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Multicriteria Comparison of Piggyback Systems




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ABSTRACT

The results of analysis and comparison of the currently most common piggyback systems refer to those which are at the stages of both commercial operation and testing development. The comparison was made to determine a piggyback system that meets the requirements of the sustainable development concept and ensures the efficient functioning of supply chains.

The authors are the first to propose a multi-criteria assessment methodology (MCDM) for piggyback systems that considers the requirements of main stakeholders of the supply chain: cargo owners, carriers and infrastructure owners. The analysis of the generated multi-criteria model for evaluating piggyback systems was carried out using the methodological apparatus of DEMATEL and MARCOS. A calculated example of ranking piggyback systems is based on the interests of supply chain stakeholders. The correctness of the results obtained was checked using other MCDM methods: TOPSIS, EDAS, MABAC and WASPAS. The results of assessing sensitivity of results of ranking piggyback systems were performed under various scenarios. The Flexiwaggon, Megaswing and Rolling Road piggyback systems received the highest scores.

The proposed methodology is recommended for developing rationally based management decisions aimed at harmonising the technical and technological parameters of piggyback systems, as well as at the unification of intermodal transport units for development of sustainable supply chains.

Keywords: transport, sustainable development, supply chain, multimodal transportation, combined transportation, intermodal transportation, piggyback system, MCDM, DEMATEL, MARCOS.

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INTRODUCTION

Creating conditions for implementation of the concept of sustainable development and ESG principles is becoming an increasingly important task for all sectors of the economy. The international community recognises the need for a balance between economic efficiency, the interests of society and environmental protection. The problems of sustainable development are especially relevant for transport, which is the connecting link of the economy and one of the main pollutants of the environment [1; 2]. The formation of «environmentally friendly» transport systems is currently following the development of multimodal cargo delivery systems, including those using intermodal technologies.

A variety of types of intermodal technology comprises a piggyback technology, based on the interaction of railway and road transport. The competition of design and technological solutions in the transport industry has contributed to the emergence of various options for implementing piggyback technology, which have significant differences in engineering solutions. Currently, these options are being developed as independent piggyback systems.

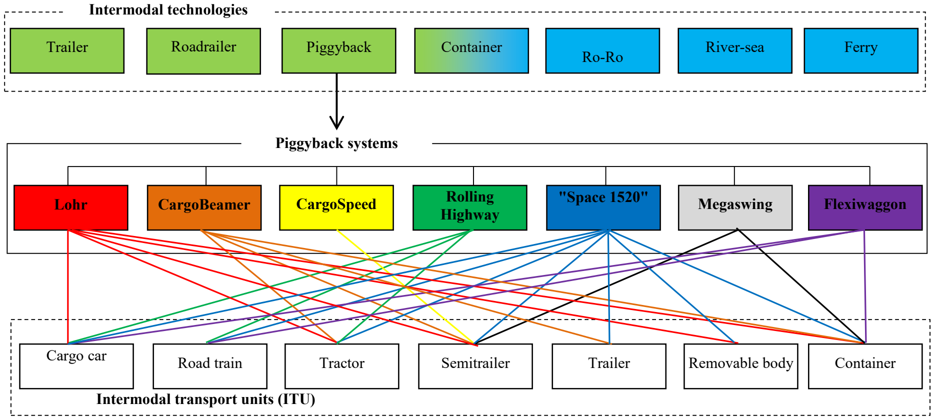
The variety of technical and technological solutions used, the lack of standards, the territorial isolation of specific piggyback systems in the world, the low degree of their use in supply chains – these are the facts, the analysis of which allows us to assert that this intermodal technology is still at the stage of formation [3].

As a result of the increasing number of participants and the diversity of technical and technological parameters of piggyback systems, the configuration of the network structure of supply chains is becoming more complex. In solving this problem, carriers, forwarders or logisticians must consider the technical and technological requirements and constraints of various piggyback systems to meet the requirements of cargo owners for timely, safe and environmentally friendly transportation of goods.

REVIEW OF RESEARCH AND PROBLEM STATEMENT

The works exploring the conditions for introduction of intermodal technologies in supply chains highlight the following main problems: the complexity of coordination and interaction of various participants in intermodal transportation [4]; lack of common standards for the parameters of terminals, intermodal transport units (ITU) and information systems [5]; the variety of piggyback systems and the presence of many parameters and indicators for their assessment and selection [6; 7]; difficulty in choosing technologies for servicing ITU at terminals [8; 9]; differences in approaches to organising piggyback transportation by rail, developing and agreeing on schedules [10]; differences in determining the rational transportation distance [11]; lack of an integrated approach to organising the interaction of rail and road transport [12]; the need to take into account the specifics of the use of intermodal technologies in continental and maritime transportation [13].

