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Sustainability Criteria for a Piggyback System

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ABSTRACT

Achieving the goals of the sustainable development concept stimulates the use of multimodal systems and intermodal cargo delivery technologies in supply chains. The configuration of the network structure of supply chains in this case becomes more complex following the increase in the number of participants and the diversity of technical and technological parameters of transport systems. The authors have analysed the problems of using piggyback technology as part of supply chains.

The objective of this study is to establish a set of universal characteristics of piggyback systems that determine their sustainability in supply chains. The study used a systems approach to present piggyback technology as to a complex technical system, the main elements of which are intermodal transport units, railway rolling stock and terminals connected by the technology and organisation of piggyback transportation. A developed original system of criteria for choosing a piggyback system considers the current trend in development of transport systems and supply chains from the perspective of their sustainable development.

It is shown that the decision to use piggyback systems as part of sustainable supply chains must be made based on a multi-criteria assessment of the parameters of all elements and relationships within these systems. The system of criteria developed by the authors allows adequate evaluating piggyback systems, coordinate their engineering and technological parameters, and also justify decisions on unification of intermodal transport units.

Keywords: multimodal transportation, combined transportation, intermodal transportation, piggyback system, supply chain, sustainable development.

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INTRODUCTION

Evolution of environmentally friendly transport systems is focused inter alia on development of multimodal cargo delivery systems based on the integrated interaction of various modes of mainline transport [1; 2]. Multimodal technology has as one of its types a piggyback (or contrailer) technology, which uses railway and road transport on an integrated basis [3]. The implementation of this technology involves placing cargo in an intermodal transport unit (ITU), capable to be transported by the specified modes of transport within the entire multimodal delivery system.

Within the global transport system, regular transportation of goods using piggyback technology began to be performed in the second half of the 20th century. Strong competition in design and technological solutions in the transport industry has contributed to the emergence of various piggyback technology options with significant differences in engineering solutions. These options are currently being developed as stand-alone piggyback systems. The most common options for piggyback systems that use the horizontal method of loading and unloading items are Rolling Road, Lohr, CargoBeamer, etc. These systems compete both with each other and with Lift-on/Lift-off, Lo-Lo systems, which use vertical method of reloading ITU onto railway rolling stock [4].

The results of an analysis of the prevalence of piggyback systems in the world and the degree of their use in supply chains [5] suggest that this intermodal technology is still at the development stage. Analysis of the parameters of known piggyback systems indicates the diversity of engineering and technological solutions used in them and the lack of common standards [6; 7]. Besides, each piggyback system, as a rule, is characterised by a certain national attributes and degree of prevalence in the world. This diversity of engineering and technological parameters of piggyback systems has as consequence the constraints in the selection of ITU and conditions of their transportation that should meet the requirements of a specific piggyback system. This, in turn, imposes certain restrictions on the range of goods transported. Thus, the variety of piggyback systems and the presence of many non-standardised parameters reduces the multiplier effect of the integration and combined use of various modes of transport in multimodal delivery systems, and also complicates construction and operation of supply chains using piggyback technology.

These limitations are especially evident in formation of global supply chains, the links of which are located in regions where different piggyback systems are used. The task arises of configuring the optimal network structure of the supply chain. This task becomes more complex due to the use of different piggyback systems in different regions (countries) and the increase in possible supply chain options. In solving this problem, carriers, forwarders, or logistics managers must consider the engineering and technological requirements and constraints of various piggyback systems to meet the requirements of cargo owners for timely, safe and environmentally friendly transportation of certain goods. Due to the variety of piggyback systems, cargo owners are forced to either take into account the requirements of a specific system for ITU parameters or abandon the intermodal technology necessary for them [8]. Thus, determining criteria for stability of a piggyback system based on systematisation of the parameters of existing piggyback systems to form sustainable supply chains is an urgent scientific and practical task.

