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An Application of the DHI Methodology for a Comparison of SARS-CoV-2 Epidemic Hazards in Customer Delivery Services of Smart Cities

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Abstract: Current awareness of epidemic threats and critical experiences of the COVID-19 pandemic require extension of the management model in the smart city, especially in the field of mobility and transport services, with monitoring of epidemic hazards. This paper addresses the issue of epidemic hazards, a new challenge in smart cities, and customer delivery services. The novel DHI methodology for epidemic hazards assessment is presented and applied to compare customer delivery services in aspects of SARS-CoV-2 epidemic hazards. The case studies presented a detailed analysis of epidemic hazards on the basis of process algorithms and dedicated quantitative scales to assess factors influencing the mechanisms of virus transmission. The developed DHI methodology and the results obtained for transport services constitute important cognitive knowledge for the administrative personnel in smart city.

Keywords: epidemic hazards and threats; COVID-19; customer delivery; transport

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1. Introduction

The origin of the concept of a smart city refers to the concepts and models of ancient cities and urban solutions of subsequent historical epochs. An example is the ancient cities of Piraeus and Pergamon, built on the basis of a concept attributed to Hippodamus of Miletus, with urban layouts based on a rectangular grid of streets and functionally diverse districts—administrative, commercial, and sacral [1]. Philosophically considered, the smart city concept should recognize, understand, and meet the needs of its residents. In this aspect, a smart city is a set of optimized conditions that ensure a high quality of life for its inhabitants, efficiency and reliability of technical infrastructure, and efficiency in the management of natural and technical resources [2].

Smart city uses different types of sensors to collect the data required to efficiently manage all resources. ITS data are used to monitor and manage traffic and secure the safety of transportation systems. Sensing technologies are also widely used for monitoring the performance of vehicles [3,4] and more and more often, transport infrastructure [5]. Sensing technologies allow to monitor not just the safety performance of means of transport but also comfort [6] and reliability [7]. Smart cities sensing is an emerging paradigm to facilitate the transition into smart city services [8]. Currently, we can observe a dynamic development and a lot of research in the field of monitoring and safety support systems in transport, especially in large urban agglomerations headed towards smart cities. An example is the system described in [9]. Video monitoring systems (VMSs) operate in smart cities infrastructure, such as buildings, parking lots, airports, and collective public transport, and are one of the electronic security systems. Another example is presented in [10]. The authors present the implementation of the proof-of-concept of an IoT architecture to collect pollution metrics within a smart city using the best practices in software development technologies. A correct decision requires proper interpretation of the data. The paper [11] presents some signal processing algorithms applied in ITS (at intersections for traffic signal control), such as the distributed multi-agent reinforcement learning algorithm and the cutting-edge advantage actor-critic algorithm with deep neural networks used for value approximations. The analysis concluded by [12] confirms that vehicular sensor networks (VSNs) also play a key role in the development of efficient ITS; therefore, security in VSNs is a critical subject that must be addressed in emerging intelligent transport systems. Moreover, the amount of interaction among different internet of things sensors becomes massive and insecure over the internet as we probe for smart cities. The paper [13] presents an architecture called safe city, which highlights the system of smart cities that consists of cameras, sensors, and other real-world physical devices. Smart city challenges also deal with generalized vehicle routing problem (GVRP). The paper [14] presents a method based on bio-inspired algorithms in order to find the optimum routing of product delivery.

An important feature of a smart city is data openness and a big data information system. The importance of being connected to online services and having access to real-time data has been further exacerbated in the SARS-CoV-2 pandemic, where many essential activities are carried out remotely via digital online methods [15]. In the paper [16], as one of the reasons in some less developed countries that have led to the underestimation of the actual number of COVID-19 cases or death rates, the hindering of data openness was indicated. This paper presents an interesting summary of the scores assigned to different tiers of the data openness assessment of COVID-19 information for selected five east Asian cities. These assessments were based on data provision and centralization within city-wise dashboards and the COVID-19 pandemic websites.

The concept of smart cities faces many challenges and needs updating. Especially considering the last 3 years, during which new global threats and crises appeared. At the beginning of 2020, the global coronavirus pandemic broke out, which changed the perception of safety by all people, especially in heavily urbanized cities. Then, at the beginning of 2022, as a result of Russia's aggression against Ukraine, global geopolitics changed, and an energy and food crisis occurred. As a consequence of these events, there was a financial recession and crisis, as well as increased inflation and the cost of maintaining the smart city. In relation to the subject matter presented in this paper, a particularly important component of a smart city is smart mobility [17,18]. Its importance is confirmed by the smart city transportation team, specially appointed by the European Commission. In this context, transport systems of the ITS (intelligent transport system) category are crucial. The main role of the smart mobility area is to connect all the city resources—people, goods, and information [18]. The authors of [19] specified the following key objectives that guide the implementation of smart mobility solutions: reducing mobility costs; reducing air pollution; reducing noise pollution; reducing traffic congestion; increasing safety; and improving the speed of mobility. An interesting study is presented in [20]. The authors indicated, using a difference-in-differences data analysis from the period 2005 to 2017, that smart city initiatives in China reduced industrial exhaust gas and industrial wastewater by approximately 20.7% and 12.2%, respectively. Another important area of smart cities is sustainable reverse logistics. A novel modified metaheuristic algorithm developed to optimize the performance of polystyrene disposable appliances is presented in [21].

At the beginning of the COVID-19 pandemic, some preliminary concepts have been studied to secure safety in smart cities. The paper [22] discusses potential solutions and reviews some approaches that can be used to develop feasible development trends for the construction of the newly expected health-centric smart cities. The paper [23] presents the 15 min city model as an alternative planning approach in light of the global COVID-19 pandemic. Innovative methods using autonomous means of transport were also analyzed in order to reduce the risk of infection during the delivery of goods to the customer. For example, drones minimize personal contact, so they are also suitable for use in the current COVID-19 pandemic, for example, for light product delivery or even in the form of crowd surveillance [24]. The paper [25] presents the role and potential inherent characteristics of surveillance systems in smart cities today in the context of the COVID-19 pandemic. The authors of [26] discussed three challenges for urban centers in terms of COVID-19 and the future of cities. One of them is mobility and the challenges of urban public transport [27]. In this regard, the authors of [28] indicate the need to analyze the risk of coronavirus infection as the basis for limiting mobility in cities. A comprehensive methodology for risk assessment and epidemic risk management in transport services was presented by the author of this article in his book [29]. The paper [30] presents a review based on a content analysis of the literature that has discussed actual and/or potential applications of smart technologies to combat the COVID-19 pandemic in cities. The authors identified 10 main contributions of smart solution technologies to combat the COVID-19 pandemic. These major contributions are the result of a thematic analysis of the four resilience abilities, i.e., planning, absorption, recovery, and adaptation. In the area of planning, it covers preparing and providing smart city infrastructure, facilitating collaborative and integrated planning and management, and using smart technologies for forecasting and prediction and for identifying hotspots that can contribute to preventing or minimizing disease outbreaks. Absorption refers to the ability to minimize functionality loss in the immediate aftermath of a disruptive event. The authors of [30] focus on measures that are directly related to absorption, such as measures taken to prevent the spread and/or reduce the transmission speed of the virus. The literature synthesis shows that smart solutions can also facilitate a timelier recovery by providing support to the overstretched healthcare staff and by providing alternative means to ensure continuity of basic processes and functions. The adoption of smart technologies to deal with the pandemic has provided opportunities to accelerate the transition towards digitalization of different sectors and has also offered lessons that can be used to optimize city operations. In the paper [30], the ideas of using transportation and mobility were limited almost only to collecting data and tracking the person. After more than three years of pandemic, we know what we did wrong and what we can and should do about it.

A review of the current state of knowledge shows huge disparities in research on epidemic risks in the transport of people and goods. There is practically no research devoted to the analysis of pathogen transmission threats in freight transport services. These are important issues that must not be omitted, especially due to the dynamic growth of services related to the delivery of goods, food, or groceries to customers. This was due to the participation of people in quarantine and restrictions on their mobility, but also to the greater interest of other people who saw safer shopping and limiting contact with others in this form. In addition, services of this type are characteristics of the smart city concept.