The complexity of solving these problems limits the use of intermodal technologies in supply chains and creates the need for monitoring and management decisions considering many

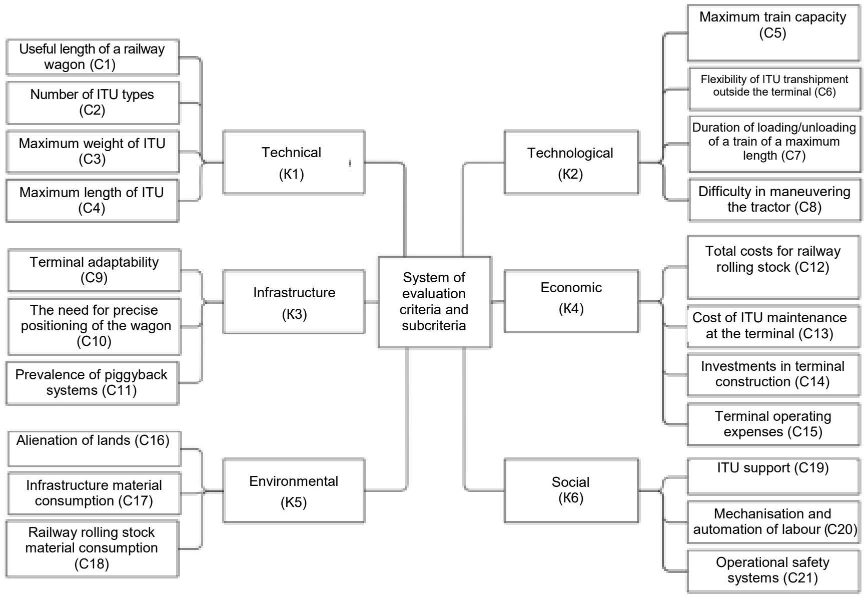


Pic. 1. An aggregate of intermodal technologies, piggyback systems and intermodal transport units [performed by the authors].

Table 1

Grouping and brief characteristics of piggyback systems [compiled by the authors]

System name/origin	Group of systems	Design features of a railway wagon	Type of a wagon and a terminal
Lohr Lohr Group (France)	1 – Systems represented by specialised terminals based on the modular principle of creating terminal infrastructure, using structurally complex specialised railway rolling stock	A car with two platforms (pockets). Horizontal loading and unloading of ITU is based on rotation of wagon platforms relative to the longitudinal axis of the track. The system allows vertical transshipment of ITU	
CargoBeamer CargoBeamer AG (Germany)		A wagon with a removable pallet that extends parallel to the rail track using the horizontal method of ITU reloading. Vertical transshipment of the pallet is ensured by the presence of structural grips in the pallet body	
CargoSpeed International consortium consisting of BLG Consult GmbH (Germany), University of Newcastle (GB), Newrail (GB), The Warbreck Engineering and Dry Dock Company Ltd (GB)		A wagon has a removable floor (platform), as well as lowering ramps, allowing the entry and exit of the road train onto the floor of the wagon. Horizontal loading and unloading of ITU is based on lifting to ground level and rotation of the wagon platform relative to the longitudinal axis of the track using stationary lifting and turning equipment located along the axis of the rail track	
Rolling Road (Rolling Highway, Rolling Motorway, Rollende Landstrasse) (Sweden)	2 – Systems available at railway stations with separate freight platforms for operations with piggybacks. Such systems use the least complex railway wagons (piggyback platforms) in design.	A wagon is represented by a platform with a lowered floor level. The loading height of the wagon is ensured by two bogies with small-diameter wheelsets. The wagon is equipped with end crossing platforms, ensuring the passage of motor vehicles between the coupled platforms when performing loading and unloading operations	
«Space 1520» Under development with participation of JSC Russian Railways (Russia)		A flat wagon with lowering platforms for movement of vehicles along the train. Loading of ITU into wagons is carried out by entering them from one side from the longitudinal sides of the wagon	
Megaswing Kockums Industrier AB (Sweden)	3 – Systems, not requiring the development of terminal infrastructure and using highly specialised high-tech railway wagons	A wagon with two platforms (load sections), equipped with a mechanism for their independent movement. Horizontal loading and unloading of ITU is based on rotation of the wagon platforms relative to the longitudinal axis of the track and their lowering to floor level. The direction of rotation of the platforms ensures the possibility of entry and exit of vehicles on both sides of the track	
Flexiwaggon Flexiwaggon AB (Sweden)		A wagon is equipped with mechanised ramps located on the end sides. Ramps provide forward entry and exit for vehicles. The wagon has an autonomous power supply using rechargeable batteries. The batteries are charged by shaft generators that generate energy while the train is moving.	