Currently, in the Russian-language scientific literature, the concept of «*stability*» [in general terms], in relation to complex systems, is used to denote the properties of such systems operating under different conditions. Traditionally, *stability* means the ability of a system to maintain its key functions in conditions of uncertainty, failures, and changes [9; 10]. In English-language literature, this property is designated by the term «*resilience*». This term in most cases is applicable to technical systems for which it is possible with sufficient accuracy to both predict external influences and describe the patterns of their behaviour in various situations. However, supply chains operate under conditions of significantly greater uncertainty in the external economic (market factor), natural and climatic (ecological factor), and social environment (geopolitical factor). Complex systems in such conditions must not only maintain their key functions, but also develop, providing the necessary stability for the future. The stability of complex systems exposed to the natural, social and economic environments is usually referred to in the English-language scientific literature by another term – «*sustainability*»[1]. This property is associated with

[1] GOST R [Russian State standard] ISO 28002–2019 Security management systems for the supply chain. Resilience of the supply chain. Requirements with guidance for use. Moscow, Standartinform publ., 2020, 53 p.

the concept of «*sustainable development*»[2] and the presence of this property is a necessary condition for achieving the goals of this concept.

In this study, supply chain *sustainability* refers to the state of supply chains in which sustainable development goals are achieved. This is ensured by developing and maintaining a balance of social, environmental, and economic indicators [11]. This approach, in our opinion, is applicable to both sustainable supply chains, green supply chains, reverse supply chains, and closed loop supply chains.

RESULTS

Systematisation of Parameters of Piggyback Systems and Identification of Criteria for their Stability

The authors of the work used *a systems approach* to consider piggyback technology as a complex system formed by the following structural elements: an intermodal transport unit, railway rolling stock and a terminal. Each of the elements under consideration is characterised by a set of parameters that determine the technology and organisation of piggyback transportation.

The systematisation and structuring of the parameters of piggyback technology elements was carried out through the analysis of seven most common piggyback systems that are at different stages of development, testing and commercial use: Lohr, CargoBeamer, CargoSpeed, Rolling Road, «Space 1520», Megaswing and Flexiwaggon. The collection of data for analysis was carried out based on information from the official websites of companies producing piggyback systems[34],[5],[6],[7],, websites of companies producing railway rolling stock[89],[10],[11],, regulatory documents[1213],, as well as scientific literature [12–19]. Analysis of the parameters of piggyback systems allows them to be divided into three groups:

• Systems represented by specialised terminals, based on the modular principle of creating terminal infrastructure, using structurally complex specialised railway rolling stock. The authors include the Lohr, CargoBeamer and CargoSpeed systems in this group.

• Systems located at railway stations with separate cargo loading facilities for piggyback operations. In such systems, the least complex railway cars (piggyback platforms) are used. Systems in this group include Rolling Road and «Space 1520».

• Systems that do not require creation of terminal infrastructure and use highly specialised high-tech railway cars. The systems in this group are Megaswing and Flexiwaggon.

Analysis of engineering and technological features, as well as the theory and practices of using these piggyback systems, allowed us to draw the following preliminary conclusions.

Firstly, available sources of information contain contradictory and fragmented descriptions of the characteristics and parameters of piggyback systems, which reduces reliability of data and complicates assessment and selection of these systems. The piggyback systems that currently have the widest geographical spread are described in detail. Developers of such systems are interested in their further promotion, attracting new clients and investments, and entering new markets. On the contrary, systems that are in the early stages of their life cycle are poorly represented both on the Internet and in scientific

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[2] GOST R [Russian State standard] ISO/IEC 15288–2005 Information technology. System engineering. System life cycle processes. Moscow, Publishing house FSUE Standartinform, 2006, 57 p.

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[9] Flat car model 13–5205. [Electronic resource]: https://infomach.ru/vagon-platforma-modeli-13–5205. Last accessed 01.06.2023.

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[11] Platform model 13–9961 is suitable for piggyback trailers. [Electronic resource]: http://xn-1520-u4d3ahgsb9pe.xn – p1ai/new/6593/. Last accessed 01.06.2023.

[12] The concept of organising piggyback transportation in the «1520 space». Moscow, RZD publ., 2011, 149 p.

[13] Regulations for loading and securing road trains, cars, semi-trailers and trailers, tractors on specialised platforms of model 13–9961. [Electronic resource]: https://company.rzd.ru/ru/9353/page/105104?id=909. Last accessed 01.06.2023.

publications. This reduces interest in them and prevents their further development.

