Scientific Journal of Silesian University of Technology. Series Transport
Zeszyty Naukowe Politechniki Śląskiej. Seria Transport

Volume 121 **2023**

p-ISSN: 0209-3324

e-ISSN: 2450-1549

DOI: https://doi.org/10.20858/sjsutst.2023.121.3

Journal homepage: http://sjsutst.polsl.pl

Article citation information:
Burdzik, R. Original DHI method for assessing epidemic hazards in transportation services. *Scientific Journal of Silesian University of Technology. Series Transport*. 2023, **121**, 31-43. ISSN: 0209-3324. DOI: https://doi.org/10.20858/sjsutst.2023.121.3.

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ORIGINAL DHI METHOD FOR ASSESSING EPIDEMIC HAZARDS IN TRANSPORTATION SERVICES

Summary. In the situation of the global SARS-COV-2 coronavirus pandemic, epidemic threats are dominant and ubiquitous. The article attempted to estimate the hazards of virus transmission in various transport services. In the author's opinion, numerous and very serious problems in the transport sector and transport services are in this case the result of a lack of a methodical approach to the problem of epidemic threats, including infection in a global epidemic. The paper presents a proposal for an original DHI method for assessing epidemic hazards in transportation services, taking into account various hazards and routes of virus transmission (droplet and contact) based on dedicated scales of hazard evaluation and multi-criteria assessment. This methodology is named Deep Hazard Identification (DHI). The primary stage of the methodology is the identification and estimation of transmission mechanisms of pathogen that can occur in transport services. For this purpose 15 criteria and weighting factors were defined and used for a multi-criteria epidemic hazards assessment. It enables the determination of the matrix of hazard assessment separately for the passenger transport and freight transport groups, which allows for the comparison of the DHI hazard factor between different transport services.

Keywords: epidemic, hazard and risk, transport services, deep hazard identification

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1. INTRODUCTION

By the end of 2019 and the beginning of 2020, the approach to safety in transportation underwent a radical change. The rapidly spreading epidemic of the SARS-CoV-2 virus and the global COVID-19 pandemic caused nearly everyone worldwide to experience fear of the coronavirus. The risk of viral infection started to be analyzed in almost all social activities [1]. Due to its inherent function of moving from one point to another, transportation became a significant factor in the spread of the pandemic. The definition of safety in transportation was revised to include new criteria regarding the hazards of virus transmission while transportation processes are conducted. Consequently, the definition of risk in transportation was also expanded, leading to the recognition of new hazards that are significant in assessing risk in transportation. These issues are addressed in the book [2], which presents an original and fully complementary method for estimating epidemic risk in transportation. The number of publications focused on the risk of viruses (especially COVID-19) has greatly increased since 2020. However, the vast majority of these publications have focused on passenger transportation [3,4], specifically on the analysis and simulation of the spread of virus-laden droplets within means of transportation [5-7]. But transport, which is treated as the bloodstream of the world economy and also the foundation of human mobility, has also been affected by a global pandemic. One of the most critical crises in transport was the imbalance in global supply chains, which is associated with economic and trade stability at local, national and continental levels. Of course, supply chain problems were also caused by production downtime, drastic changes in the product demand structure, and political decisions.

In the author's opinion, numerous and very serious problems of the transport sector and transport services are in this case the result of the lack of a methodical approach to the problem of epidemic threats, including infection in a global epidemic. All the more so as the SARS-CoV-2 pandemic is a phenomenon that has never been seen before and the effects of the COVID-19 disease and the death rate make it necessary to adopt new measures and scales of epidemic hazard. Therefore, the author of this manuscript decided to approach the problem of the coronavirus pandemic in transport services methodically. The dedicated proprietary methodology with the purposes of complete identification and comprehensive assessment of virus and epidemic threats and hazards during the implementation of all kinds of transport services based on the risk management methodology were developed [2]. In addition to the assumed effects of the developed methodology, it seems very important to use it to limit the spread of the coronavirus through transport processes, as the identification of risk factors, selection of security systems and the decision of the method of providing the transport service. This paper presents an application of Deep Hazard Identification (DHI) method for preliminary virus and epidemic hazards and threats assessment in cases of transport services. The aim of the presented research is to demonstrate the capabilities provided by DHI in comparing epidemic threats present in various transportation services.