This paper is devoted to the issues of transport and security for services specific to smart cities and related to the delivery of goods to the customer. As a result of global changes and social behavior in 2020 due to the COVID-19 pandemic, security should be considered the main determinant of smart mobility. The attitude toward safety in transport has also changed because it currently concerns the elimination of the risk of viral infection, for example, the SARS-CoV-2 virus. The article presents the original method of epidemic hazards assessment and its application for the initial assessment of epidemic risk for services related to the delivery of goods and food to the customer. The structure of the paper is as follows: an introduction section with the literature review on smart city properties in aspects of transport and mobility and epidemic issues; a description of the DHI method and factors that affect epidemic hazards in transport; a presentation of the application as case studies on courier parcel services, catering delivery, and shopping delivery; a discussion of the results; and a conclusion.

The developed deep hazard identification (DHI) method enables the identification and assessment of epidemic hazards in transport processes, which are key processes that determine mobility and additional services important for the functioning of smart cities. The assumptions and principles of the DHI method include the possibility of a comparable assessment of all transport processes, including the transport of passengers and goods. Therefore, universal scales for the assessment of risk factors that affect the risk of pathogen transmission during activities in the transport process have been developed. The conditions for using this method are knowledge of the transport process and the conditions of transport, taking into account the means of transport and additional activities. The only limitation in the use of this method is the lack of complete knowledge of the implementation of the transport process. Therefore, it is assumed that the analysis should be performed by a person familiar with the details of the process and the infrastructure and superstructure of transport. The practical significance of the DHI method is the initial assessment of epidemic hazards and the identification of dominant factors that affect pathogen transmission during the transport process. This is the basis for estimating the probability of infection and risk assessment, as well as developing a practical risk management model by minimizing or eliminating the dominant risk factors in a given process. Alternatively, make the decision to completely replace one process with another, for which the DHI index is lower. This method may be an extension of the smart cities monitoring area, especially during epidemic threats. It should be remembered that one of the basic foundations of smart cities is security, including epidemic safety.

2. Materials and Methods

With such a dynamic increase in the number of customer delivery services since the beginning of the SARS-CoV-2 virus pandemic related to social isolation and quarantine, extended analyses of this transport sector are advisable. Analyses and development of this sector should not be limited only to increasing the efficiency and quality of transport processes but also include additional aspects, especially those related to the assessment of epidemic hazards and pathogen transmission.

Very often, the choice of this type of service is determined by concern for safety and the elimination of the risk of coronavirus infection. That is why the identification and assessment of epidemic threats and hazards are so important. This will allow the development of additional safety solutions and alternative variants of process implementation.

Therefore, the research problem was defined as the identification and assessment of epidemic hazards in transport services related to the delivery of products to customers. On the example of the COVID-19 pandemic, the author, based on his own research and directed research projects, developed a new and original method for identifying epidemic hazards and threats and a multi-criteria weighted method for assessing these hazards. The methodology developed was called deep hazard identification (DHI). A complete and detailed description of this method is provided in [29]. The application of the DHI methodology requires the following steps:

- development of universal scales to evaluate potential virus transmission mechanisms and factors,
- calculation of weighting factors expressing the mutual significance levels of the evaluation factors,
- algorithm of transport service processes,
- identification and assessment (score) of epidemic hazard factors considering the subsequent operations of the transport process,
- calculation of total hazard assessment (score),
- calculation of multi-criteria weighted assessment as the DHI hazard assessment.

The process of implementing the DHI method and the subsequent stages of the final calculation of the DHI hazard assessment are presented in Figure 1.

The first very important stage in the development of the DHI method was the identification of factors that affect the mechanisms of infection and transmission of the coronavirus pathogen. Only factors related to the implementation of transport processes were selected. Two independent expert groups conducted research aimed at identifying epidemic threats in transport, taking into account all types of virus transmission (droplets, touching surfaces, and touching people). Subsequently, transport experts identified factors in transport processes that affect pathogen transmission mechanisms and the risk of infection. Expert groups were formed to select representatives with qualifications in the organization of transport services (experts from transport companies), the construction and maintenance of means of transport (transport engineers), and the expertise involved in two research projects. One focused on the project of a system that supports epidemic safety in transport, and the second focused on the identification of epidemic hazards in transport. At this stage of the development of the DHI method, two separate expert groups were selected. Both groups worked separately, and at the end, the results were compared by an external project supervision team. Each of the expert groups consisted of five members (10 in total). One expert in each group represented transport companies offering transport services. These experts were responsible for the analysis of the organization of the transport process and the identification of all operations and activities during the service. Two experts in each group represented engineers who specialize in the construction and operation of means of transport. They were responsible for analyses in the field of construction and equipment of means of transport and all technical parameters (including air exchange, seat distances, etc.). In addition, two experts in each of the groups represented experts working during the implementation of two research projects in the fields of developing systems that improve epidemic safety in transport and identifying factors of epidemic threats in transport. Unfortunately, there were no epidemiologists or virologists in the expert groups, but experts (two per group) involved in the implementation of projects for a year conducted analyses and reviews of the current state of knowledge in the field of pathogen transmission mechanisms, supported by numerous studies and reports of epidemiology experts publishing their results in publications in 2020–2022. As part of the research for the project, surveys were also conducted on the assessment of hazards in public transportation during an epidemic threat. A total of 321 respondents participated in the investigation. At the last stage of this process, the common meeting was held with the presentation of results and brainstorming discussion. The final results come as a compromise and the best selection.

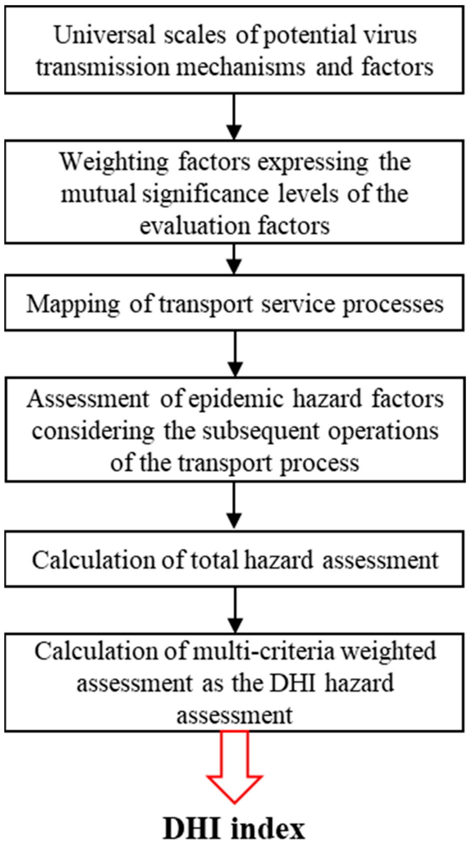

Figure 1. The process of implementing the DHI method and calculation of DHI index.

These factors involved, inter alia, the construction of the means of transport, passenger flow, transport operations, including loading, document flow, and payment. These factors should be considered as criteria that affect the occurrence of epidemic threats in transportation. As a result of these studies, the following factors that affect epidemic hazards in transportation were defined and are presented in Table 1.

Table 1. Factors that affect epidemic hazards in transport.

No	Hazard Factor
(1)	- social distance of contact with another person for the mechanism of infection by droplets
(2)	- the number of people per unit time who may touch the same surfaces as the means of transport for the infection by surface contact mechanism
(3)	- the time of exposure of the loads in the immediate vicinity of the potentially infected person
(4)	- methods of disinfecting the loads or the time of isolating the loads
(5)	- exposure time and number of people exposed
(6)	- time interval between successive vehicle users
(7)	- exposure time and distance of the operator of the process from the potentially infected person
(8)	- transport time,
(9)	- distance between seats or free space per person in transport mean
(10)	- time between consecutive stops in passenger transport
(11)	- type of air circulation and exchange in the means of transport
(12)	- time and number of people involved in loading/unloading activities
(13)	- participation of people during activities related to securing cargo during transport
(14)	- type of document flow in transport
(15)	- type and form of receipt (delivery) of loads in transport

The factors presented in Table 1 are related to passenger and freight transport. For the assessment of only freight transport, as in cases of customer delivery services, the overall assessment is limited to factors such as social distance (1), touching a surface (2), loading time (3), isolation time (4), time between uses (6), operator exposure time (7), number of delivery stops (10), air circulation (11), type of loading (12), securing the cargo (13), document flow (14), and type of delivery point (15), which are 12 through 15 and written in italics in Table 1.