Secondly, researchers most often limit themselves to analysing the engineering and technological parameters of piggyback systems. There is virtually no analysis of social and environmental parameters reflecting the current priorities of transport policy in developed countries. These systems are poorly represented in the ESG (Environmental, Social, and Corporate Governance) ranking, which evaluates the environmental, social, and economic areas of key business decisions.

Thirdly, we were unable to find studies in which piggyback technology is considered as a complex engineering system and where modern methods and tools of system analysis are used. The result is either a one-sided consideration or an incorrect comparison of quantitative, qualitative, and subjective parameters characterising this technology.

Finally, the given parameters of piggyback technology do not account for the interests and strategies of various actors in transport and logistics processes: cargo owners, logistics service providers and transport infrastructure owners. Moreover, each of the listed stakeholders is guided by the parameters that he identifies as priorities when choosing a particular piggyback system.

The listed factors, on the one hand, complicate the choice of piggyback systems, and on the other, determine the need to use multi-criteria methods for assessing systems that consider the diversity of both the interests of stakeholders and the parameters of these systems.

The authors propose to be guided by the following general principles for determining the sustainability criteria of a piggyback system:

• Multiple engineering, technological and economic parameters of piggyback technology elements are considered as subcriteria for choosing a system and are combined into groups of criteria.

• Isolated values of criteria are represented by precise quantitative values, and qualitative values of criteria are unified by presenting them through a common and unambiguously understood rank scale. A four-level ranking of quality subcriteria is used through the terms: «Very High», «High», «Medium», «Low».

The subcriteria of the engineering group include the most significant technical parameters that characterise piggyback systems from the perspective of transport and cargo units that perform the function of «territorial» movement of goods in supply chains. The subcriteria included in this group are used to evaluate railway rolling stock and road vehicles, acting in piggyback transportation as ITU (Table 1).

According to the authors of the work, two stakeholders have a predominant interest in the subcriteria of this group: «Logistics service provider» – the owner of the rolling stock, engaged in formation and management of the fleet and «Owner of the transport infrastructure» – who determines the parameters of the piggyback terminal in terms of their compliance with the parameters of cargo flow and the flow of rolling stock passing through the terminal.

Considering a significant number of engineering parameters of railway rolling stock, the authors limited themselves to only one subcriterion – «Useful length of the railway car», characterising the capacity of the car in relation to the transported cargo – ITU. Increasing the useful length of a car's cargo area increases its carrying capacity and versatility, influencing the ITU parameters.

The subcriteria «Number of types of ITU» and «Maximum weight of ITU» determine the functionality of piggyback systems, creating, first, for the «Provider» a variety of options for transporting ITU (or vice versa, limiting options), as well as determining the size of the cargo lot.

The technological group of subcriteria combines parameters that characterise piggyback systems from the point of view of organising loading and unloading of items onto railway cars (Table 2). According to the authors of the work, the predominant interest in the subcriteria of this group should be from behalf of the «Logistics Service Provider» stakeholder, whose functional responsibilities include organising transportation on a «door-to-door» basis.

The subcriterion «Maximum capacity of a train» allows determining the size of a cargo lot for a full train and estimate the costs of its accumulation and transportation. Since piggyback systems are characterised by a variety of transported types of ITU, this

Table 1

Values of engineering subcriteria for piggyback system sustaianability [compiled by the authors]

Subcriteria	Lohr	CargoBeamer	CargoSpeed	Rolling Road	«1520 space»	Megaswing	Flexiwaggon
Useful length of the car, m	27.4	14.2	16.3	18.2	20.3	29.4	17.3
Number of types of ITU	5 (semi-trailer, tractor, truck, swap body, container)	4 (semi-trailer, trailer, tractor, container)	1 (semi-trailer)	3 (road train, tractor, cargo car)	7 (road train, semi-trailer, trailer, tractor unit, truck, swap body, container)	2 (semi-trailer, container)	3 (road train, truck, container)
Maximum weight of ITU, t	38	37	38.5	38	44	38	52
Maximum length of ITU, m	13.7	14.2	13.6	20	20	14.7	17.3

subcriterion is quantitatively expressed through the most common type of ITU for piggyback transportation – a semi-trailer.