Pic. 2. Criteria and subcriteria for stability of a piggyback system [performed by the authors].

factors that influence the effectiveness of their use. Options for intermodal technologies used in various modes of transport, existing and developing piggyback systems, as well as the intermodal transport units used in them are shown in Pic. 1 [3].

To solve these problems, various scientific methods are widely used, in particular, mathematical models and methods [14], including multi-criteria decision-making methods (MCDM) [3]. The choice of MCDM methods is due to the variety of characteristics and properties of piggyback systems, their elements, as well as the need to consider many parameters and indicators of their functioning [15]. Methods belonging to this group are also used to quantify trade-offs between economic, social and environmental criteria for sustainable development of supply chains [16].

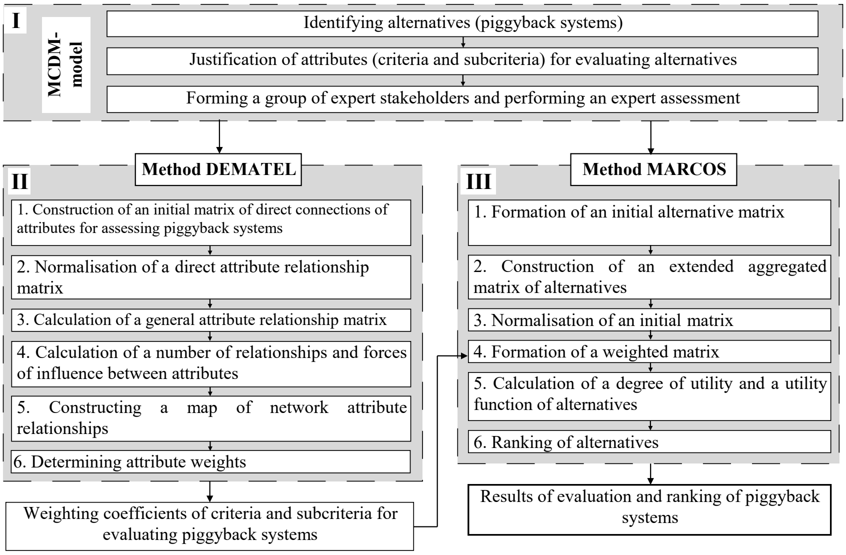
The *objective* of the study is to develop a methodology for multi-criteria selection of a piggyback system that ensures formation and functioning of sustainable supply chains. The methodology is based on systematisation of the parameters of all known piggyback systems: Lohr, CargoBeamer, CargoSpeed, Rolling Road, «Space 1520», Megaswing and Flexiwaggon. Analysis of the parameters of piggyback systems made it possible to identify three groups of such systems (Table 1), as well as to form a universal system of criteria for the stability of a piggyback system in supply chains (Pic. 2).

RESULTS

Methodology for Assessing Piggyback Systems

At the first stage, a multicriteria model (MCDM model) is developed for assessing piggyback systems. The elements of the MCDM model are alternatives – piggyback systems, as well as attributes – criteria and subcriteria for evaluating piggyback systems. The following alternative designations are used in this work: Lohr (A1), CargoBeamer (A2), CargoSpeed (A3), Rolling Road (A4), Space 1520 (A5), Megaswing (A6) and Flexiwaggon (A7). The system of criteria and subcriteria for stability of a piggyback system in supply chains developed by the authors is used as attributes in the MCDM model [17] (see Pic. 2).

At the second stage of the implementation of the method, the weight of the attributes of the MCDM model is calculated using the DEcision MAking Trial and Evaluation Laboratory method, abbreviated DEMATEL [18]. The choice of the DEMATEL method [19] is justified by the possibility of establishing the interdependence between the criteria and subcriteria of the piggyback system and developing a map of network relationships reflecting the mutual influence of the criteria and the cause-and-effect relationships between them. The final result of applying the DEMATEL method is identification of the weight of the attributes of piggyback systems.



Pic. 3. Stages of implementation of the DEMATEL–MARCOS combined method for assessing piggyback systems [performed by the authors].

The main steps for implementing the DEMATEL method are [3]:

1. Construction of an initial matrix of direct connections between attributes of piggyback systems and pairwise assessment of the influence of attributes, performed based on an analysis of the opinions of expert stakeholders.

2. Normalisation of the matrix of direct connections between attributes of piggyback systems.

3. Formation of a general matrix of connections between the attributes of piggyback systems.

4. Calculation of the number of relationships and forces of influence between the attributes of piggyback systems. Completing this step is necessary to establish cause-and-effect relationships in the system of criteria and subcriteria of piggyback systems. Each attribute can be assigned either to the «cause» group (i. e., it affects other attributes) or to the «effect» group (i. e., it is influenced by other attributes).

5. Construction of a cause-and-effect diagram (map of network relationships). It shows the structural relationship between the attributes under consideration and the correlation between them.