The next step was to develop the scales of potential virus transmission mechanisms in transportation services for all selected hazards. For each of the factors, a five-point scale was used to assess the risk hazard in a given transport process. A value of one corresponds to a situation in which a given factor minimally affects or eliminates the risk of infection (pathogen transmission), e.g., distance between people over 6.5 m. A value of five corresponds to a situation in which a factor greatly increases the risk of infection, e.g., very close proximity to a potentially infected person (less than 0.5 m). The value scaling (rating) was performed according to the current knowledge and epidemic characteristics of the biological hazards of the SARS-CoV-2 pandemic. All tables with rating scales for all factors are provided in [29] and in the supplementary materials. As an exemplary rating scale for the first factor related to droplet transmission and social distance with another person, the hazard score with description is depicted in Table 2. Based on current knowledge of SARS-CoV-2 droplet transmission, a scale of hazards based on the distance of contact with another person for the mechanism of infection by droplets was developed.

The next step was the calculation of the weighting factors expressing the levels of mutual significance of the epidemic hazard factors. Therefore, an analysis of the mutual dominance of hazard factors by the two independent expert teams was conducted. When using weighted measures, it is critically important to properly estimate the weighting factors. Incorrectly estimated weighting factors result in completely incorrect final results and wrong conclusions. Therefore, when estimating the weighting factors, appropriate methods should be used to extend the analysis of dependencies objectively.

Table 2. Scale of hazards—social distance with another person for the mechanism of infection by droplets.

Hazard Score	Description
1	Direct contact with another person at a distance of more than 6.5 m.
2	Direct contact with another person from 3 m to 6.5 m.
3	Direct contact with another person from 1.5 m to 3 m.
4	Direct contact with another person within 0.5 m to 1.5 m.
5	Direct contact with another person within 0.5 m.

For the quantitative evaluation of the impact of the criteria on the risk of virus infection in transport, the AHP method was used [31]. The analytic hierarchy process (AHP) is a multi-criteria selection method that is applied to the solution of complex problems that can have multiple objectives that affect decision-making [32]. The AHP method allows one to create a decision table and a weight vector based on the pairwise comparison method. The ranking is calculated using a simple additive weighting method. An example of an AHP application for managing the demand for urban public transport travel is presented in [33]. This made it possible to include complexity in the analyses of the considered problem, where it is necessary to take into account many aspects of it, such as economic, technical, environmental, and social. Another application of AHP is presented in [34]. It deals with solving for the most salient determinants in selecting or organizing a destination for conventions and seeing out their success. The application of AHP in the introduction weights to social assessment of the life cycle of mobility services has been presented in [35]. Experts in the field of sustainable urban mobility were questioned from three different groups: academic institutions, city authorities, and mobility service providers, to analyze differences and similarities among these groups. The AHP allowed us to obtain the vector of priority factors. An interesting application of AHP for comparative evaluations of the liveability and health conditions of districts towards future city development has been presented in [36]. In most of these examples, AHP is used in multi-criteria decision-aid methods. For the study presented in this paper, the AHP is used as a method of objective and multi-threaded estimation of the weights of factors determining the risk of transmission of the SARS-CoV-2 virus pathogen during the transport process.

According to the AHP method, a pairwise comparison matrix was created as a matrix of the relative importance of the criteria. An in-depth process of a series of pairwise comparisons was carried out at each level of the hierarchical model. The result of comparing two elements from the same hierarchy level reflects the preferential dominance between them. A nine-point Saaty [32] scale indicating the importance of preferences is used to define dominance.

To interpret and give relative weights to each factor, it is necessary to normalize the comparison matrix. To do so, the following expression is used:

$$\hat{w}_{ij}^{(k)} = \frac{c_{ij}^{(k)}}{\sum_{i=1}^{m} c_{ij}^{(k)}} \quad (1)$$

where

c is factor (criterion) of hazard,

k is number of factors,

m is the total number of factors to be compared (15).

Based on the elements of the normalized matrix, individual preference indices (weighting factors) are further determined according to the formula:

$$w_{ij}^{(k)} = \frac{\sum_{i=1}^{m} \hat{w}_{ij}^{(k)}}{m} \quad (2)$$

The advantage of the modified AHP method is the verification of the logic of assessments of the mutual dominance of factors by matrix consistency. First, it is necessary to obtain the maximum value of the eigenvalue for each matrix as the coefficient of consistency through the following equation:

$$\lambda_{max}^{(k)} = \frac{1}{m} \sum_{i=1}^{m} \frac{c_{ij}^{(k)} \cdot w_{ij}^{(k)}}{w_{ij}^{(k)}} \quad (3)$$

where

c_{ij}—elements of matrix (pairwise comparisons)

w—weight of factor

Now it is possible to calculate the index of consistency (CI):

$$CI = \frac{|m - \lambda_a|}{m - 1} \quad (4)$$

where

λ_a—matrix eigenvalue as a measure of agreement in comparisons

In conducting a decision problem with the AHP method, consistency of assessments is an important criterion, identical to the transitivity of factor weights. To evaluate the validity criteria that could be considered consistent, the value of the calculated consistency ratio (CR) should not be greater than 0.1. The compliance rate is determined by the following equation:

$$CR = \frac{CI}{RI(n)} \quad (5)$$

RI(n) is a fixed value based on the number of criteria (factors). The *RI* value for $n = 15$ is taken from [32]. If $CR < 0.1$, the degree of consistency is satisfactory, but if $CR > 0.1$, serious inconsistencies may exist and AHP may not yield meaningful results.

The analysis of the mutual dominance of hazard factors was carried out according to this methodology. Each of the selected factors was assessed based on scales presented in supplementary materials. The results are representative values of the assessment, as dominant among the individual assessments of transport experts. People participating in the analysis of dominance are a group that implements a wider project in the field of identifying epidemic risk in transportation services. Therefore, it should be assumed that their knowledge and awareness of the subject are very up-to-date and broad.

For the identification and validation of the dominance of hazard factors, an expert survey was conducted online for transport service users to collect data and determine the risk of COVID-19 infection. For the assessment, a fishbone diagram was used for the risk of infection to identify the categories of its causes, which were then explored for possible causes that pose a risk of infection. In general, 321 transport users and two groups of transport experts responded to the research. The fishbone diagram considers the risk of infection by identifying the categories of its causes, which are then explored for possible causes that pose a risk of infection. The next step is to determine the assessment of these risks. The adopted scale of 1–10 determines the risk of infection. The diagram collected from the group of experts, which focused on the identification of epidemic hazards in transport and estimating the exposure and result of the COVID risk, is depicted in Figure 2.

