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RESILIENCE OF THE URBAN LOGISTICS SYSTEM

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Purpose: Cities and regions are currently facing a range of challenges related to natural and civilizational threats. The growing number of threats, as well as the crisis situations that cities have faced in recent years, require the search for mechanisms that enhance their resilience. A cognitive gap in this area concerns the resilience of urban logistics systems. The aim of the research presented in this article is to conceptualize the resilience of a city's logistics system and to highlight the role of stakeholder collaboration in building resilience. Collaboration with stakeholders requires identifying their needs and expectations. The identification of these needs was the objective of empirical research.
Design/methodology/approach: The article analyzes the similarities and differences in the perception of urban logistics system resilience between two stakeholder groups: residents and the volunteer fire department. For this purpose, a questionnaire-based survey was conducted. The results enabled the application of the SERVQUAL method for satisfaction analysis. The final stage of the research involved a risk analysis.
Findings: The research resulted in recommendations for city and regional authorities regarding collaboration with the two studied stakeholder groups to enhance the resilience of cities and regions to threats.
Research limitations/implications: The conducted research focuses on two stakeholder groups and one region. Therefore, it is important to expand the research to include other stakeholder groups and regions.
Originality/value: The development of a construct for the resilience of a city's logistics system and the identification of the role of relational competencies in strengthening resilience.
Keywords: Resilience, logistics system resilience, urban resilience, stakeholders, SERVQUAL, risk analysis.
Category of the paper: Research paper.

1. Introduction

Complex systems, such as urban logistics systems, are highly susceptible to disruptions in the flow of people and goods. Cities that are able to cope with emerging disturbances are considered resilient cities. Resilience is currently a key aspect, also emphasized in the context of the Fifth Industrial Revolution. The etymological roots of resilience derive from the Latin word resilio, meaning "to bounce back" (Klein et al., 2003). As an academic concept, its interpretation is not unambiguous (Adger, 2000) Holling first stated in 1973: Resilience determines the persistence of relationships within a system and is a measure of the ability of these systems to absorb changes and still persist. He paired this notion of resilience with the concept of stability, defined as: „the ability of a system to return to an equilibrium state after a temporary disturbance". In this context, the article considers the resilience of the city logistics system. The city logistics system consists of the subsystem of freight transport and storage, and the subsystem of passenger transport. Some authors additionally distinguish a subsystem for the movement and storage of waste. There is a lack of publications on a holistic approach to the resilience of urban logistics systems. However, the resilience of logistics systems, as well as urban resilience, are issues addressed by researchers in various contexts. At the same time, publications also appear that deal with the resilience of selected logistics subsystems of a city. These relationships between the concepts that collectively constitute the resilience of the urban logistics system are presented in figure 1.