6. Calculation of the weight of each attribute of the piggyback system.

At the third stage of the implementation of the method, piggyback systems are ranked using the «Measurement of Alternatives and Ranking according to COmpromise Solution» method, hereinafter MARCOS [20]. The basis of this method is the identification of the relationships between alternatives and reference values («ideal» and «anti-ideal» alternatives). The best alternative is considered to be the one that is closest to the ideal and at the same time further from the anti-ideal alternative.

The main steps of the MARCOS method are [3]:

1. Formation of an initial matrix for evaluating alternatives, consisting of evaluation values of each alternative for all attributes.

2. Construction of an extended initial matrix and determination of ideal and anti-ideal alternatives.

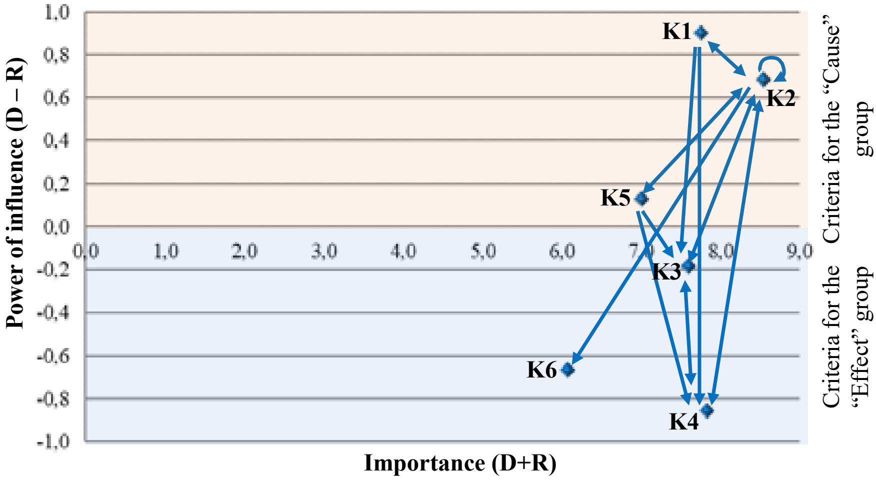
3. Normalisation of an original solution matrix.

4. Formation of a weighted matrix. The weight values of the attributes are taken based on the results of calculations using the DEMATEL method.

5. Calculation of the rate of utility of alternatives and finding of the utility function of alternatives. The value of the utility function shows how close each alternative is to the ideal alternative and how far it is from the anti-ideal alternative.

6. Ranking of alternatives. The best alternative is considered to be the alternative with the maximum value of the utility function.

A general framework for using the combined DEMATEL–MARCOS method for the



Pic. 4. Network relationship map of piggyback system criteria (assessed by academic experts).

comprehensive specification and assessment of piggyback systems in sustainable supply chains is presented in Pic. 3.

Piggyback System Evaluation Results

The assessment and ranking of piggyback systems to ensure sustainable development of supply chains was carried out using an MCDM model represented by seven alternatives (A1–A7), characterised by six groups of criteria (K1–K6), including 21 subcriteria (C1–C21) (Pic. 2). The analysis of this model was carried out by the following groups of experts: cargo owners, logistics service providers, infrastructure owners and academic experts [3].

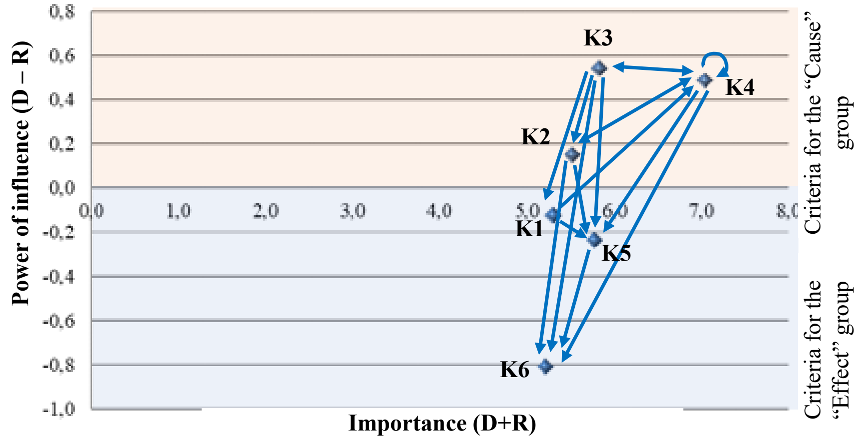
Using the DEMATEL method, maps of network relations of criteria and subcriteria for evaluating piggyback systems were constructed and their weighting coefficients were calculated. As an example, Pics. 4–7 show a map of network relationships based on the results of assessments by academic experts. The light zone on the map shows the criteria that make up the «Cause» group. Technical criteria (K1) have the strongest influence on all criteria. Infrastructure criteria (K2) are characterised by the largest number of connections, which indicates their greatest importance in this system of criteria.