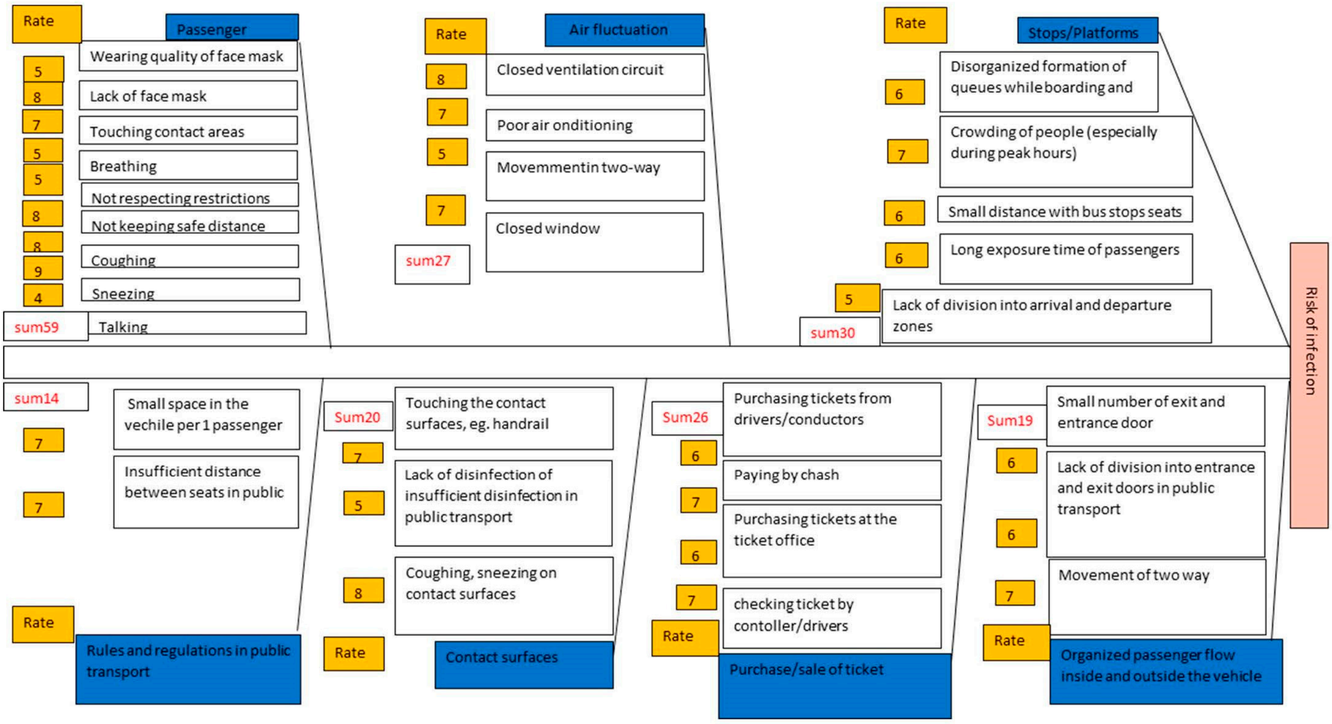

Figure 2. Fishbone diagram identifying the causes and effects of the risk of infection, members of the project on the identification of epidemic hazards in transport.

As a result of hazard identification and the AHP method, the following weighting factors, presented in Table 3, were determined for all adopted criteria.

Table 3. Weighting factors for the hazard factors of the DHI methodology.

Factor Number	Factor Name	Weighting Factors
1	social distance (droplets)	0.16
2	touching an infected surface	0.07
3	loading time	0.02
4	isolation time (load)	0.03
5	time between use	0.02
6	exposure time and number of people	0.19
7	operator exposure time	0.13
8	transportation 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
	SUM:	*1.00*

These values represent the impact of factors on the hazard of virus transmission during the realization of the transport process.

For the identification and detailed assessment of potential factors of epidemic hazards in transport services, the process approach was employed. To fully assess the risk hazards, all operations in the process should be identified, and the best method for this purpose is the process algorithm method. It allows us to prepare the process flow chart. Based on the detailed process algorithm, an analysis of possible risk factors (hazards) for each subsequent activity or operation is performed by evaluating all the assumed factors of epidemic risk for SARS-CoV-2 coronavirus infection. As a result, an assessment of epidemic hazard factors as a total hazard assessment for the complete transport process is calculated.

The final stage of the DHI method is the calculation of multi-criteria weighted assessments as the DHI hazard assessment (DHI index). For this purpose, the weighted sum of the assessments of subsequent risk factors is calculated, multiplied by the appropriate weighting factors of these hazard factors, according to Formula (6):

$$DHI_i = \sum_{i=1}^{n} H_i \cdot w_i \tag{6}$$

where:

m is the total number of all factors
H_i is hazard score for i-th factor
w_i is weighting factor for i-th factor

As the final result, the DHI index is obtained, representing the overall assessment of epidemic hazards for the transport process.

3. Results

For the purpose of assessing the epidemic hazards of customer delivery services, the DHI method has been conducted for selected delivery services. As the representative delivery services for smart city, the courier, catering, and shopping delivery were chosen. The results obtained through successive case studies are presented in the following subheadings. The same hazard assessment (score) scales and weighting factors were used for each case.

3.1. Case Study on Courier Parcel Services

The process algorithm of courier parcel services in terms of the occurrence of contact (human or surface) operations is depicted in Figure 3.

Taking into account the significant differences in the potential hazards of coronavirus infection depending on the type of delivery (personal or parcel locker), separate analyses should be performed. In the presented example, the hazard score for personal pickup (d2d—door to door) for the factors that make differences has been added as a value in brackets. The identification and assessment of the epidemic hazard factors in courier parcel services are presented in Table 4.

The conducted analysis makes it possible to determine the quantitative measure of the assessment of total hazards, which in this case takes into account 12 factors that influence epidemic hazards. The analysis shows that for courier parcel services, the total hazard assessment is 25, and for the personal pickup variant of direct delivery (d2d), it is 42. The maximum value of the total hazard assessment is 60, which means the highest level of epidemic threats and hazards.

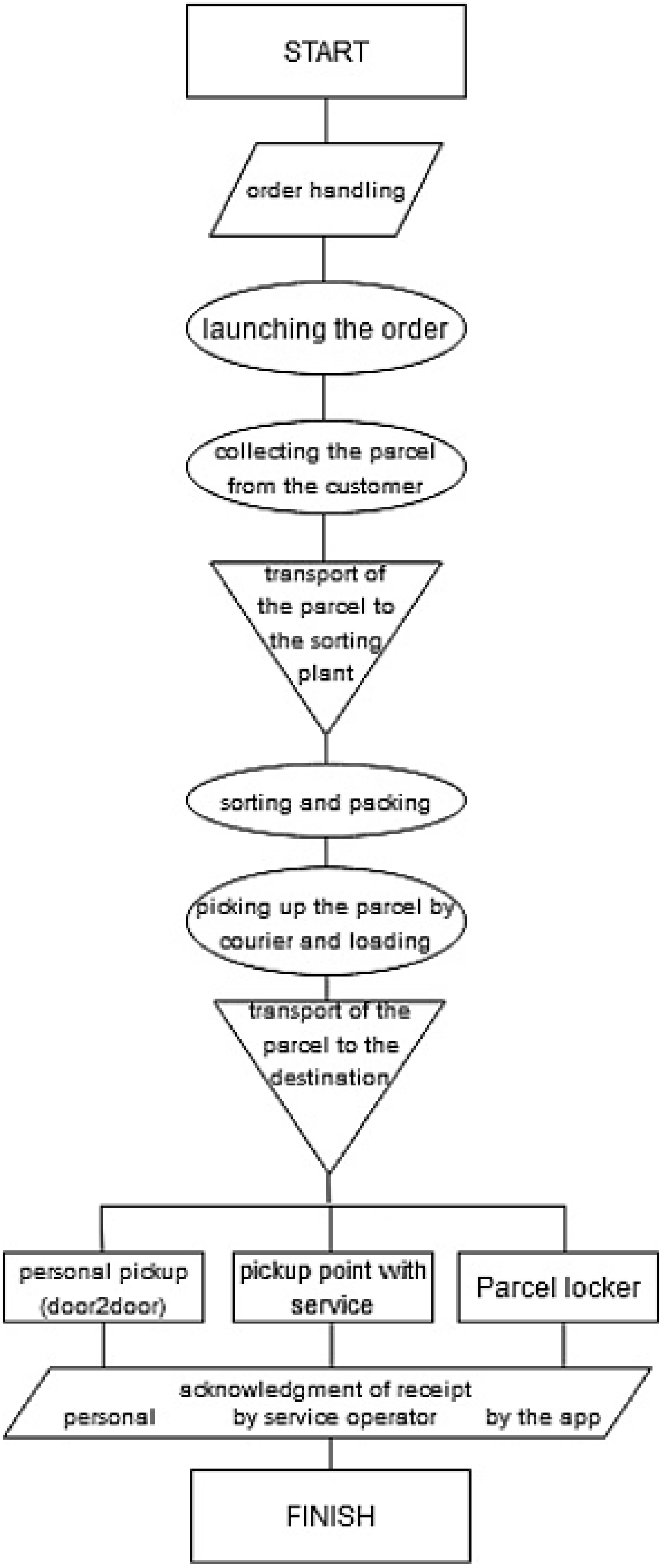

Figure 3. Courier parcel services follow an algorithm in terms of the DHI methodology.

Table 4. Assessment of epidemic hazards due to criteria of the DHI methodology—courier and parcel services.