2. MATERIALS AND METHODS – DHI METHOD

The transmission mechanisms of coronavirus pathogens are divided into two main categories: airborne transmission (droplet transmission and inhaled aerosol) and transmission through contact with an infected surface (objects and human skin) [8]. Research from [9-11] has an important impact, and the fundamentals to study the SARS-COV-2 transmission problem in transport are from [9-11]. These papers present mathematical models applied for the calculation of the likelihood of virus transmission. Most of the models assume that the number of people being infected corresponds to a Poisson probability distribution [9], models of epidemics based on random mixing model without repetition of contacts, the SIR model (Susceptible, Infectious, or Recovered) [10], aerosol transmission as a major contributor to the spread of influenza [11]. There are four main routes for the transmission and spread of pathogens: infested fomites, direct contact, airborne, and vector-borne [12]. Most of the investigations indicate that the airborne route transmits the highest amount of pathogen, so the infection risk by this mechanism is the highest [13]. To complete the analysis of all potential mechanisms of pathogen transmission, air and surface transmission paths have to be considered [14].

The author has developed a comprehensive methodology for the assessment of epidemic infections in transport services. An important feature of this method is that it takes into account various transmission routes of pathogens (droplet and contact surface) and various epidemic threats determined by the conditions of the transport process based on dedicated scales of hazard evaluation and multi-criteria assessment. The assumption of this method is an in-depth analysis of the transport process in terms of identifying epidemic hazards and factors determining the mechanisms of pathogen transmission on predefined scales [15]. That's why this method was named DHI - Deep Hazard Identification.

The developed methodology of DHI is universal; however, the proposed scales of hazard evaluation are dedicated to the epidemic threat of the SARS-CoV-2 coronavirus. The levels of hazard assessment were scaled each time according to the epidemic characteristics of the coronavirus. In developing the methodology, a representative number of different types of transport services were selected. It was assumed that in order to fully identify the risk factors, the transport of people and goods should be analysed. As a representation, the following transport services were selected for the analysis:

- taxi,
- car-sharing,
- mini bus (up tp 9 passengers),
- coach bus (ordered),
- coach (line bus),
- collective urban transport (bus),
- collective urban transport (tram),
- railway transport (regional),
- railway transport (intercity),
- medical transport (ambulance),
- air transport,
- courier (parcel locker),
- courier (d2d),
- catering (food transport),
- delivery of purchases,
- heavy transport (with directed contact),
- heavy transport (without directed contact).

The DHI method procedure requires the implementation of six subsequent steps: predefinition of universal evaluation scales of epidemic factors, estimation of weighting factors representing influence on pathogen transmission, mapping of transport service processes, assessment of all hazards in subsequent process operations according to defined scales, calculation of the product of values assessment and weighting of subsequent hazards, and final calculation of a multi-criteria weighted assessment as the DHI hazard assessment.

2.1. Epidemic hazard factors

The DHI method involves an in-depth analysis and evaluation of the level of epidemic threats. Therefore, it is necessary to determine environmental, procedural, and systemic factors that influence the potential occurrence of a threat during the execution of transportation processes [16]. In accordance with the assumed goal, possible mechanisms of coronavirus infection were identified as methods of virus transmission between participants in the transport process, considering droplet transmission and contact by infected surfaces' transmission [17]. The development of value ranges for assessing the level of impact of subsequent determinants of virus transfer mechanisms required a review and synthesis of the state of knowledge in the field of epidemiology and the spread of the epidemic. However, it should be emphasized that it is recommended to verify the adopted values periodically in accordance with the progress of the epidemic, methods of combating it, and the latest global research and WHO reports. Based on an in-depth study of the issue for specific transport services [18], the 15 factors determining the mechanisms of infection in means of transport were defined and detailed in [2].