The final weighting coefficients of the criteria and subcriteria for assessing piggyback systems, obtained from the results of assessment by various groups of stakeholder experts, are presented in Tables 2 and 3.

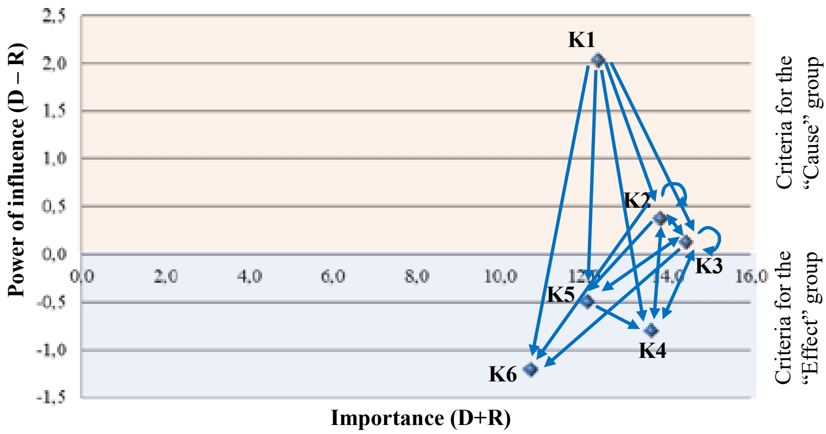
The results of criteria ranking indicate differences in assessment of their importance by different groups of stakeholders (Table 2). The highest ranks were received by the subcriteria of the infrastructural and environmental groups of criteria. The average values of the ranks of the subcriteria of these groups were 2,6 and 6,5, respectively. The second most important criteria for experts were the criteria of technological, economic and social groups. The average value of the ranks of the subcriteria of these groups was 12,6. The subcriteria of the technical group received the least importance (average rank 16,2).

Thus, experts agree that the main condition for including piggyback technology in the supply chain is the presence of a widespread network of piggyback terminals with the ability to adapt it to customer needs. Stakeholders appreciate also the technology's positive impact on reducing the environmental impact of transport. The low assessment of the influence of criteria characterising piggyback systems through technical parameters is of interest. This, to a certain extent, contradicts the thesis stated at the beginning of the article about the problem of considering the requirements of a specific system for ITU parameters and can be explained by the use by suppliers and providers of a limited number of types of ITU, as well as the exclusion of transportation schemes using various piggyback systems in different regions (countries)).

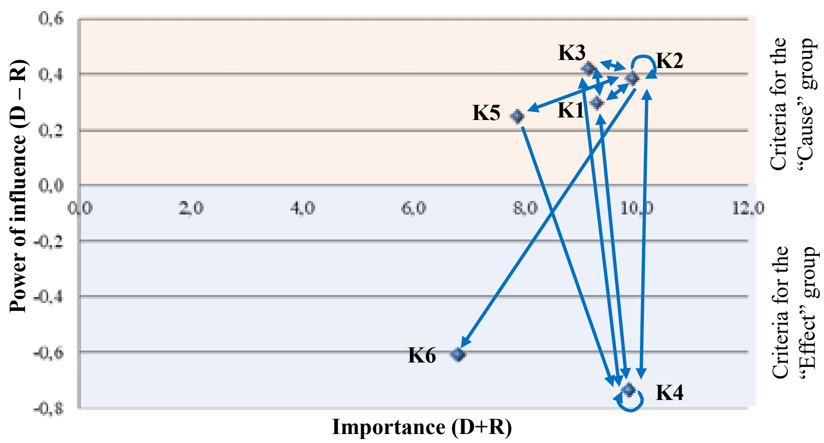
Regarding the importance of criteria and subcriteria for stakeholders, the following trend is observed. Cargo owners express less interest in the technical and technological characteristics of piggyback systems, since they are not involved in the process of organising transportation. At



Pic. 5. Network relationship map of piggyback system criteria (assessed by cargo owners).



Pic. 6. Network relationship map of piggyback system criteria (assessed by infrastructure owners).