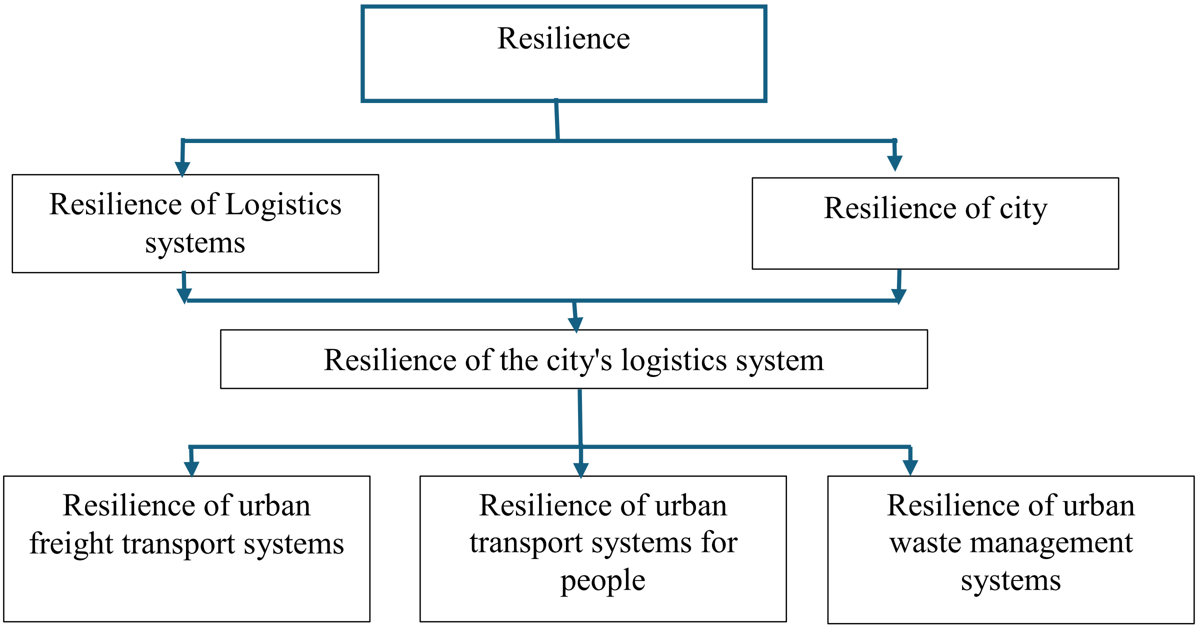

Figure 1. Resilience of the city's logistics system as a component of the city's resilience and the resilience of the logistics system.

Source: own study.

Taking into account these relationships as well as the epistemological gap, the aim of the article is to conceptualize the resilience of the city logistics system to disruptions, especially to natural and anthropogenic threats.

The authors, referring to the stated aim of the article, formulated three research questions:

1. What characteristics should resilient urban logistics systems possess?
2. How do urban logistics stakeholders contribute to building the resilience of the city logistics system?

3. What are the similarities and differences in the perception of factors building the resilience of the city logistics system between two stakeholder groups: residents and members of the Volunteer Fire Department?

To achieve the set aim and obtain answers to the research questions, a literature review was conducted focusing on the construct of logistics system resilience and urban resilience. Subsequently, the methodology for studying factors affecting city resilience was indicated. The methodology included the Servqual method and risk analysis. In the next part, the research results conducted in four municipalities: Olkusz, Bukowno, Bolesław, and Klucze were presented. The conclusions included recommendations for the authorities of the mentioned regions.

2. Resilience and disruptions in the city's logistics system - theoretical background

In interpreting the concept of resilience, disruptions play a key role. In logistics systems, disruptions are interpreted as events that cause deviations in material flows (Peng, 2011). A deviation in a logistics system can include a delayed delivery, an incomplete shipment, a missing delivery, or damaged goods. Therefore, it can be said that disruptions in logistics systems negatively affect the reliability of flow execution (Choi, Chan, 2016). Previous research on disruptions in material flows has led to a classification based on the source of disruption: endogenous and exogenous disruptions (Yang, Pan, Ballot, 2017). Endogenous disruptions originate within the system and can be attributed to a specific participant in the flow. Exogenous disruptions, on the other hand, are independent of the elements within the logistics system and arise from the system's external environment. These include atmospheric factors, natural disasters, and congestion. Processing information about disruptions—meaning the integration of their type, frequency, and effects with the reactions undertaken in response—aims at developing mechanisms to strengthen the resilience of the logistics system. This process makes it possible to determine which actions, under what disruption characteristics, lead to effective outcomes in the form of compensation, elimination, or limitation of disruptions (Kramarz, 2023). The effects of disruptions include the aforementioned deviations in material flows (such as delays or unfulfilled deliveries), but also the consequences of organizational changes (e.g., shifts in order fulfillment priorities, process reorganization, the selection of new participants, and consequently, changes in the costs of logistics processes). Thus, in building logistics system resilience, two disruption compensation variants must be considered. The first variant involves compensation through pre-built mechanisms, such as capacity redundancy, system flexibility, and subcontractor redundancy (Kramarz, 2018). The second variant relates to ex-post operational actions taken after the disruption occurs (Christopher, Towill, 2002).

Both variants can yield relatively similar results in terms of minimizing delays in material flows. However, each requires different resource involvement. Additionally, the second variant involves changes to process organization, which may have delayed effects over time (Sultana et al., 2024).