Hazard Factor	Description	Hazard Assessment
social distance (droplets)	*hazards—social distance from another person for the mechanism of infection by droplets:* There may be direct contact between employees of the courier company, but currently the contact between the courier and the customer has been virtually eliminated. Only in the case of direct collection of the parcel, which in the current situation is estimated at 10–15%, but still in safe contact with a protective mask (for the personal delivery it can even—score 5); overall assessment: 1.	1 (5)
touching an infected surface	*hazards—threats attributable to touching a contaminated surface in means of transport:* Several employees (up to 10) at the reloading point have direct contact with the shipment. Contact of loads with elements inside the vehicle, including the cargo area. The vehicle is usually used within an hour or even a whole day by one employee (score 2). For the personal delivery there is close contact with the customer when sending, receiving (score 4); overall assessment: 2.	2 (4)
loading time	*hazards—time during which cargo (goods) remains in a close distance from a potentially infected person:* From the moment of collection from the sender, the loads are in contact with the courier upon receipt, delivery to the reloading point, picking up from the reloading point and delivering the shipment to the collection point. Assuming that each of these activities takes on average up to 2 min (picking up, putting away, and scanning the barcode), the display of the loads takes less than 10 min (for the personal delivery it can be 10–15 min—score 3); overall assessment: 2.	2 (3)
isolation time (load)	*hazards—time during which cargo in transport remains without contact with a potential source of infection:* The time from the receipt of the goods from the transshipment point to the release to the collection point is usually closed within 12 h. In the case of parcel machines, the delivery time is usually 48 h (score 3). Therefore, it is possible to isolate the goods from harmful factors, but it depends on the customer's will. For direct pickup, pickup is immediate (score 5); overall assessment: 3 (5).	3 (5)
time between use	*hazards—time between consecutive uses of means of transport after contact with a potential source of infection:* The car has many plastic elements on which the virus can survive the longest (up to 72 h), posing a threat. After the entire working day, the vehicle is handed over to another employee or handed over to the employee who used the vehicle that day. It is not subject to disinfection and insulation after each user; overall assessment: 5.	5
operator exposure time	*hazards—potential infection depending on worker (operator) exposure time:* The courier may have a short-term contact with the employees when being released to the reloading point and picked up from the reloading point or in the event of personal collection with customers at the distance less than 2 m. Assuming that each of these activities takes up to 2 min on average (picking up, putting away and scanning the barcode and issuing the parcel), the employee's total exposure ranges from 10 min to 30 min but always shorter than 2 min; overall assessment: 1.	1
number of delivery stops	*hazards –frequency and number of stops (delivery points):* In the case of non-contact delivery (parcel lockers), the number of stops does not matter as there is no risk of the courier becoming infected (score 1). In the case of direct deliveries, it can be even a dozen people (every 30 min), but in a very short contact with precautionary measures (masks) (score 3); overall assessment: 1 (3).	1 (3)
air circulation	*hazards—possible infection depending on air circulation and exchange, as well as air conditioning:* In vehicles, it is possible to exchange air in an open circuit, through ventilation and opening windows; overall assessment: 2.	2

Table 4. *Cont.*

Hazard Factor	Description	Hazard Assessment
type of loading	*hazards—potential infection depending on the type of loading and unloading:* Sending the parcel by the customer takes place in a parcel locker without contact. The courier picks up and delivers the package on its own, without contact. There is no contact with the service/customer, but there is contact with the loads (score 2). In the case of personal delivery, sending the parcel by the customer takes place through contact. The courier picks up and delivers the package himself. There is contact with the customer and the loads (score 3); overall assessment: 2 (3).	2 (3)
securing of the cargo	*hazards—potential infection conditioned by cargo preparing and securing:* The courier collects the goods from the parcel locker and secures them on the vehicle himself. In the sorting plant, the goods are also secured (packed) by 1 employee; overall assessment: 3.	3
document flow	*hazards—potential infection depending on the document flow system and driver involvement:* The majority of courier services are dominated by fully electronic data interchange (score 1). However, when delivering goods to the address, there is an electronic signature of the documents (score 4); overall assessment: 1 (4)	1 (4)
type of delivery point	*hazards—potential infection depending on the delivery point type:* Contactless delivery takes place to a parcel locker. So the courier has no contact with the other person, but has contact with the infrastructure of a given facility. (score 2). Contact delivery takes place to the recipient's address. The driver has direct contact with the recipient, but the pickup is carried out by one person (score 4); overall assessment: 2 (4)	2 (4)
Total score:		25 (42)

3.2. Case Study on Catering Delivery

The second transport service was catering delivery. This service is related to food transportation. The process algorithm of catering delivery in terms of the occurrence of contact operations (human or surface) has been depicted in Figure 4.

The identification and assessment of the epidemic hazard factors for catering delivery are presented in Table 5.

The analysis shows that for catering delivery, the total hazard assessment is 37. The analysis of the catering service also includes the preparation and packaging of dishes; in this respect, in the factor called "loading time", the hazard rating is the highest 5. However, due to the short delivery time and usually direct delivery to the customer, during the delivery process, the driver does not come into contact with too many additional recipients. In the case of catering services, the shortest possible delivery time is expected. Therefore, there is no disinfection or isolation of the product. It results in an overall assessment is high (5). The hazard related to the time between consecutive uses of a means of transport after contact with a potential source of infection was also assessed as 5. This comes from the fact that the car has many plastic elements on which the virus can survive the longest (up to 72 h) creating a threat. After a whole day of work, the vehicle is handed over to another employee or handed back over to the employee who used the vehicle on a given day. It is not disinfected or isolated after each use. The hazard related to the type of possibility of infection depending on the delivery point is also high and is assessed at 4. The contact delivery takes place at the recipient's address. The deliveryman has direct contact with the recipient, but the pickup is carried out by one person.

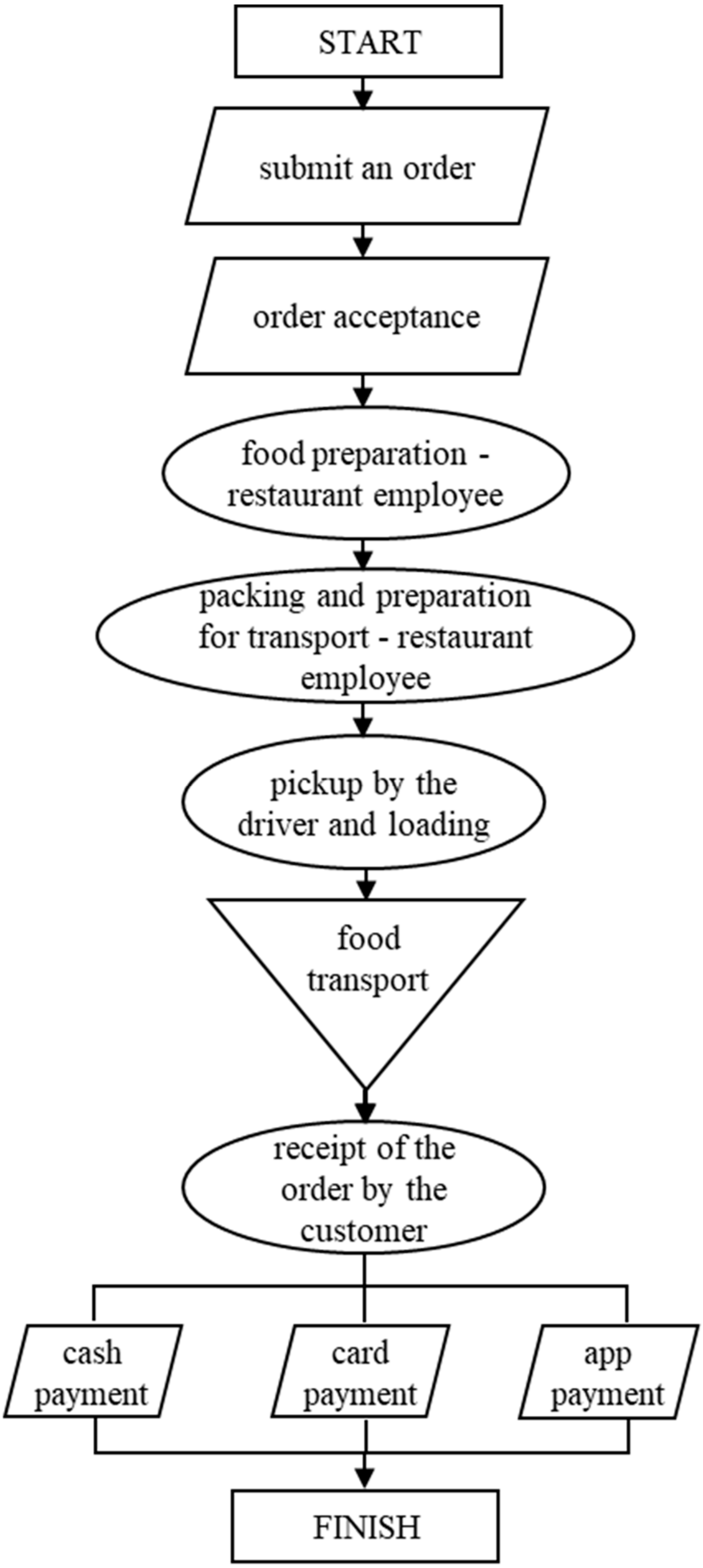

Figure 4. Catering delivery process algorithm in terms of the DHI methodology.