The subcriterion «Flexibility of transshipment of ITU equipment outside the terminal» evaluates the capabilities of the piggyback system by the number of loaded and unloaded cars in the train. The authors believe that the greatest flexibility is provided by systems that allow the transshipment of any number of ITU on a train, including in places that do not require special terminal equipment. Systems focused on reloading only the entire train at the terminal, due to technological limitations or the economic disadvantage of reloading a small number of ITU, have less flexibility (mobility).

The subcriterion «Duration of loading/unloading of a train of maximum length» allows one to assess the level of technological sophistication of a particular piggyback system, and also characterises the parallelism of loading/unloading of items into cars. The quantitative values of the subcriterion indicate the minimum time for loading and unloading a full train at the most technically equipped terminal for each piggyback system.

The subcriterion «Difficulty of manoeuvring a vehicle tractor» determines the sequence of movements of the tractor when loading/unloading items into a railway car. In general, the movement of the tractor can be performed in reverse or forward, but for different piggyback systems a unique combination of movement is formed. This determines the time of transhipment, its complexity, as well as the safety of this cargo operation and the admission of the persons carrying it out. The authors proceed from the position that the safest option for loading and unloading ITU is to move the tractor forward, and the least safe option is to move the tractor forward/reverse.

The infrastructure subcriteria of assessment are formed by parameters characterising piggyback systems from the perspective of the conditions for the creation and use of a terminal that performs the function of technological interaction between the modes of transport involved in piggyback transportation (Table 3). The subcriteria included in this group are of interest to the «Infrastructure Owner» stakeholder, who is an investor and solves the problem of choosing an investment object, as well as the «Logistics Service Provider» stakeholder, who models the design of the supply chain, the choice of transport technology and determines the inclusion of piggyback technology as a link in the chain.

The subcriterion «Terminal Adaptability» assesses the need to create a specialised terminal, the modularity of its construction and the degree of its technical sophistication. The authors believe that when drawing up business plans and assessing project investment risks, systems that require lower capital costs and allow for the staged creation and development of terminal infrastructure are preferable.

Table 2

Values of technological subcriteria for the sustainability of a piggyback system [compiled by the authors]

Subcriteria	Lohr	Cargo Beamer	CargoSpeed	Rolling Road	«1520 space»	Megaswing	Flexi waggon
Maximum capacity of a train (in semi-trailers)	48	36	30	40	48	44	22
Flexibility of transshipment of ITU equipment outside the terminal	Medium	Medium	Medium	Low	Low	High	Very high
Duration of loading/ unloading of a train, min.	90	20	30	100	60	30	15
Difficulty of manoeuvring a vehicle tractor	Very high (Reverse/ Forward movement)	Medium (Forward/ reverse movement)	Medium (Forward/ reverse movement)	Low (Forward movement)	High (Reverse/ forward movement)	Very high (Reverse/ Forward movement)	Low (Forward movement)

Table 3

Values of infrastructure subcriteria for piggyback system sustainability [compiled by the authors]

Subcriteria	Lohr	Cargo Beamer	CargoSpeed	Rolling Road	«1520 space»	Megaswing	Flexi waggon
Terminal adaptability	Medium	Medium	Medium	Low	Low	High	Very high
Need for precise positioning of the cars	Very high (< 20–30 cm)	Very high (< 20–30 cm)	High (< 35 cm)	Medium (< 1 m)	Medium (< 1 m)	Low (> 1 m)	Low (> 1 m)
Prevalence of the piggyback system	Very high	High	Low	Very high	Low	Medium	Medium

The subcriterion «The need for precise positioning of railway cars» determines the level of design and technological preparation of the terminal and indirectly affects the cost of creating infrastructure.

The subcriterion «Prevalence of the piggyback system» evaluates the territorial representation of the piggyback system. For the «Infrastructure Owner» stakeholder, this subcriterion forms an understanding of how well a particular system has been implemented and which is the result of its operation. For «Logistics Service Provider», this subcriterion is important from the perspective of using different systems in the design of global supply chains, the links of which are located in regions with different piggyback systems.