The vulnerability of a logistics system to disruptions refers to its sensitivity, while the ability to mitigate the negative effects of disruptions is understood as the resilience of that system. A measure of the supply chain's vulnerability is the impact of a given disruption on the achievement of the goals of cooperating organizations. This impact can be assessed in terms of organizational or financial consequences (Romano, 2022). These aspects have been well recognized in the case of logistics systems of production and commercial enterprises, as well as entire supply chains and networks. Transferring these considerations to urban logistics systems requires identifying the characteristics of a city that determine the vulnerability of its logistics system to disruptions. To understand this, one must delve into the concept of „urban resilience".

Publications on urban resilience discuss issues related to urban policy and spatial planning (Vale, 2014). The socio-environmental resilience of a city can be understood and practiced at various scales and configurations, from individuals to households, communities, neighborhoods, businesses, civil society institutions, governance structures, and infrastructure networks, as well as governance at the local, regional, and national levels, even including multinational regional perspectives.

Defining the context of resilience assessment is a key aspect of research. One possible context is the stakeholder perspective. Mechanisms to enhance resilience will differ depending on whether the focus is on businesses operating in the city or on its residents. In the practice of urban planning, it is emphasized that the goals of ecologists, planners, and economic development researchers are often divergent. The term urban resilience has been adopted by planners and urban designers as a way of describing the ability of cities to respond to systemic threats. However, the concept of resilience also has deep roots in multiple disciplines—from engineering, ecology, and psychology to its growing use in business, economics, information technology networks, and even homeland security. Currently, urban resilience in the literature is most commonly linked to climate change (climate resilience) (Boulanger, 2023; Dhar, Khirfan, 2023), as well as to the impact of the COVID-19 pandemic on urban functioning (Wolniak, 2023).

Urban resilience refers to the capacity of an urban system, including all its social-ecological and socio-technical networks across time and space, to maintain or rapidly return to desired functions in the face of disruptions, to adapt to changes, and to transform systems that limit current or future adaptive capacities. This is a very broad interpretation. Not all authors agree that adaptability is a component of resilience. Another publication emphasized a definition of resilience focused on coping with resource depletion and a changing planet (Zhu et al., 2020).

Urban resilience is also studied by analyzing the ability of designed buildings to withstand terrorist attacks, while other works, such as those focusing on everyday urban resilience, assess a broader set of socio-spatial impacts of counter-terrorism measures on cities. These publications link urban resilience with internal security (Okeke, 2019). As these diverse approaches suggest, a single concept of resilient cities can involve a focus on urban safety, economy, building technology, architecture, anti-terrorism, communities, social capital, natural disasters, and climate change.

Within this diverse, interdisciplinary academic discourse, the following definition becomes useful: "Resilience is the ability of individuals, communities, institutions, businesses, and systems within a city to survive, adapt, and thrive no matter what kinds of chronic stresses and acute shocks they experience". This definition and the accompanying resilience indicator framework were developed by the ARUP International Development Team (2014) in a study commissioned and coordinated by the Rockefeller Foundation. Initially, the research focused on climate resilience and was gradually expanded to a broader view of disaster risk reduction, including financial shocks, terrorism, natural disasters, and critical infrastructure failures, with the overall goal of ensuring urban continuity (ARUP, 2014). One of the main challenges identified was the development of frameworks that allow cities to understand, analyze, and assess resilience (Martin-Breen, Anderies, 2011).

The aim of the ARUP resilience framework is to present a comprehensive, integrated set of indicators and variables. The proposed City Resilience Index serves as a foundation for assessment that enables decision-makers to make better investment decisions and to be more effectively engaged in urban planning practices (ARUP, 2014, p. 21). In this way, seven categories of city system resilience were identified (Table 1).

Table 1.
Key Dimensions of the City Resilience Index

Dimiension	Characteristic
Reflective	Reflective systems are accepting of the inherent and ever-increasing uncertainty and change in today's world. They have mechanisms to continuously evolve and will modify standards or norms based on emerging evidence, rather than seeking permanent solutions based on the status quo. As a result, people and institutions examine and systematically learn from their past experiences and leverage this learning to inform future decision-making.
Robust	Robust systems include well-conceived, constructed and managed physical assets, so that they can withstand the impacts of hazard events without significant damage or loss of function. Robust design anticipates potential failures in systems, making provision to ensure failure is predictable, safe, and not disproportionate to the cause. Over-reliance on a single asset, cascading failure and design thresholds that might lead to catastrophic collapse if exceeded are actively avoided.
Redundant	Redundancy refers to spare capacity purposely created within systems so that they can accommodate disruption, extreme pressures or surges in demand. It includes diversity: the presence of multiple ways to achieve a given need or fulfil a particular function. Examples include distributed infrastructure networks and resource reserves. Redundancies should be intentional, cost-effective and prioritised at a city-wide scale, and should not be an externality of inefficient design.