Pic. 7. Network relationship map of piggyback system criteria (assessed by carriers).

the same time, the amount of transport costs for transportation, as well as the need to accompany the goods, is important for them. Logistics service providers who are involved in organisation of transportation, on the contrary, pay more attention to the criteria that characterise systems from a technological, infrastructural and environmental perspective. This is due to their

Table 2

Weight values of criteria for evaluating piggyback systems using the DEMATEL method [compiled by the authors]

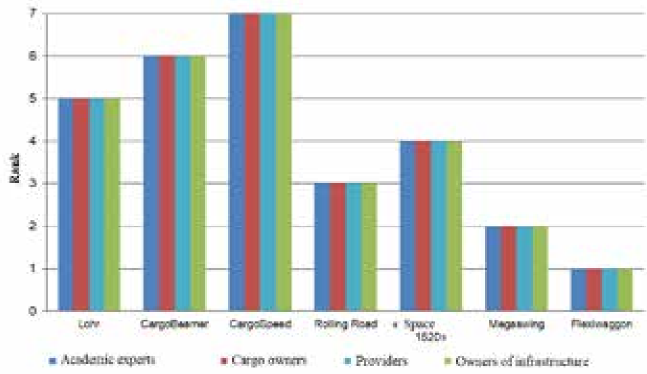
Criteria	Academic experts	Cargo owners	Providers	Infrastructure owners
Technical (K1)	0,1737	0,1525	0,1754	0,1618
Technological (K2)	0,1905	0,1587	0,1875	0,1787
Infrastructure (K3)	0,1689	0,1684	0,1728	0,1869
Economic (K4)	0,1752	0,2027	0,1867	0,1764
Environmental (K5)	0,1558	0,1661	0,1487	0,1565
Social (K6)	0,1359	0,1517	0,1289	0,1398

interest in choosing a delivery option that provides high quality transportation at lower own operating costs for transportation, as well as a desire to cooperate with companies that pay attention to «green» technologies. Owners of transport infrastructure pay the greatest attention to technological and infrastructural parameters, since they consider piggyback technology as a business project that requires significant but quickly payback investments. This group of stakeholders gives a low assessment of importance of the total costs of railway rolling

Table 3

Weight values of subcriteria for evaluating piggyback systems using the DEMATEL method [compiled by the authors]

Subcriteria	Academic experts	Cargo owners	Providers	Infrastructure owners
Useful length of a wagon (C1)	0,0445	0,0390	0,0470	0,0396
Number of types of ITU (C2)	0,0375	0,0368	0,0352	0,0347
Maximum weight of ITU (C3)	0,0425	0,0384	0,0443	0,0414
Maximum length of ITU (C4)	0,0491	0,0382	0,0490	0,0460
Maximum train capacity (in semi-trailers) (C5)	0,0477	0,0385	0,0473	0,0472
Flexibility of ITU transshipment outside the terminal (C6)	0,0466	0,0385	0,0438	0,0418
Duration of loading/unloading of a train of maximum length (C7)	0,0502	0,0431	0,0516	0,0487
Difficulty in manoeuvring the tractor (C8)	0,0460	0,0386	0,0448	0,0410
Terminal adaptability (C9)	0,0619	0,0571	0,0572	0,0635
The need for precise positioning of a wagon (C10)	0,0526	0,0526	0,0580	0,0617
Prevalence of a piggyback system (C11)	0,0544	0,0587	0,0576	0,0617
Total costs for railway rolling stock (C12)	0,0344	0,0465	0,0464	0,0389
ITU maintenance cost on the terminal (C13)	0,0483	0,0538	0,0529	0,0468
Investments in construction of terminal infrastructure (C14)	0,0459	0,0477	0,0427	0,0457
Terminal operating expenses (C15)	0,0466	0,0547	0,0448	0,0449
Alienation of lands (C16)	0,0521	0,0561	0,0444	0,0546
Infrastructure material consumption (C17)	0,0543	0,0561	0,0545	0,0578
Material consumption of railway rolling stock (C18)	0,0494	0,0538	0,0498	0,0442
ITU support (C19)	0,0398	0,0554	0,0416	0,0395
Mechanisation and automation of labour (C20)	0,0477	0,0466	0,0425	0,0501
Safety of operation of a piggyback system (C21)	0,0485	0,0497	0,0448	0,0502



Pic. 8. Ranking of piggyback systems using the MARCOS method [performed by the authors].

stock, assuming that these costs are borne by the operators of their own cars. The opinion of academic experts is generally consistent with the opinion of logistics service providers and transport infrastructure owners.

The ranking of piggyback systems was carried out using the MARCOS method using the obtained weight values of the subcriteria and their quantitative and qualitative values [3]. The ranking results are presented in Pic. 8.