The subcriteria of the economic group are formed by parameters characterising piggyback systems from the perspective of capital and operating costs for the use of piggyback technology (Table 4). The predominant interest in the subcriteria of this group, according to the authors, should arise from the stakeholders «Logistics Service Provider» and «Infrastructure Owner», since

Table 4

Values of economic subcriteria for piggyback system sustainability [compiled by the authors]

Subcriteria	Lohr	Cargo Beamer	CargoSpeed	Rolling Road	«1520 space»	Megaswing	Flexi waggon
Total costs per car	Very high	Very high	Medium	Medium	Low	High	High
Cost of servicing ITU at the terminal	Very high	Very high	High	Medium	Low	Medium	Low
Investment in construction of the terminal	High	High	High	Low	Very high	Medium	Low
Operating expenses of the terminal	High	Very high	High	Low	Medium	Low	Low

Table 5

Values of environmental subcriteria for piggyback system sustainability [compiled by the authors]

Subcriteria	Lohr	Cargo Beamer	CargoSpeed	Rolling Road	«1520 space»	Megaswing	Flexi waggon
Alienation of land	High	High	High	Medium	Very high	Medium	Low
Infrastructure material intensity	High	High	High	Low	Very high	Medium	Low
Material intensity of railway rolling stock	High	High	Medium	Medium	Low	High	Very high

their tasks include searching for financial sources for formation of a fleet of specialised railway rolling stock and a network of piggyback terminals.

The authors highlighted separately the subcriteria «Investment in construction of terminal infrastructure» and «Operating expenses of the terminal», since the amount of capital costs is not always directly dependent on the amount of operating costs.

Also, for all stakeholders, an important subcriterion of this group is the «Cost of servicing ITU at the terminal», since the capital and operating costs of the system will ultimately form the transport fee for transporting ITU and interest in piggyback technology.

The environmental group of subcriteria includes parameters that characterise piggyback systems from the perspective of their impact on the biosphere (Table 5). The «Infrastructure Owner» stakeholder has an increased interest in the subcriteria of this group, since the state and environmental organisations impose obligations on him to reduce the polluting impact of transport on the environment.

The subcriterion «Alienation of land» determines the volume of territory subject to environmental requirements and indirectly affects the costs of its acquisition and maintenance. The subcriterion «Infrastructure material intensity» is used to assess the volume of material resources spent on the creation and operation of the piggyback system infrastructure. The authors did not combine these subcriteria. The scale of alienated land is not always comparable to the volume of materials for its development. There are systems that, despite the large areas of piggyback terminals, have a fairly low material consumption.

The authors also believe that the interests of the «Infrastructure Owner» stakeholder include the search for piggyback systems located in smaller areas, up to the complete absence of this need.

The subcriterion «Material intensity of railway rolling stock» characterises the amount of materials for the creation and operation of rolling stock within a piggyback system and is a priority for the «Logistics Service Provider» stakeholder. The material consumption of rolling stock significantly affects the cost of the car and the costs of its operation.

The subcriteria of the social group include parameters characterising piggyback systems from the perspective of the labour resources involved in their opertion (Table 6). The authors believe that all stakeholders of piggyback technology will be interested in the subcriteria of this group.

For logistics service providers, the subcriterion «ITU support» will be important, since it determines the organisation of activity, forms the work and rest schedule of vehicle drivers, and affects personnel needs. For cargo owners, this subcriterion is important because it allows them to assess the performance and quality of transport services in terms of ensuring safety and timely delivery of cargo. The most preferred are piggyback systems that organise accompanied and unaccompanied transportation, and the least preferred are those in which ITU support is a prerequisite.

The subcriterion «Mechanisation and automation of labour» characterises piggyback systems from the perspective of their technological excellence and is important, first, to infrastructure owners. Since there is a direct connection between the technical level of production and the results of operations,

Table 6

Values of social subcriteria for piggyback system sustainability [compiled by the authors]

Subcriteria	Lohr	Cargo Beamer	CargoSpeed	Rolling Road	«1520 space»	Megaswing	Flexi waggon
ITU support	Low (Possibly)	Medium (Exclusively)	Medium (Exclusively)	.Very high (Mandatory)	Low (Possibly)	Medium (Exclusively)	High (Mandatory)
Mechanization and automation of labor	High	High	Medium	Medium	Low	High	Very high
Safety of system operation	High	Very high	Medium	Low	Medium	High	Very high

piggyback systems with a high level will be preferred.