Cont. table 1.

Flexible	Flexibility implies that systems can change, evolve and adapt in response to changing circumstances. This may favour decentralised and modular approaches to infrastructure or ecosystem management. Flexibility can be achieved through the introduction of new knowledge and technologies, as needed. It also means considering and incorporating indigenous or traditional knowledge and practices in new ways.
Resourceful	Resourcefulness implies that people and institutions can rapidly find different ways to achieve their goals or meet their needs during a shock or when under stress. This may include investing in capacity to anticipate future conditions, set priorities, and respond, for example, by mobilising and coordinating wider human, financial and physical resources. Resourcefulness is instrumental to a city's ability to restore the functionality of critical systems, potentially under severely constrained conditions.
Inclusive	Inclusion emphasises the need for broad consultation and engagement of communities, including the most vulnerable groups. Addressing the shocks or stresses faced by one sector, location, or community in isolation of others is an anathema to the notion of resilience. An inclusive approach contributes to a sense of shared ownership or a joint vision to build city resilience.
Integrated	Integration and alignment between city systems promotes consistency in decision-making and ensures that all investments are mutually supportive of a common outcome. Integration is evident within and between resilient systems, and across different scales of their operation. Exchange of information between systems enables them to function collectively and respond rapidly through shorter feedback loops throughout the city.

Source: ARUP, 2014, p. 5.

The concept of resilience of urban logistics systems is significantly less recognized. There is a lack of studies in this area, however, the importance of resilience of individual subsystems of urban logistics is being acknowledged. In this respect, the most publications have been devoted to the subsystem of passenger transport. Urban mobility systems consist of various elements that strongly interact with each other. These elements (which may themselves be subsystems) exposed to threats may cause not only unexpected effects in some parts of the system but also threaten the entire functioning of the system. A resilient urban system should be able to withstand serious negative threats while maintaining basic functionality.

In urban transport, the aim of actions increasing resilience is to reduce the effects by maintaining or restoring the normal level of mobility in the shortest possible time, taking into account both passenger and freight transport. Therefore, indicators are an important tool for monitoring the level of resilience. These indicators can be used to compare different regions, which enables the identification of regions that require more attention due to low resilience. (Leobons et al., 2019). Bruneau et al. (2003) presented a resilience framework indicating that resilience could be measured by four determining properties of resilient systems, the 4R structure (Robustness, Redundancy, Resourcefulness, Rapidity). In transport, Robustness reflects the ability of the network and its elements to resist the effects of a disruptive event without significant degradation of the system. Redundancy is the degree to which alternative routes and modes of transport can be used if certain components are damaged; Resources are associated with the availability of materials, consumables, and teams aimed at restoring functionality; Rapidity is the ability to restore functionality in a timely manner, thus resulting from the other three (Tierney, Bruneau, 2007). In this way, redundancy and resources are the "means" of improving resilience, while robustness and rapidity are the desired "goal" of achieving a resilient system (Bruneau et al., 2003; Bruneau, Reinhorn, 2007).

In the context of transport systems, it should be noted that resilience is usually associated with the continuity of the service provided or the restoration of normal functioning after an event. Thus, transport resilience is understood as the ability to maintain mobility at an acceptable level and to recover normal transport operations.

As can be seen, the categories of resilience of logistics systems, city resilience, and resilience of urban transport systems are described with similar measures, especially robust, redundancy, rapid, and resourceful. At the same time, all definitions of resilience are aimed at indicating the impact of disturbances on the functioning of the system and maintaining reliability. The resilience of the urban logistics system will therefore be understood as the ability of the city's logistics system to reliably carry out logistics processes under conditions of endogenous and exogenous disturbances and to restore the system to its original state after disturbances occur.