Therefore, final factors determining the hazards of virus infection in transport are presented in Table 1.

Tab. 1

Factors determining the hazards of virus infection in transport

No	Hazard Factor
1.	Social distance (droplet)
2.	Touching a contaminated surface
3.	Loading time
4.	Isolation time (load)
5.	Exposure time and number of people
6.	Time between use cases
7.	Operator exposure time
8.	Transport time
9.	Distance between the seats
10.	Number of stops
11.	Air circulation
12.	Type of loading
13.	Securing the cargo
14.	Document flow
15.	Type of delivery point

Table 1 presents all factors influencing the efficiency of pathogen transfer mechanisms in various modes of passenger and freight transport. Due to the specificity of transport and the fundamental difference in the context of infection risk for the transport of passengers and goods, some of the factors listed in Table 1 apply only to one or the other group of transport. Thus, in freight transport, 12 out of 15 factors are assessed, and in passenger transport, 9 out of 15 factors are assessed. A detailed justification and description are presented in [2].

Universal scales of epidemic hazard level ranging from 1 (for minimal values) to 5 (for maximum values) have been developed for each of the defined hazard factors. For each factor, 5-level thresholds have been established based on quantitative values such as distance measured in meters (radius), number of people, or time values. The determination of these values and subsequent levels (1-5) utilized technical knowledge regarding the construction of means of transport, as well as knowledge about pathogen transmission through droplets and contact with contaminated surfaces (such as transported goods, seats, or handles). A detailed description of the criteria for defining assessment values and all scales for evaluating hazard factors is provided and presented in [2].

2.2. Indicators of the impact of hazard factors on the risk of infection

Fundamentally and generally, risk assessment involves a multiplicative assessment of key risk factors related to their occurrence and effects. These factors are grouped as sources of hazards and have different influences on risk levels. Therefore, these hazards have to be selected by impact. It can be considered a problem of multiple factors that simultaneously affect the final result. For the quantitative evaluation of the criteria's impact on infection risk during transport processes, the modified AHP method was employed [19]. Originally, the Analytic Hierarchy Process method (AHP) was used as a decision support tool in terms of multi-criteria selection of various combinations and variants of complex problems [20]. As a result of using this method, decision tables are obtained based on a pairwise matrix with mutual dominance of criteria. The information obtained in this way enables precise estimation of weighting factors resulting from all interdependencies and domination of the analyzed criteria. The final ranking can be calculated by using a simple additive weighting method. As part of the decomposition of the problem of epidemic hazards during the SARS-CoV-2 pandemic, a set of hazards factors (criteria) were performed. In further proceedings, the hierarchical model is used by subsequent analyzes of the dominance of subsequent pairs of all criteria. In order to assess the level of dominance in subsequent pairs of criteria, Saaty's nine-point scale of importance of preferences is used [21].

The detailed results and process of analyzing the mutual domination of all epidemic threat factors are presented in [2]. The summary of the final results is presented in Table 2. These are the values accepted as representative of the assessments of two independent expert teams. The first team consisted of experts in the fields of transport organization and engineering, while the second team consisted of experts in the identification of epidemic threats in transport. Both groups of experts were involved in the implementation of two independent projects in the field of epidemic safety in transport in 2020 and 2021 and represented current, in-depth knowledge on these issues. As a result of this adopted methodology, the following weight factors were determined for all accepted hazard factors (Table 2).

