec_2	/	(1.00, 1.32, 3.00)	(0.33, 1.25, 4.00)	(0.33, 1.25, 4.00)
Ec_3	(0.33, 0.76, 1.00)	/	(0.25, 1.06, 3.00)	(0.25, 0.92, 3.00)
Ec_4	(0.25, 0.80, 3.00)	(0.33, 0.94, 4.00)	/	(1.00, 1.00, 2.00)
Ec_5	(0.25, 0.80, 3.00)	(0.33, 1.08, 4.00)	(0.50, 1.00, 1.00)	/

Relative weights of the elements for the defined fuzzy matrices are obtained (Step 5.2) by solving the non-linear priority model (7) and normalizing the obtained values using the Equation (8). In order to control the results, CR values for each matrix are obtained using the Equation (9). By applying the described procedure the weight vector (Ec_2, Ec_3, Ec_4, Ec_5) = (0.309, 0.235, 0.228, 0.228) for the evaluations of the economic requirements (given in Table 3) is obtained. The value of CR = 0.094 is obtained for this matrix, which is less than 0.10, therefore it can be said that the comparison is acceptable. All the other weights for the established relations are obtained in the same manner and all CR values were less than 0.10. Obtained weight vectors formed the matrix W^I. The matrix of interdependencies strengths between the development features (W^{II}), as well as the matrices of interdependencies strengths between the stakeholders' requirements and the development features (W^{III} and W^{IV}), are obtained in the same manner.

Matrices W^I, W^{II}, W^{III} and W^{IV} form the HOQ supermatrix (W^{HOQ}) (Step 6). Supermatrix is then weighted (Step 7) by the weights of the requirement and development features categories, obtained in the same manner as the priority vectors in the Step 5, and after the pairwise comparison of interdependent requirement and development feature categories. By raising the initial supermatrix to the power $2p + 1$, where p is a sufficiently large number, the matrix is converging thus forming the limit supermatrix (Step 8). The limit supermatrix is obtained by applying the software SuperDecisions made by Creative Decisions Foundation (n.d.). Converged values in the rows representing the development features (obtained in the limit supermatrix) are adopted as the absolute weights of the development features, based on which the absolute factors are obtained using the Equation (12) (Step 9). Absolute weights, absolute factors and ranking of the development features are given in Table 4.

Table 4. Absolute factors and ranking of development features.

	Po_1	Po_2	Po_3	Po_4	Th_1	Th_2	Th_3	Th_4	Th_5	Tn_1	Tn_2	Tn_3	Tn_4	Tn_5
t_p	0.060	0.061	0.010	0.021	0.053	0.034	0.060	0.029	0.036	0.068	0.059	0.054	0.006	0.024
f_p	0.104	0.107	0.017	0.037	0.092	0.059	0.104	0.051	0.062	0.118	0.102	0.094	0.011	0.042
Rank	4	2	13	12	7	9	3	10	8	1	5	6	14	11

4.4. Sensitivity Analysis

In order to examine the stability of the obtained solution, a sensitivity analysis was performed in which it was examined the influence of the change of certain parameters on the result. For this purpose, seven additional scenarios have been defined, each of which implied the exclusion of one of the seven most important stakeholders' requirements, i.e., the ones with the greatest impact on the development features. The scenarios excluded In_3 (Sc.1), Ec_1 (Sc.2), Ec_2 (Sc.3), Ec_4 (Sc.4), Qu_1 (Sc.5), En_6 (Sc.6) and En_2 (Sc.7), respectively. The results obtained in these scenarios are shown in Table 5, and changes in the final ranking of the development features, in relation to the initial (basic) scenario are shown in Figure 3. As it can be seen from the results, in all scenarios the Tn_1 was ranked as the first, the Po_2 was ranked as the second in all scenarios but the Sc.2, the Th_3 was ranked as the third in four scenarios while in the remained ones it was ranked as the fourth and fifth, while the ranking of the Po_1 was ranging from the second to the fourth, with an exception in the Sc.4, in which it was ranked as the seventh. The remainder of the development features had much lower values of the absolute factors and did not have significant changes in the ranking. Having in mind all of the above, it can be concluded that the obtained results are stable enough and that the most important development features are "Adequate location selection" (Tn_1), "Subsidies" (Po_2), "Adequate planning of facilities and premises" (Th_3), "Connection with other terminals in the network" (Po_1). The least important development feature according to the results is "Development of adequate utility infrastructure" (Tn_4).

Table 5. Sensitivity analysis.