In building a disruption-resistant urban logistics system, the involvement of urban logistics stakeholders as well as the use of information and communication technologies is necessary. High relational competences are an attribute of an organization that is emphasized in various areas of managing complex systems. In the context of network coordination, it is included in the group of relational mechanisms (Klimas, 2013). Network coordination is, in turn, key in city management and determines its resilience. Relational competences are further strengthened through digital support of relationship management. This issue is especially highlighted by those researchers who conducted studies on city resilience during the Covid-19 pandemic (Lara, et al., 2023). The research showed that the use of digital services, e-tools, remote work, and smart city solutions significantly supplemented policies aimed at pandemic control and helped develop more resilient and environmentally friendly behaviors (Kakderi et al., 2021). After the implementation of actions, the systems gradually resumed activities deemed essential. To strengthen the resilience of cities in the face of the pandemic, Sharifi and Khavarian-Garmsir (2020) also suggested strengthening flow mechanisms, including increasing the space allocated to public transportation and public spaces, as well as implementing intelligent transport systems and sustainable planning of logistics processes in the city. Similar postulates were also indicated by other authors, including Chinazzi et al. (2020), Mahmoudi and Xiong (2022), and Wells et al. (2020). In the indicated publications, a link can be observed between solutions shaping the resilience of the urban logistics system and solutions identified at the highest level of urban logistics maturity.

Taking into account the indicated relational competences as those mechanisms that, through network coordination, influence the resilience of the urban logistics system, the next part of the article focuses on the cooperation of the city with urban logistics stakeholders.

3. Methodology

While conducting research aimed at obtaining answers to the research questions posed in the Introduction, the authors adopted the research methodology presented in Figure 2. It consists of four main stages.

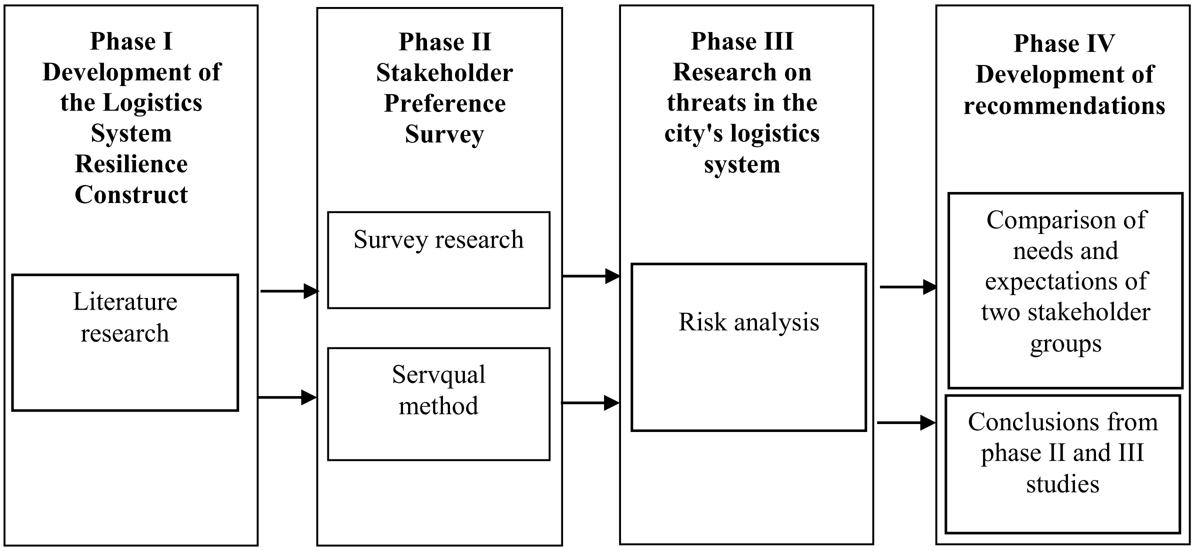

Figure 2. Research methodology

Source: own study.

The Servqual method was used to assess the expectations, feelings and needs of stakeholders. This method is used to assess the quality of services offered by various entities or institutions. The result of the Servqual analysis is a comparison of the expectations of survey respondents with their actual experiences. This allows for an assessment of which areas the surveyed service providers achieve good results and which areas they should work on.