Tab. 2

Weight factors of selected hazard factors applied in the DHI methodology

No	Hazard Factor	Weight Factors
1.	Social distance (droplet)	0.16
2.	Touching a contaminated surface	0.07
3.	Loading time	0.02
4.	Isolation time (load)	0.03
5.	Exposure time and number of people	0.02

6.	Time between use cases	0.19
7.	Operator exposure time	0.13
8.	Transport time	0.10
9.	Distance between the seats	0.10
10.	Number of stops	0.04
11.	Air circulation	0.07
12.	Type of loading	0.01
13.	Securing of the cargo	0.01
14.	Document flow	0.02
15.	Type of delivery point	0.02

The estimated weight factors constitute a quantitative dimension of the impact and importance of a given hazard factor on the risk of pathogen transmission during the transport process.

2.3. Application of process approach for identification of epidemic hazards in transport services

For the purpose of preliminary hazard assessment in transport services in the aspect of epidemic threads during the SARS-CoV-2 pandemic, process mapping has been employed [22]. Process mapping enables the preparation of the process flow chart of the transport service and the recognition and evaluation of factors that influence epidemic hazards in the subsequent operations of the transport process. By analyzing in detail, the successive steps in the process presented in the flow chart in terms of potential hazard factors and considering the scale of factor assessment of the endemic risk of SARS-COV-2 coronavirus infection, a general epidemic hazard assessment is done. For this purpose, the developed scales of evaluation values described in subsection 2.1 are used.

Due to some discrepancies and the specificity of passenger and freight transport, dedicated sets of factors were proposed, divided into these two groups. However, in order to fully analyze the hazards, it was assumed that for all transport processes, all factors assigned to a given group (passenger transport or freight transport) should be assessed. This approach systematizes the hazard identification process and enables comparability of the obtained results between different transport services in a selected group.

As part of the research, a detailed analysis of the sources of hazards was carried out using the methodology of mapping the processes of all transport services indicated in section 2. Identification of the hazard factors consisted of the evaluation of all 15 factors according to the developed scales (score points 1 to 5), analysing all activities and operations in the process map one by one. This approach guarantees the universality and comparability of assessments for various transport services and a comprehensive approach as a deep analysis step by step. As the example of process flow chart for car-sharing in aspect of occurrence of contact (human or surface) and potential hazard of pathogen transmission have been depicted in Figure 1. Based on the analysis of the process map, an assessment of each epidemic hazard factors was conducted using predefined scoring scales. The results and final assessment are presented in Table 3.

The presented analysis of hazard factors with description in Table 3 allows determining the total hazard assessment in car-sharing as 18 (maximum 45). The total assessment of epidemic hazard for this service is rather low. However, two hazard factors are highly rated: time between use cases (5) and exposure time and number of people (4). By employing such an approach, the implementation of appropriate actions to mitigate these threat factors becomes highly evident, such as vehicle disinfection after each use.