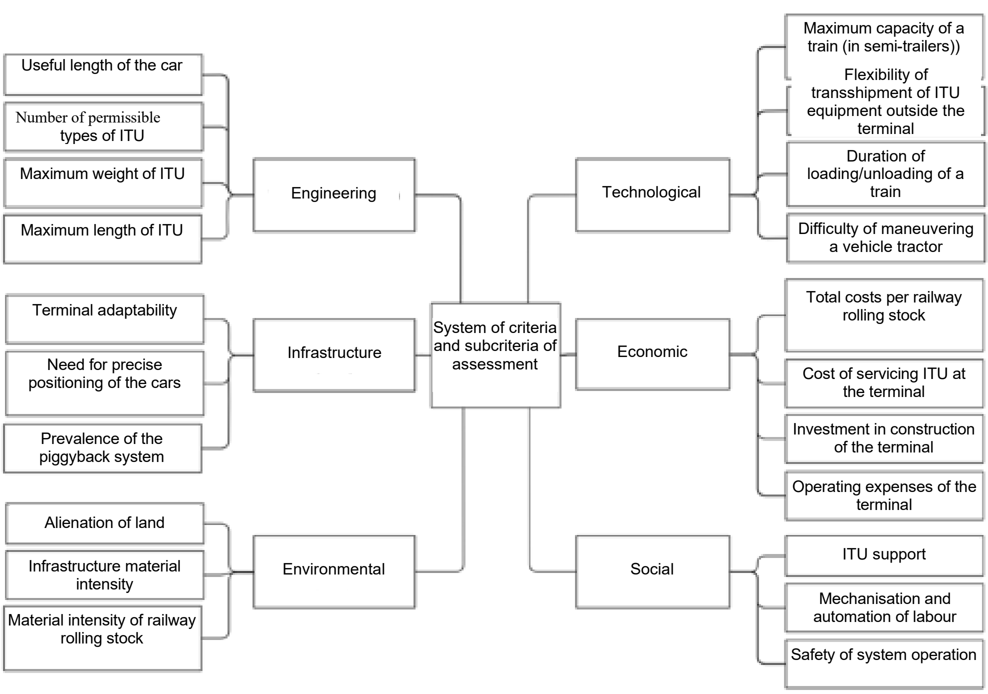
The subcriterion «Safety of system operation» determines the state of security of the piggyback system from internal threats and applies to all stakeholders, since they are all interested in the safe use of piggyback technology in supply chains.

Using the principle of hierarchical display of criteria and subcriteria when grouping criteria, as well as considering the current trend in development of transport systems and supply chains from the perspective of their sustainable development, ensures the development of a universal system of criteria for piggyback system sustainability in supply chains (Pic. 1).

The presented criteria form a set of universal characteristics of any piggyback system at the stage of development, testing or commercial operation. The criteria values can be used to individually evaluate the piggyback system when determining its sustainability in supply chains. The criteria also allow for comparisons of piggyback systems for the purpose of ranking them and selecting the best system using multi-criteria methods.

CONCLUSION

The effectiveness of using piggyback technology in sustainable supply chains is not constant and depends on the characteristics of the specific piggyback system. The variety of engineering and technological solutions for piggyback systems also limits their joint use in forming the network structure of global supply chains. The developed system of criteria allows



Pic. 1. Criteria and subcriteria of piggyback system stability [developed by the authors].

for a comprehensive assessment of piggyback systems when making decisions about their use in supply chains and can also be used to harmonise the engineering and technological parameters of piggyback systems.

Further research is associated with development of a methodology for multi-criteria assessment of piggyback systems, based on considering both the objective opinion of academic experts and the opinions of interested cargo owners, carriers and infrastructure owners. In addition, the authors set the task of identifying and analysing the goals, interests and behavioural strategies of participants in piggyback transportation to determine the system of their effective interaction.

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