The analysis included two groups of stakeholders: residents of the surveyed areas and firefighters belonging to Volunteer Fire Brigades operating in those areas. The selection of these groups was intentional and justified both methodologically and substantively. Residents constitute a key stakeholder group because they are the direct recipients of public services and the individuals most exposed to the effects of crisis situations. Their sense of security, access to information, as well as the possibility of evacuation or obtaining emergency assistance, reflect the effectiveness of local logistics systems. At the same time, volunteer firefighters are one of the pillars of the response system. They are the first to respond to emergency calls and are among the few who possess practical experience and operational knowledge regarding the effectiveness of local crisis procedures. The relationship between these two groups is not only practical but also systemic. Firefighters are responsible for the safety of residents, while residents are a source of information on the needs and effectiveness of actions taken by the services. Including these two perspectives thus enabled a multidimensional assessment of the resilience of the city's logistics system, both in terms of its functionality and social usefulness.

The first stage of the Servqual analysis involved the creation of questionnaires to assess expected and actual service quality. The questionnaires used a five-point scale, where 1 meant very poor and 5 meant very good. Such a scale enabled the execution of subsequent computational stages of the analysis. The questions in the questionnaire concerned the effectiveness of communication during a crisis, the reliability of the transmitted information, the timeliness and availability of crisis procedures, and the sense of security. Additionally, the questionnaire for firefighters also included questions about crew training levels and the efficiency of rescue equipment. The next step was to assign the questions to dimensions that were modified for the purpose of adapting the method to research on urban logistics systems. The classic Servqual model is based on five fundamental dimensions: tangibles, reliability, responsiveness, assurance, and empathy. Each of these areas refers to a different aspect of the functioning of the surveyed entity, from infrastructure and employee competencies to the effectiveness of response and the ability to understand the user's needs. Due to the specificity of the subject, it was reasonable to modify the classic Servqual categories. In place of the original dimensions, four categories tailored to the context of the analysis were proposed: Information and Communication, Safety and Preparedness, Response and Effectiveness of Actions, and Support and Cooperation.

The next stage involved entering the questionnaire results into a spreadsheet and then calculating the difference between perceived and expected ratings. Based on the obtained differences for each dimension, an arithmetic mean was calculated. The unweighted means thus obtained provided information about the average level of agreement between reality and respondents' expectations in each area. Similarly, an overall unweighted average was calculated, including all questions, which allowed for an evaluation of the system's performance from the perspective of the surveyed group. In the next step, weighted averages were calculated, both at the level of individual dimensions and overall. For this purpose, the researcher assigned each of the four dimensions a weight expressing a subjective assessment of the importance of a given area in the context of effective crisis management and the resilience of urban logistics systems. These weights were set so that their total equaled 1. The use of weighted averages allowed for obtaining results that more accurately reflected the importance of each dimension for the efficiency and resilience of the system, in accordance with the adopted research assumptions.

The final stage of the Servqual analysis conducted within this study involved visualizing the obtained results using graphs and their detailed interpretation. To this end, after calculating the average differences between perceived and expected ratings—both unweighted and weighted—graphical summaries were created for each stakeholder group in the form of bar charts showing quality differences for individual dimensions. The graphical presentation of the results allowed for a clearer depiction of the level of satisfaction (or lack thereof) with the functioning of the logistics system in crisis situations, as well as for quickly identifying the areas with the most significant quality deficits. The charts presented comparisons of average differences for the four surveyed dimensions, both for residents and for Volunteer Fire Brigade firefighters. Based on the charts, a comparison of the results obtained from both stakeholder groups was made. This analysis revealed significant differences in the perception of the effectiveness of the crisis management system. The results of the Servqual study, conducted separately among residents and representatives of the Volunteer Fire Brigades, made it possible to identify key quality gaps and indicate areas requiring urgent intervention.

According to the adopted research model, the next stage of the conducted research was a risk analysis referring to threats affecting the functioning of the logistics system of the surveyed municipalities in crisis situations. The purpose of this analysis was to determine the level of risk associated with different types of disruptive events that may affect the safety of residents, the availability of public services, transport, and critical infrastructure. This analysis constituted a key diagnostic element for identifying priority areas requiring preventive or remedial actions.