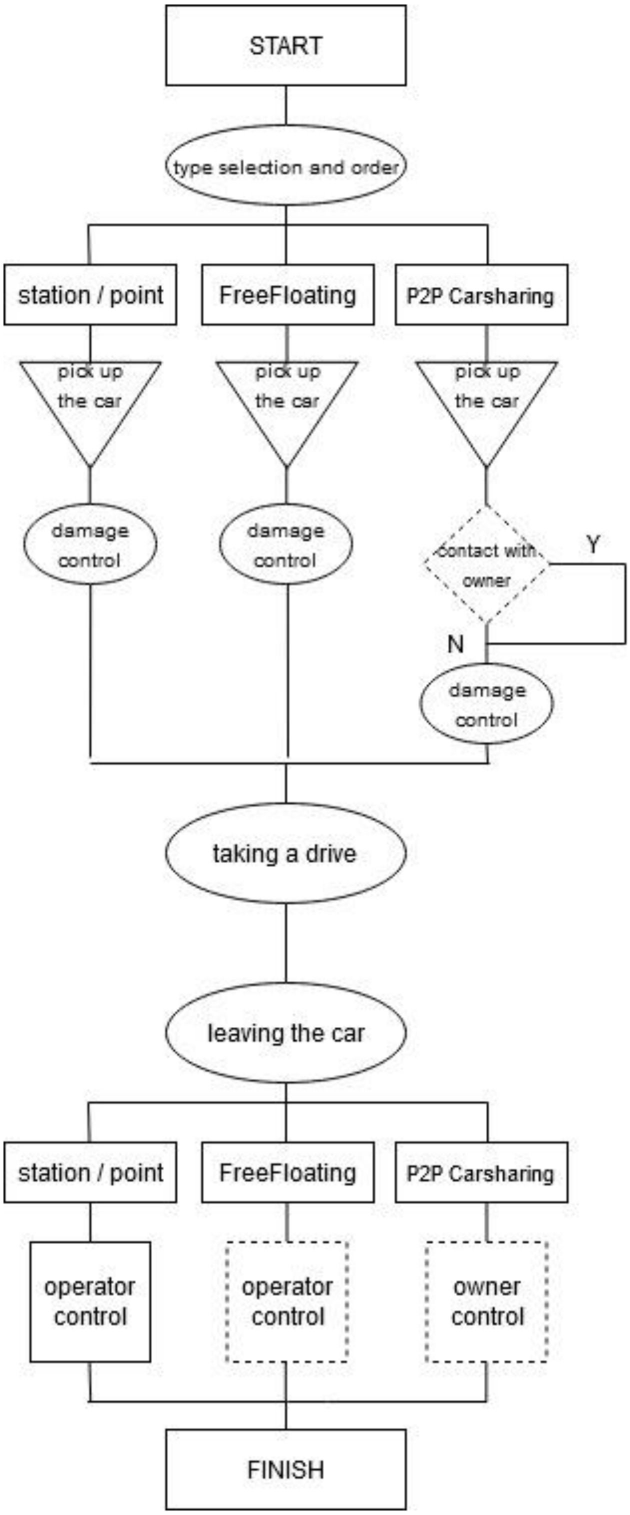

Fig. 1. Process flow chart for car-sharing in aspect of DHI methodology

Tab. 3

Assessment of the epidemic hazards in aspect of DHI methodology – car-sharing

Hazard factor	Description	Hazard score
Social distance (droplets)	There is often only one person in a vehicle, if there are more of them, they are friends (knowing their health condition)	1
Touching a contaminated surface	Potentially infected vehicle components - exterior door handles, interior door handles, seats, seat belts and other components inside the vehicle within easy reach. Within an hour, it is assumed that the vehicle is only used by the driver, which, with an average time of use of 30 minutes, results in a replacement of 2 people per hour. The vehicle is not cleaned after each user.	2
Exposure time and number of people	The vehicle is not cleaned after each user. It was assumed that the vehicle's exposure is over 30 minutes, and during that time it is operated by less than 10 people.	4
Time between use cases	Vehicles are equipped with many plastic elements inside, on which pathogens can be active for up to 72 hours. The vehicle is not cleaned after each user. During 72 hours, on average, up to 120 people can use the car.	5
Operator exposure time	The car-sharing service operator has no contact with the customer.	1
Transport time	Transportation only with the participation of one driver	1
Distance between the seats	The square area of passenger cars is approximately 2.5 to 3.7 m^2 and the distance between the seats is less than 1.5 meters. However, it was assumed that the driver was alone in the vehicle.	1
Number of stops	There are no stops during the service, the transportation is directly from the starting point to the ending point.	1
Air circulation	In cars used in car-sharing systems, air exchange is possible in open and closed circulation. To do this, you can ventilate the vehicle by opening the windows or turn on closed-circuit air conditioning or open-circuit ventilation.	2
	Total score:	**18**

2.4. Final epidemic hazard assessment – DHI index

The table presented in the previous section allows determining a multivalued vector of the epidemic hazard state of a transport service. However, due to the differences in the impact on the immediate threats of SARS-COV-2 coronavirus infection by various hazard factors, the determined state vector should be corrected with appropriate weighting factors. In addition, due to the specificity of the passenger and freight transport, the criteria for hazard identification were also selectively grouped, so each time the comparison is made separately for two groups of transport services (passenger transport and freight transport).