Table 5. Assessment of epidemic hazards due to criteria of the DHI methodology—catering delivery.

Hazard Factor	Description	Hazard Assessment
social distance (droplets)	*hazards—social distance from another person for the mechanism of infection by droplets:* There may be direct contact between employees of the restaurant (cook, helper, packing person); mostly direct contact between the deliverer (driver) and the customer during order checking; if the payment is in cash or card direct contact with deliverer (driver)—the distance during contact is approximately 0.5–1.5 m; overall assessment: 4.	4
touching an infected surface	*hazards—threats attributable to touching a contaminated surface in means of transport:* Close contact with the order by cooks and employees responsible for preparing for transport, contact of packaging with the driver, direct contact between the deliverer (driver) and the customer when checking the order and paying the fee (cash or card); contact of packaging and products with the customer checking the status of the order; on the other hand, less than 10 people have contact with the vehicle, infrastructure and packaging within an hour; overall assessment: 2.	2
loading time	*hazards—time for which cargo (goods) remains in a close distance from a potentially infected person:* Estimated time for delivery of the order is about an hour of waiting. During this time, dishes are prepared, packed and delivered. The product stays for more than 30 min in the close vicinity of a potentially infected person; overall assessment: 5.	5
isolation time (load)	*hazards—time for which cargo in transport remains without contact with a potential source of infection:* In the case of catering services, the shortest possible delivery time is expected. There is no disinfection, isolation of product; overall assessment: 5.	5
time between use	*hazards—time between consecutive uses of means of transport after contact with a potential source of infection:* The car has many plastic elements on which the virus can survive the longest (up to 72 h) creating a threat. After a whole day of work, the vehicle is handed over to another employee or handed over again to the employee who used the vehicle on a given day. It is not disinfected and isolated after each user; overall assessment: 5.	5
operator exposure time	*hazards—potential infection depending on worker (operator) exposure time:* The deliverer has contact with the customer when giving and paying for the order. Customer exposure is less than 10 min; overall assessment: 1.	1
number of delivery stops	*hazards–frequency and number of stops (delivery points):* Most often, there are no additional delivery stops during the catering delivery; overall assessment: 1.	1
air circulation	*hazards—possible infection depending on air circulation and exchange, as well as air conditioning:* In vehicles, it is possible to exchange air in an open circuit, through ventilation and opening windows; overall assessment: 2.	2
type of loading	*hazards—potential infection depending on the type of loading and unloading:* The restaurant staff hand over the load to the driver. Loading and unloading is contactless (driver only). The driver is responsible for unloading and loading and only he has contact with the product; overall assessment: 2.	2
securing of the cargo	*hazards—potential infection conditioned by cargo preparing and securing:* The deliverer collects the products from the staff and secures them on the vehicle himself.; overall assessment: 3.	3
document flow	*hazards—potential infection depending on the document flow system and driver involvement:* In the case of catering services, only a document confirming the sale of the service (receipt) is issued; overall assessment: 3.	3
type of delivery point	*hazards—potential infection depending on the delivery point type:* Contact delivery takes place to the recipient's address. The deliverer has direct contact with the recipient, but the pickup is carried out by one person; overall assessment: 4.	4
	Total score:	37

3.3. Case Study on Shopping Delivery

The next transport service was shopping delivery. This service is related to grocery transportation, as offered by stores or malls, because other products are mostly delivered by courier service. The process algorithm of shopping delivery in terms of the occurrence of contact (human or surface) operations has been depicted in Figure 5.

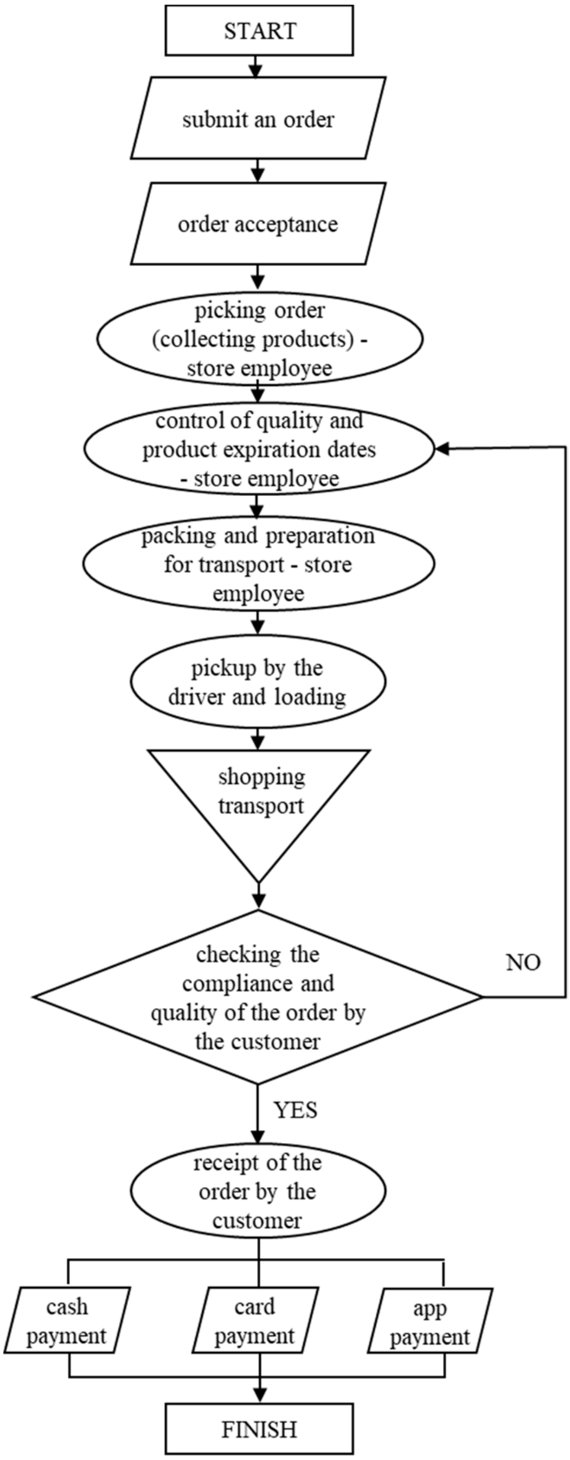

Figure 5. Shopping delivery process algorithm in terms of the DHI methodology.

The identification and assessment of the epidemic hazard factors for shopping delivery are presented in Table 6.

Table 6. Assessment of epidemic hazards due to criteria of the DHI methodology—shopping delivery.