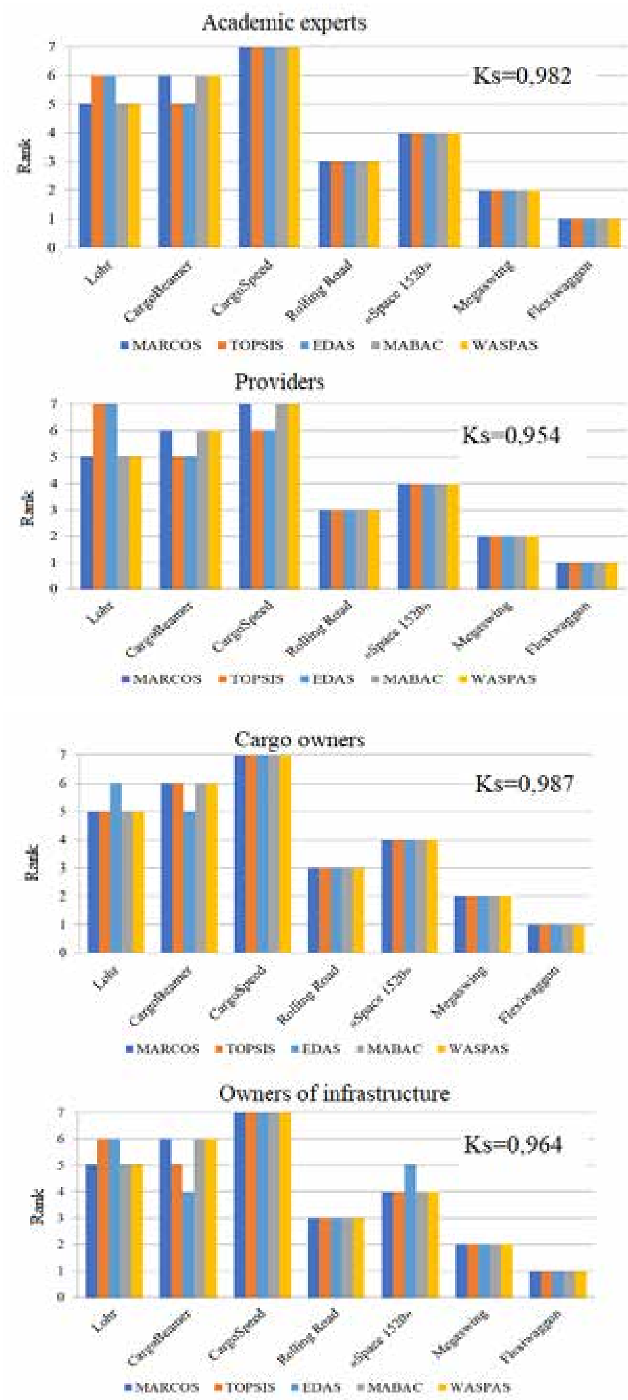
Despite certain differences in expert opinions about the importance of criteria and subcriteria, a comparison of piggyback systems showed consistency in expert opinions. All experts place the Flexiwaggon system in first place, the Megaswing system in the second place, and the CargoSpeed system in the third place. Thus, based on the totality of characteristics, systems of the third group (Table 1) are prioritised as piggyback systems for ensuring the sustainable development of supply chains. They do not require the creation of complex terminal infrastructure and use high-tech railway rolling stock, which ensures the mobility of loading/unloading ITU. Systems of the second group: Rolling Road and the domestic «Space 1520» arouse less pronounced interest in their use in supply chains. This is proven by the fact that these systems received high scores for subcriteria that are not significant («Number of ITU types» and «Cost of a car and its operating costs») and, conversely, low scores for significant subcriteria («Terminal adaptability» and «Prevalence piggyback system»). The systems of the first group, which require the largest investments in formation of a network of intermodal terminals and a fleet of specialiыed railway rolling stock, received the lowest rank.

To verify the correctness of the results obtained by the MARCOS method, a multicriteria comparison of piggyback systems was performed using other MCDM methods: TOPSIS – Technique for the Order of Preference by Similarity to Ideal Solution [21], EDAS – The Evaluation based on Distance from Average Solution [22], MABAC– Multi-Attributive Border Approximation Area Comparison [23] and WASPAS – Weighted Aggregated Sum Product Assessment) [24]. Pic. 9 shows the results of a comparison of calculations using various methods. The first three ranks are retained for the Flexiwaggon, Megaswing and Rolling Road systems, respectively. The «Space 1520» system predominantly receives fourth place. The exception is the results of processing the opinions of experts belonging to the «Infrastructure Owners» group obtained with the EDAS method, according to which this system ranks fifth.

The use of additional MCDM methods and obtaining convergence of results indicates a high correlation of the obtained ranks. The Spearman rank correlation coefficient used for this assessment was Ks=0,954–0,987 (see Pic. 9).

The sensitivity of the results of ranking piggyback systems was assessed. The sensitivity assessment is based on an analysis of the impact of changing the weight of subcriteria on the rank of a certain piggyback system. The description of the considered scenarios and the results of stability of ranking of piggyback systems are given in Table 4 and Pic. 10.

The results of assessing the sensitivity of ranking piggyback systems show that in all scenarios, alternative A7 (rank No. 1), represented by the Flexiwaggon system, remains stable. Alternative A6 (Megaswing system – rank No. 2) is stable in scenarios S1, S2 and S4 for all groups of experts. Minor changes in stability of the assessment results are observed for the remaining alternatives.