In the final stage of applying the DHI method, the DHI index is determined, which is the result of a multi-criteria and weighted assessment of epidemic hazards. The mathematical notation of the DHI index is a weighted sum, calculated according to Formula (1):

$$DHI_i = \sum_{i=1}^{n} H_i \cdot w_i \tag{1}$$

where:
n is the number of all considered factors
H_i is single hazard assessment value for i-th factor
w_i is weight factor for i-th hazard factor

The final value of the DHI index obtained by this method is a quantitative measure representing the overall assessment of epidemic hazards and threats for a given transport process. The results of these transformations are presented in the Table 4. An example of calculating the DHI index is presented in Table 4 using the case of car-sharing. The procedure for obtaining the final DHI index results in the analysed case is presented in the Table 4.

Tab. 4

Assessment of DHI index – car-sharing

Hazard	Weighting factors	Car-sharing - score	Car-sharing - weighting score
Social distance (droplets)	0.16	1	0.16
Touching a contaminated surface	0.07	2	0.15
Exposure time and number of people	0.19	4	0.76
Time between use cases	0.02	5	0.11
Operator exposure time	0.13	1	0.13
Transport time	0.10	1	0.10
Distance between the seats	0.10	1	0.10
Number of stops	0.04	1	0.04
Air circulation	0.07	2	0.13
	SUM:	18.00	**1.68**

The DHI method enables a preliminary assessment of the level of epidemic hazards depending on the implementation of transport processes. Thanks to the analysis of many factors determining the risk of infection in means of transport, the assessment of all operations of the transport process and the final validation of the results based on the adopted weight factors, the final measure of the DHI index is a preliminary but also precise measure of the level of epidemic hazards. However, you should be aware that this is not yet a measure of the risk of infection.

3. MULTI-CRITERIA WEIGHTED MATRIX OF HAZARD ASSESSMENT IN TRANSPORT SERVICES

By employing DHI method, we can obtain a matrix of hazard assessment for the of transport services. It shows the collection of vectors of the state of epidemic hazards in selected transport services. The final evaluation is corrected with the weighting factors of the hazards, in effect obtaining a multi-criterion weighted matrix of hazard assessment in passenger (Tab. 5) and freight (Tab. 6) transport services.

Tab. 5

Multi-criteria weighted matrix of hazard assessment in passenger transport services

Hazard	Weighting factors	Car sharing	Railway transport (intercity)	Railway transport (regional)	Taxi	Air transport	Collective urban transport (bus)	coach bus (regular service)
Social distance (droplets)	0.16	0.16	0.81	0.65	0.81	0.81	0.65	0.81
Touching a contaminated surface	0.07	0.15	0.22	0.22	0.15	0.37	0.22	0.22
Exposure time and number of persons	0.19	0.76	0.76	0.95	0.76	0.95	0.95	0.95
Time between use cases	0.02	0.11	0.11	0.11	0.11	0.02	0.11	0.07
Operator exposure time	0.13	0.13	0.26	0.26	0.65	0.26	0.39	0.65
Transport time	0.10	0.10	0.51	0.41	0.31	0.51	0.31	0.51
Distance between seats	0.10	0.10	0.50	0.50	0.50	0.50	0.50	0.50
Number of stops	0.04	0.04	0.08	0.16	0.04	0.04	0.20	0.08
Air circulation	0.07	0.13	0.20	0.20	0.13	0.07	0.27	0.20
DHI index:		**1.68**	**3.45**	**3.45**	**3.45**	**3.52**	**3.59**	**3.98**

Tab. 6

Multi-criteria weighted matrix of hazard assessment in freight transport services