Hazard Factor	Description	Hazard Assessment
social distance (droplets)	*hazards—social distance from another person for the mechanism of infection by droplets:* There may be direct contact between employees of the shop during collecting products; mostly direct contact between the deliverer (driver) and the customer during order checking; if the payment is in cash or card direct contact with deliverer (driver)—the distance during contact is approximately 0.5–1.5 m; overall assessment: 4.	4
touching an infected surface	*hazards—threats attributable to touching a contaminated surface in means of transport:* Close contact with the order by employees responsible for collecting products and preparing for transport, contact of packaging with the driver, direct contact between the deliverer (driver) and the customer when checking the order and paying the fee (cash or card); contact of packaging and products with the customer checking the status of the order; on the other hand, less than 10 people have contact with the vehicle, infrastructure and packaging within an hour; overall assessment: 2.	2
loading time	*hazards—time for which cargo (goods) remains in a close distance from a potentially infected person:* From the moment of accepting the order, depending on the size and type of the order, it is carried out in different time periods. On the other hand, the products are constantly in the shop hall to which every customer has access, therefore the exposure of the products to hazard factors is more than 30 min; overall assessment: 5.	5
isolation time (load)	*hazards—time for which cargo in transport remains without contact with a potential source of infection:* Products from the moment of accepting the order to the start of its implementation and delivery takes place without the isolation process. There is no disinfection, isolation of product; overall assessment: 5.	5
time between use	*hazards—time between consecutive uses of means of transport after contact with a potential source of infection:* The car has many plastic elements on which the virus can survive the longest (up to 72 h) creating a threat. After a whole day of work, the vehicle is handed over to another employee or handed over again to the employee who used the vehicle on a given day. It is not disinfected and isolated after each user; overall assessment: 5.	5
operator exposure time	*hazards—potential infection depending on worker (operator) exposure time:* The deliverer has contact with the customer when giving, controlling and paying for the order. Customer exposure time is approximately 10–15 min at distance less than 2 m; overall assessment: 4.	4
number of delivery stops	*hazards–frequency and number of stops (delivery points):* Most often, there may be several delivery points during the delivery of purchases, but the time between them is over 30 min; overall assessment: 2.	2
air circulation	*hazards—possible infection depending on air circulation and exchange, as well as air conditioning:* In vehicles, it is possible to exchange air in an open circuit, through ventilation and opening windows; overall assessment: 2.	2
type of loading	*hazards—potential infection depending on the type of loading and unloading:* The shop staff hand over the load to the driver. Loading and unloading is contactless (driver only). The driver is responsible for unloading and loading and only he has contact with the product; overall assessment: 3.	3
securing of the cargo	*hazards—potential infection conditioned by cargo preparing and securing:* The deliverer collects the products from the staff and secures them on the vehicle himself.; overall assessment: 3.	3
document flow	*hazards—potential infection depending on the document flow system and driver involvement:* In the case of shopping delivery, only a document confirming the sale of the service (receipt) is issued, in addition, the customer often signs the confirmation of receipt of the goods; overall assessment: 4.	4
type of delivery point	*hazards—potential infection depending on the delivery point type:* Contact delivery takes place to the recipient's address. The deliverer has direct contact with the recipient, but the pickup is carried out by one person; overall assessment: 4.	4
Total score:		43

The analysis shows that for shopping delivery, the total hazard assessment is 43. The total assessment of epidemic hazard for this case is the highest, even greater than the courier service (d2d). This is due to the order picking in the store and the participation of employees in the preparation of delivery and display of products in the store, which results in the risk of pathogen transmission of the product. Furthermore, the time to receive the delivery by the customer is the longest because it includes checking the compliance of the order.

These case studies show how to proceed with the DHI method and the analysis of logical deduction to determine the value of epidemic hazards according to successive factors without considering the importance or significance of these factors. Due to the different impacts of individual factors on the risk of infection and the emergence of epidemic threats, the designated partial measures must be multiplied by the designated weighting factors representing the later impact on epidemic hazards in transport (see Table 3). Table 7 presents a summary of the results obtained and the values corrected by weighting factors. This enables the calculation of multi-criteria weighted assessments, such as the DHI hazard assessment, and the determination of the DHI index.

Table 7. Comparison of total assessment and weighted assessment of epidemic hazards.

Hazard Factor	Courier (Parcel Locker)—Score	Courier (Parcel Locker)—Weighting Score	Courier (d2d)—Score	Courier (d2d)—Weighting score	Catering (d2d)—score	Catering (d2d)—Weighting Score	Shopping (d2d)—Score	Shopping (d2d)—Weighting Score
social distance (droplets)	1	0.16	5	0.81	4	0.65	4	0.65
touching a surface	2	0.15	4	0.30	2	0.15	2	0.15
loading time	2	0.03	3	0.05	5	0.08	5	0.08
isolation time (load)	3	0.10	5	0.16	5	0.16	5	0.16
time between use	5	0.11	5	0.11	5	0.11	5	0.11
operator exposure time	1	0.13	1	0.13	1	0.13	4	0.52
number of stops	1	0.04	3	0.12	1	0.04	2	0.08
air circulation	2	0.13	2	0.13	2	0.13	2	0.13
type of loading	2	0.02	3	0.04	2	0.02	3	0.04
securing of the cargo	3	0.04	3	0.04	3	0.04	3	0.04
document flow	1	0.02	4	0.07	3	0.05	4	0.07
type of delivery point	2	0.05	4	0.09	4	0.09	4	0.09
SUM:	**25**	**0.98**	**42**	**2.05**	**37**	**1.66**	**43**	**2.12**

4. Discussion

Due to the lack of comparable results on the assessment of epidemic hazards in transport studies, the discussion of the obtained results includes mutual comparisons and possible applications in broader issues of risk management in transport. Research hypotheses assume that the identification of epidemic hazards requires in-depth analysis and a process algorithm. The developed DHI method is based on a process approach, and the results obtained confirmed the effectiveness of such an approach. Furthermore, the identified factors of epidemic threats and hazards in transport and the universal rating scales enabled comparable assessments of epidemic threats for various transport processes.

Based on the results obtained, it was possible to compare the importance of individual hazard factors for the delivery services. The results are shown in Figure 6.

The comparison of total hazard assessment and DHI indices for the analyzed transport services is presented in Figure 7. The highest value of epidemic hazard was estimated for shopping delivery, followed by courier d2d delivery in third place and catering delivery, while courier parcel locker turned out to be the safest.

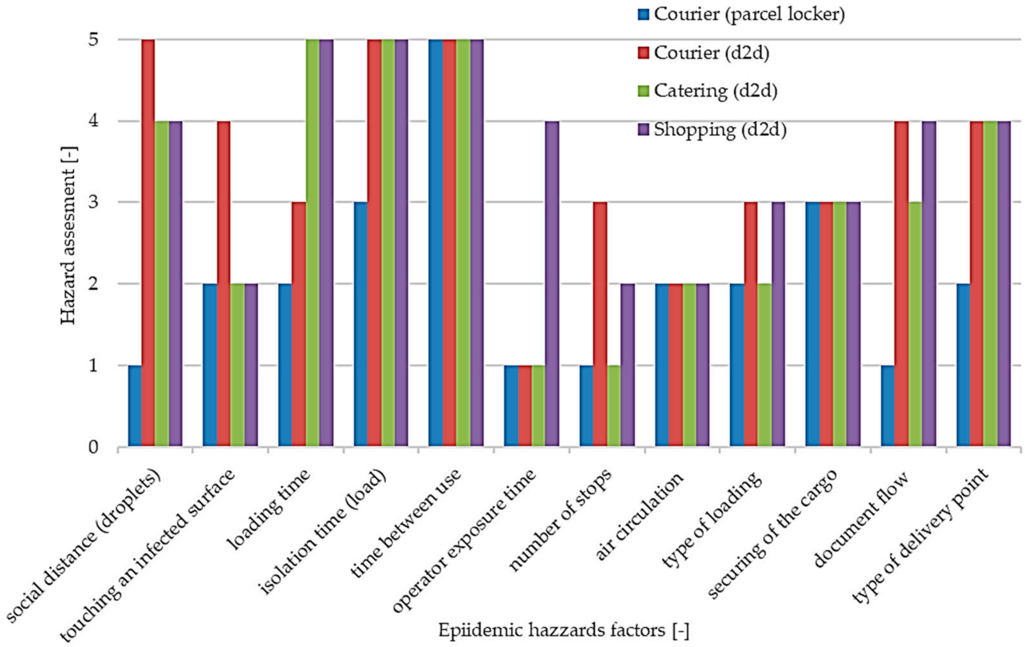

Figure 6. Assessment of all hazards and factors for delivery services.