Pic. 9. Ranking of piggyback systems using MCDM methods [performed by the authors].

CONCLUSION

The impact of piggyback technology on supply chain sustainability is not constant and depends on the characteristics of the specific piggyback system. The variety of technical and technological solutions for piggyback systems also limits their joint use in development of the network structure of global supply chains and transport corridors.

The highest priority for use in supply chains are systems that have high mobility of IT service and do not require significant investments in creation of terminal infrastructure. First, this is achieved because of the use of high-tech railway

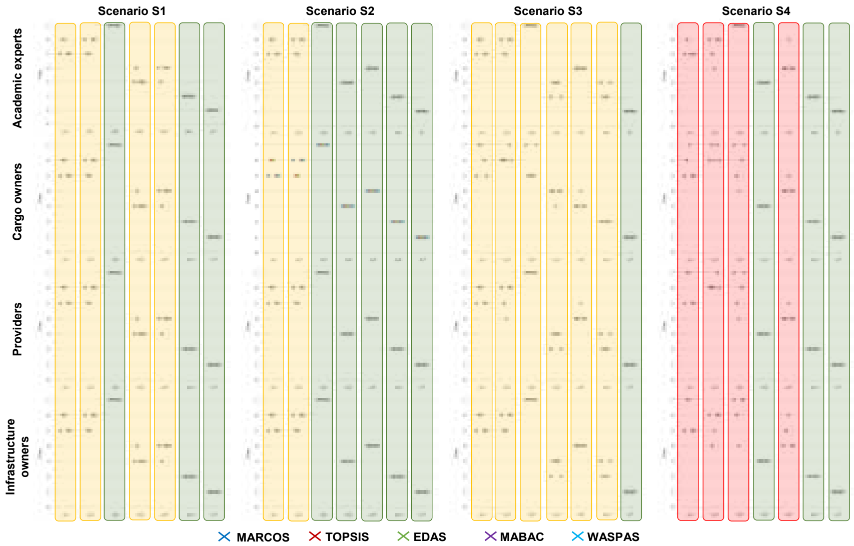
Table 4

Description of scenarios for assessing stability of ranking results of piggyback systems [compiled by the authors]

Scenario	Scenario description	Ranking results
S1	The weight of all subcriteria is the same and is equal to the arithmetic mean value of 0,0476	The ranks of alternatives A3, A6 and A7 are stable among all experts for all MCDM methods (green area in Pic. 10). Alternatives A1, A2, A4 and A5 have minor changes in ranks 3, 4, 5 and 6 among MCDM methods (yellow area in Pic. 10)
S2	The weight of each subcriterion is taken equal to the arithmetic mean of the assessment for all four groups of experts (for example, C1 = 0,0425)	The ranks of alternatives A3, A4, A5, A6 and A7 are stable among all experts for all MCDM methods. Alternatives A1 and A2 have minor changes to ranks 5 and 6.
S3	Eliminating the criterion with the highest weight and changing the weight of the remaining subcriteria proportionally to the value of this subcriterion. For the group of academic experts, C9=0,0619 was excluded, for cargo owners C11=0,0587, for carriers C10=0,058 and for infrastructure owners C9=0,0635	Alternative A7 (rank 1) is stable among all experts for all MCDM methods. Alternative A3 has a stable rank of 7 among all experts except cargo owners. Alternatives A1, A2, A4, A5 and A6 have minor changes, both in rank, and according to MCDM methods.
S4	Eliminating the subcriterion with the lowest weight and changing the weight of the remaining subcriteria proportionally to the value of this subcriterion. For the group of academic experts, C12=0,0344 was excluded, for cargo owners C2=0,0368, for carriers C2=0,0352 and for infrastructure owners C2=0,0347	The ranks of alternatives A4, A6 and A7 are stable among all experts for all MCDM methods. Alternatives A1, A2, A3 and A5 have minor changes in ranks and MCDM methods (rose area in Pic. 10).

rolling stock, capable of providing horizontal loading and unloading of ITU without auxiliary devices and mechanisms. These conditions are met by the Swedish piggyback systems Flexiwaggon and Megaswing. The second priority area is the use of piggyback systems based on already functioning infrastructure facilities – railway stations and terminals, which leads to the use of wagons that are simpler in design. This makes it possible to reduce the amount of investment in creation of a network of intermodal terminals and formation of a fleet of specialised railway rolling stock. Such systems are Rolling Road and «Space 1520».

Further directions of this research are aimed at identification and analysis of the goals, interests and behaviour strategies of piggyback technology stakeholders to reveal the system of their interaction, as well as development of a conceptual model of functioning of a piggyback technology in supply chains that meet the goals of sustainable development.



Pic. 10. Results of assessing the stability of ranking piggyback systems [calculated by the authors].

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