		Po_1	Po_2	Po_3	Po_4	Th_1	Th_2	Th_3	Th_4	Th_5	Tn_1	Tn_2	Tn_3	Tn_4	Tn_5
	t_p	0.062	0.063	0.008	0.019	0.056	0.034	0.061	0.029	0.035	0.068	0.062	0.056	0.006	0.023
Sc.1	f_p	0.107	0.108	0.014	0.033	0.096	0.058	0.104	0.050	0.061	0.116	0.106	0.096	0.011	0.040
	Rank	3	2	13	12	7	9	5	10	8	1	4	6	14	11
	t_p	0.060	0.058	0.008	0.019	0.054	0.034	0.060	0.030	0.036	0.067	0.059	0.055	0.006	0.027
Sc.2	f_p	0.105	0.101	0.014	0.033	0.094	0.060	0.105	0.052	0.062	0.117	0.103	0.095	0.010	0.048
	Rank	2	5	13	12	7	9	3	10	8	1	4	6	14	11
	t_p	0.062	0.063	0.010	0.022	0.052	0.033	0.061	0.029	0.037	0.067	0.059	0.054	0.006	0.026
Sc.3	f_p	0.107	0.108	0.018	0.038	0.089	0.057	0.105	0.050	0.064	0.116	0.101	0.093	0.010	0.044
	Rank	3	2	13	12	7	9	4	10	8	1	5	6	14	11
	t_p	0.054	0.063	0.010	0.022	0.054	0.034	0.061	0.029	0.035	0.069	0.059	0.054	0.007	0.025
Sc.4	f_p	0.093	0.109	0.018	0.039	0.094	0.059	0.106	0.051	0.061	0.119	0.102	0.094	0.012	0.043
	Rank	7	2	13	12	6	9	3	10	8	1	4	5	14	11
	t_p	0.061	0.062	0.010	0.022	0.053	0.034	0.060	0.029	0.036	0.066	0.060	0.055	0.007	0.024
Sc.5	f_p	0.105	0.107	0.018	0.038	0.091	0.058	0.104	0.050	0.062	0.114	0.103	0.095	0.011	0.042
	Rank	3	2	13	12	7	9	4	10	8	1	5	6	14	11
	t_p	0.060	0.063	0.010	0.022	0.053	0.034	0.061	0.029	0.036	0.069	0.060	0.055	0.005	0.024
Sc.6	f_p	0.104	0.108	0.018	0.038	0.092	0.058	0.104	0.050	0.062	0.118	0.103	0.094	0.009	0.042
	Rank	4	2	13	12	7	9	3	10	8	1	5	6	14	11
	t_p	0.059	0.062	0.010	0.022	0.053	0.034	0.060	0.029	0.036	0.068	0.059	0.054	0.006	0.024
Sc.7	f_p	0.103	0.107	0.017	0.037	0.092	0.059	0.104	0.050	0.062	0.118	0.102	0.094	0.011	0.042
	Rank	4	2	13	12	7	9	3	10	8	1	5	6	14	11

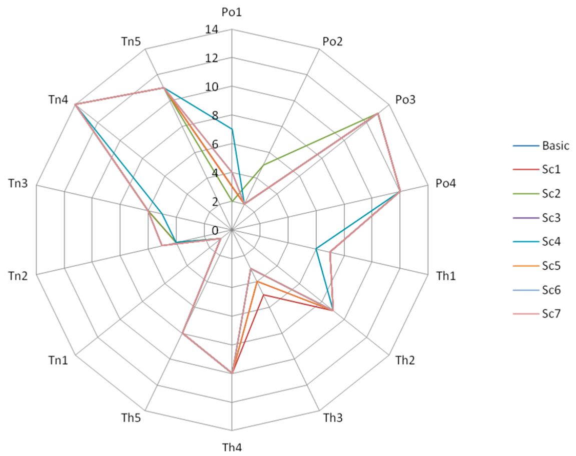

Figure 3. Sensitivity analysis.

4.5. Discussion of the Obtained Results and Analysis of the Proposed Approach

"Adequate location selection" (Tn_1) is considered as the most important intermodal terminal development feature with the value of the absolute factor of 0.118. The efficiency of the terminal and intermodal transport in general largely dependents on the location. Location also plays a key role in improving the competitive advantage in the market. Location is the basis for the development and proper utilization of intermodal transport networks and the improvement of the intermodal transport attractiveness. The terminal location concerns all stakeholders and plays a significant role in meeting their individual demands. Second development feature by relevance, with the value of the absolute factor of 0.108, is "Subsidies" (Po_2). Planning, construction and successful operation of the terminal is impossible without adequate support by the local, regional and national authorities. Construction of the terminal requires significant investments, and the terminal is exploited during the longer period of time, but the investment returns are very slow in the initial stages of the terminal development and exploitation, which generates risk for the private investors. Therefore, the support by the public authorities becomes the key element for the successful development of the terminal. Through this support, the conditions for providing the high quality services at affordable prices for the terminal users are also achieved. On the other hand, considering the area it serves and the effects it has on the local economy, the terminal becomes the major development factor of the region in which it is located, which is very important for the authorities and residents. Third-ranked development feature, with the value of 0.104, is "Adequate planning of facilities and premises" (Th_3). Planning of the terminal facilities, their dimensioning, technological connection, spatial integration, proper maintenance and security, etc., is very important for the high quality operation and implementation of the terminal services. This feature is, directly or indirectly, important for all stakeholders. Next, the development feature, also with the value of the absolute factor of 0.104, is "Connection with other terminals in the network" (Po_1). Incorporation of the terminal into a network generates the conditions for increasing the freight flow volumes which is important for investors, owners and operators of the terminal, because it allows them to generate more profit. When planning the intermodal terminal, the most attention should be paid to these developmental features in order to develop a terminal that would be in accordance with the requirements of all stakeholders. However, in this process, one should not completely neglect the other features, which were ranked lower in the process of planning (Table 4), that are more or less contributing to the performance of the terminal.