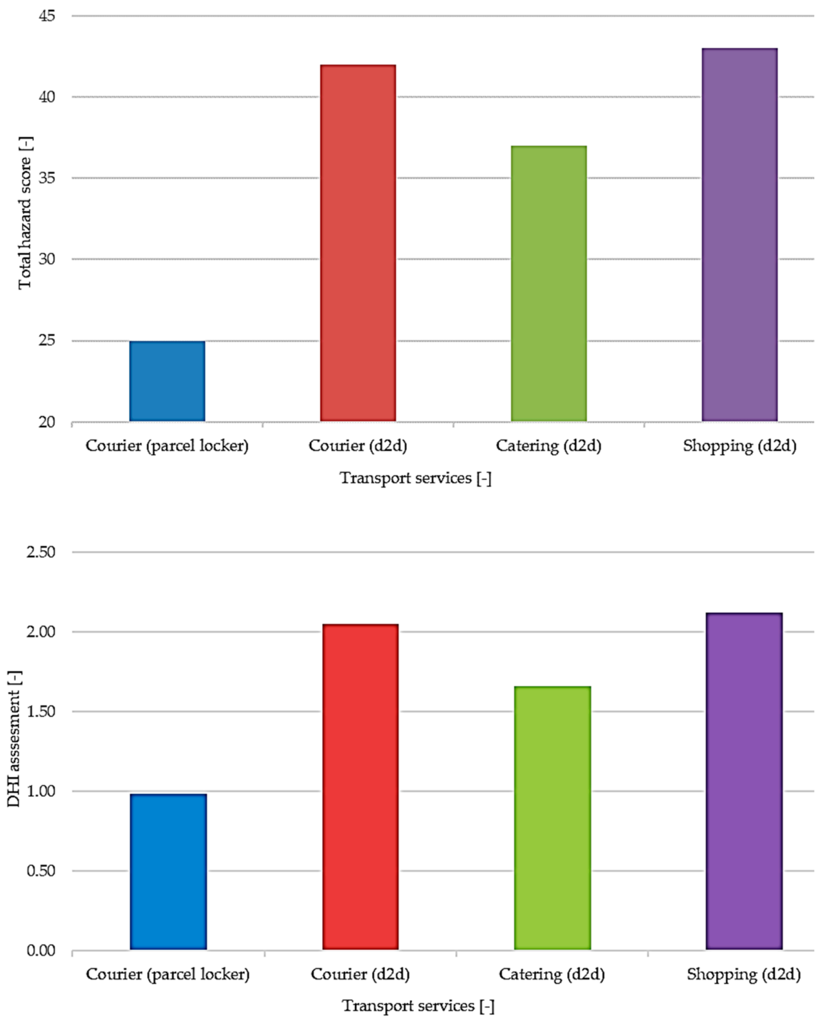

Figure 7. Comparison of total hazard assessment and DHI indexes.

The research and analysis also made it possible to assess the share of individual hazard factors in the total epidemic hazard risk in the examined transport services. Sorted from least to most important, absolute values and percentage shares are shown in Figures 8 and 9.

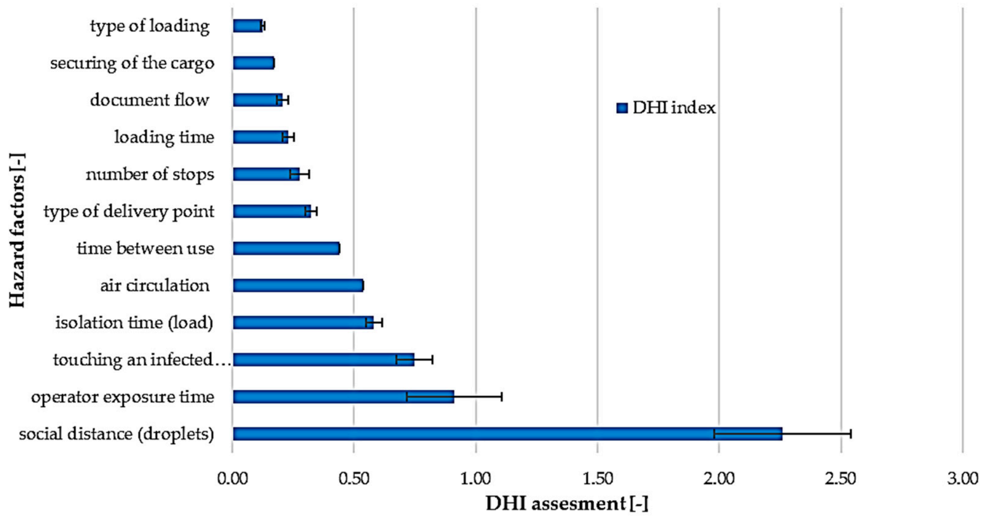

Figure 8. Sum of weighted assessments for each of the hazard factors.

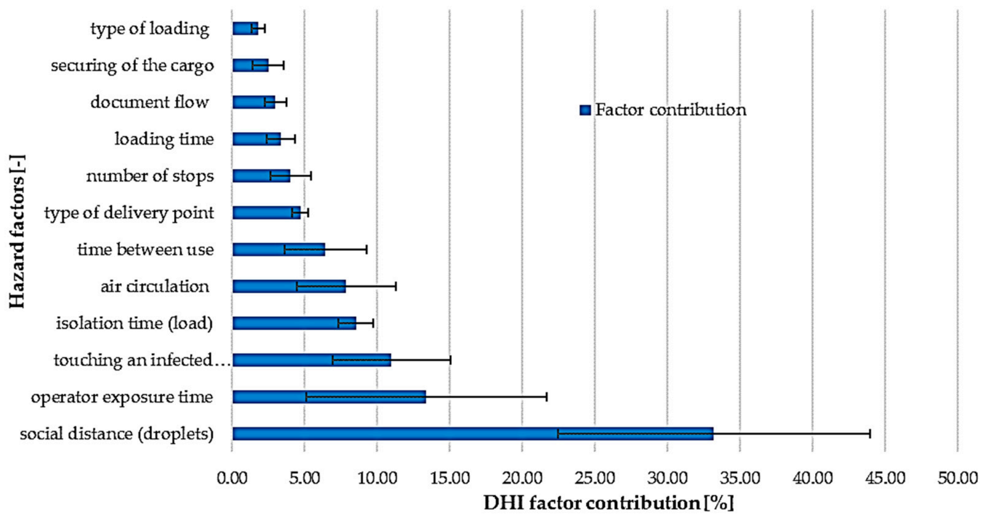

Figure 9. Contribution of the sum of weighted assessments for each of the hazard factors.

The most important findings of this research are the presentation of the application of the DHI method in the assessment of epidemic hazards in transport services and the quantitative assessment of these threats for services related to customer delivery services. Furthermore, the determined DHI indices will make it possible to compare different processes based on the same measures and universal scales of the determinants of epidemic hazards in transport. Future research directions include application of the presented methodology for other transport services, including collective public transport and transport services related to urban mobility in smart cities.

5. Conclusions

This paper addresses the issue of epidemic hazards, a new challenge in smart cities, and customer delivery services. The novel DHI methodology for epidemic hazards assessment is presented and applied to compare customer delivery services in terms of COVID-19 epidemic hazards. The case studies presented a detailed analysis of epidemic hazards on the basis of process algorithms and dedicated quantitative scales to assess factors influencing the mechanisms of virus transmission. The DHI index enables a quantitative, multi-criteria, weighted assessment of epidemic hazards. The DHI index is universal but can be adjusted for the current infection rate and related factors or another type of epidemic.

This approach will enable the DHI index to be adapted to the current general threat and preventive actions. Thanks to this, periodic analyses will be possible, which may be the basis for the development of a forecasting model. Additionally, it will allow for regional differentiation of the DHI index due to the geographical distribution of epidemics that are not global pandemics.

The DHI method presented in the article and the application described in the form of a case study show a wide range of applications as a preliminary assessment of epidemic threats in transportation. Equally important, using the DHI method, it is possible to identify threats and dominant factors that increase the risk of infection in detail. This enables the development of initial measures to minimize epidemic threats in smart cities. Furthermore, the results of the DHI analysis facilitate the estimation of the probability of transmission of virus pathogens by identifying activities in the process in which virus transmission mechanisms may occur and taking into account significant deterministic factors in the probability calculation, such as distance, exposure time, contact with a potentially infected surface, or ventilation. The probability estimated in this way, together with the time of exposure, the number of exposed people, and the effects of infection, enables a precise assessment of the epidemic risk in transportation.

The current awareness of epidemic threats, as well as critical experiences and effects of the COVID-19 pandemic, allow us to conclude that the management model in the smart city, especially in the field of mobility and transport services, must be supplemented with the monitoring of epidemic hazards. Therefore, the DHI methodology and the results obtained for transport services constitute important cognitive knowledge for the administration personnel in smart cities.

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Data Availability Statement: Data is contained within the article or Supplementary Material.

Conflicts of Interest: The author declares no conflict of interest.

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