Hazard	Weighting factors	Heavy transport (no contact)	Heavy transport (contact)	Courier (parcel locker)	Catering	Delivery of purchases	Courier (d2d)
Social distance (droplets)	0.16	0.16	0.48	0.16	0.65	0.65	0.81
Touching a contaminated surface	0.07	0.15	0.22	0.15	0.30	0.37	0.30
Loading time	0.02	0.03	0.03	0.03	0.03	0.05	0.05
Isolation time (cargo)	0.03	0.06	0.06	0.10	0.16	0.13	0.16
Time between use cases	0.02	0.02	0.02	0.11	0.09	0.09	0.07
Operator exposure time	0.13	0.13	0.13	0.65	0.13	0.13	0.65
Number of stops	0.04	0.04	0.04	0.04	0.12	0.16	0.12
Air circulation	0.07	0.13	0.13	0.13	0.13	0.13	0.13
Type of loading operation	0.01	0.01	0.06	0.02	0.02	0.04	0.04
Securing the cargo	0.01	0.03	0.07	0.04	0.06	0.04	0.04

Document flow	0.02	0.09	0.09	0.02	0.07	0.07	0.07
Type of delivery point	0.02	0.02	0.11	0.05	0.09	0.09	0.09
DHI index:		**0.88**	**1.46**	**1.50**	**1.85**	**1.95**	**2.52**

DHI indexes and complete multi-criteria weighted matrix of hazard assessment enable a quantitative comparison of value of epidemic hazards in transport services. Based on the conducted analyzes for passenger transport services, the highest score of epidemic hazards is determined for coach bus as regular line bus (DHI = 3.98), the next one is collective urban transport (DHI = 3.59). By far the lowest value was determined for car-sharing services (DHI = 1.68). When considering the impact of separate factors, the most crucial are exposure time and number of persons. Therefore, it should be recognized as the first process regulation to reduce the infection risk. For freight transport services, the highest value of epidemic hazards occurs for courier parcels services door to door (DHI = 2.52). Definitely, the lowest value was determined for heavy transport without contact with operators (DHI = 0.88).

4. CONCLUSION

The developed methodology for the assessment of epidemic hazards of epidemic in the case of the SARS-COV-2 coronavirus pandemic, referred to as Deep Hazard Identification (DHI), enables an in-depth analysis of hazards and threats based on flow chart of transport process maps and developed quantitative scales for assessing criteria influencing the risk and routes of pathogen transfer. This will allow us to seek a compromise in risk estimation not only for pathogen transmission but also for other risks related to the operational reliability of the vehicle fleet [23].

To underline the significance of the results, the matrix of hazard assessment for the large group of transport services have been presented. The developed methodology for the assessment of epidemic hazards of coronavirus infection, referred to as DHI method, enables the quantitative evaluation of hazards based on the vector of the state of epidemic hazards.

For the developed data sets and process maps of a selected group of transport services, it is possible to determine the matrix of hazard assessment. The author recommends a selective selection of evaluation criteria depending on the types of transport services. In the most general terms, it is recommended to use the division into passenger and freight (cargo) transport. Due to the reduction of the number of analyzed criteria, the final weighted estimator becomes even more representative. As part of the discussion, the author assessed 17 groups of transport services, including 11 in passenger transport and 6 in freight transport.

The matrix of hazard assessment in transport services in the aspect of hazards during the SARS-CoV-2 pandemic enables the determination of a collective table of hazard factors for a selected group of transport services. As a consequence, it allows identifying the dominant sources of hazards and comparing services in the context of the risk of epidemic threats. This may constitute the basis for making decisions regarding the selection of transport services or indicate a hierarchy of goals in the context of minimizing or eliminating hazard factors, which is the first step for risk management.

An additional possibility of using the results of the matrix of hazard assessment is the ability to identify the dominant sources of epidemic hazards. The developed DHI methodology is universal, but the obtained results should be adjusted for the current infection rate, the rate of tests performed in a given country, or even a region, and the current recommendations and restrictions related to transport, social distancing and sanitary conditions of work organization.

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Received 10.08.2023; accepted in revised form 03.10.2023