The implications of the obtained results and ranking of the developmental features in the case of intermodal terminal planning in Belgrade are the following. Most attention should be paid to the selection of the appropriate location which would be in line with the requirements of all stakeholders involved in the decision-making process, through defining an extensive set of criteria, as well as the adequate planning of facilities and premises in the terminal for which a multidisciplinary team of experts should be assembled and led by the logistics engineers. In addition, certain political activities and the promotion of the importance of intermodal terminals for the sustainable development should be carried out in order to ensure the widest possible support of local and national authorities, which would enable the construction and profitable operation of the terminal in the initial phases by granting subsidies. Certain activities should also be carried out in order to establish links, first with other terminals and logistics centers in the immediate surroundings, and then in the wider area, in order to adequately place the terminal into the existing network and ensure future sustainable growth and development. Of course, the implementation of other development features would additionally contribute to the further successful development of the intermodal terminal.

The applicability of the proposed model which combines Delphi, ANP and QFD methods in the fuzzy environment is demonstrated by solving the defined problem. QFD method is usually used for the design of a new product or a service, but in this paper it is used for the first time for intermodal terminal planning. QFD method allowed the consideration of the stakeholders' requests, based on which the developmental features that should receive special attention in the process of intermodal terminal planning are defined. The problem structured using the HOQ is further solved by applying the fuzzy ANP method with incorporated elements of the fuzzy Delphi method. The fuzzy ANP method enabled the consideration of the complex causal relationships between the requirements and features, while the fuzzy Delphi method enabled the unification of the different and often conflicting stakeholders' evaluations of the requirements and features. In addition to the advantages of the model previously described, it is important to emphasize once again the fuzzy component of the used method that allows the adequate consideration of human thinking in the process of decision-making. The proposed methodology is universally applicable and after certain adjustments it can be applied for solving various problems. The advantage of the model is the ability to solve complex real-life problems of development of the new or improvement of the existing products and services. Another advantage is that the model supports the group decision-making and allows documenting of the different views and opinions in the decision-making process. This documentation is useful because it can provide a good basis for discussion of the results obtained by the stakeholders' representatives that participated in the decision-making process. In the case of considering the problem with a large number of elements (requirements, features) model can be extended with some other methods that would reduce the problem complexity through extraction and consideration of the most important elements of the model, without affecting the quality of the results. The Delphi method is one of the methods which could be used for this purpose.

5. Conclusions

This paper deals with the problem of intermodal terminal planning by applying the newly developed model that combines Delphi, ANP and QFD methods in the fuzzy environment, as a way of improving the sustainability of freight transport flows. The applicability of the model has been successfully demonstrated by applying the same for planning the intermodal terminal in Belgrade. The model is universally applicable and after certain adjustments could be used for solving any other problem of developing or improving services, products, etc. Since the goal of this paper is intermodal terminal planning in accordance with the requirements of the various stakeholders, it was appropriate to use the QFD method to define the basic problem structure. On the other hand, considering that interdependencies between the requirements and features form the network structure, for the prioritization of the features it was justified to use the ANP method in which the Delphi method was incorporated with the goal of unifying the various stakeholders' evaluations. It is important to emphasize once again the fuzzy component of the used methods that allowed the adequate consideration of the human thinking in the process of decision-making.

The main contribution of this paper is the approach, since there are no similar examples of intermodal terminal planning which take into consideration the requirements of various stakeholders and define and prioritize the development features according to these requirements. Furthermore, the contribution of the paper stands in the development of the novel hybrid MCDM model. The future research could take into consideration the application of the model with the extended sets of stakeholders, requirements and features, as well as the adjustment of the model through the allocation of a different importance to the stakeholders, depending on the problem perspective. In addition, some future research directions could also be related to the implementation of the proposed model for solving some other problems in the field of intermodal transportation and logistics, e.g., for planning of intermodal networks, development of new technologies, modeling the supply chains, development of new services, creation of the policies, measures, initiatives and concepts of logistics, etc., as well as for the problems in some other areas. A significant aspect of the future research would be the reduction of the model complexity in the case of a large number of elements (requirements and features). Accordingly, the Delphi method could also be applied for the formation of the critical set of elements, result of which would be a model with a smaller number of relations.

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