The first stage of the risk analysis was to identify possible threats. Given that the surveyed municipalities struggle with post-mining damage, the threats were adjusted to this aspect and presented in table 2.

Table 2.
List of threats

No.	Threat	Description
1	Terrain deformation (sinkhole) in an urbanized area	Sinks in built-up areas pose a threat to residential buildings, the road network and technical infrastructure. Their sudden appearance can lead to the evacuation of residents and blocking of access to key services. They disrupt the continuity of the urban logistics system.
2	Terrain deformation (sinkhole) in a forest/ uninhabited area	Sinks in unbuilt areas do not pose a direct threat to residents but can hinder the operations of rescue services and access to natural resources. If they appear near evacuation routes or service roads, they can cause operational restrictions.
3	Flooding of a main road (treated as flooding)	Flooding of the main communication route results in limited mobility of residents and services, as well as suspension of public transport and supplies. It makes evacuation and access to strategic facilities difficult. It can lead to significant economic losses and delays in the implementation of public services.
4	Occurrence of flooding on the main road	Flooding can cause long-term inaccessibility of the road, destruction of the surface and the need for detours, which extend the response time of the services. It increases the risk of accidents and collisions, especially in the absence of warnings. It makes planning and implementation of logistics routes in the city difficult.
5	Flooding of urbanized areas	Flooding of residential estates directly affects the safety of residents and damages municipal and private infrastructure. It generates a high demand for rescue operations (the need to pump water from basements, for example), social support. In the long term, it affects the quality of life and reduces the value of real estate.
6	Obstruction of evacuation routes	Blocking evacuation routes during a crisis poses a serious threat to the life and health of residents. It makes it difficult for rescue services to reach places at risk. It can lead to organizational chaos and escalation of human and material losses.
7	Damage to the water and sewage network	A failure of the water and sewage network because of flooding or a sinkhole disrupts the supply of drinking water and sewage collection, causing secondary sanitary and epidemiological threats. It affects the functioning of public utility facilities, including schools, hospitals and workplaces. The need to carry out repairs can significantly burden the commune's budget.

Cont. table 2.

8	Flooding/ inundation of an area in an economic zone	Flooding of the economic activity zone results in production downtime, interruptions in supply chains and damage to the assets of enterprises. It entails economic consequences for local companies.
9	Landslide in an economic zone	Landslides can destroy road infrastructure, warehouses or industrial facilities, leading to material losses and job losses. They also threaten the safety of people in these areas. They require geotechnical intervention and temporary exclusion of the area from use. Insufficient or contradictory information increases panic among residents and makes it difficult to make rational decisions. It disrupts communication between services and local authorities, weakening the effectiveness of rescue operations.
10	Lack of information or disinformation during a crisis	Sinks in built-up areas pose a threat to residential buildings, the road network and technical infrastructure. Their sudden appearance can lead to the evacuation of residents and blocking of access to key services. They disrupt the continuity of the urban logistics system.
11	Insufficient number of rescue services	Staff and equipment shortages limit the ability to respond to multiple simultaneous incidents. The time it takes for services to arrive at the stage is longer, which increases the scale of losses and the risk to the lives of residents.
12	Secondary threat, e.g. contamination of groundwater	Secondary effects of the crisis, such as contamination of water intakes, may occur with a delay and remain unnoticed for a longer period. They threaten the health of residents, as well as fauna and flora. They require long-term corrective actions.

Source: own study.

The threats indicated in the table above constitute a list of events that have taken place in the last three years, as well as events that may occur in the near future and pose a real threat to the residents and infrastructure of the discussed communes.

To create a risk matrix, a table was created presenting the probability of the occurrence of a threat on a scale of 1 to 5, where 1 means very low probability, and 5 very high probability of the occurrence of a given risk. The list of probabilities is presented in table 3.

Table 3.
Risk probability scale

Probability	Scale	Description
Very small	1	An event (disturbance) that has a very low probability of occurring (the chance of occurring is between 0% and 20%, e.g. twice a year).
Small	2	An event (disturbance) that has a low probability of occurring (the chance of occurring is between 21% and 40%, e.g. once every 2 months on average).
Medium	3	An event (disturbance) that has a moderate probability of occurring (the chance of occurring is between 41% and 60%, e.g. twice a month on average).
Large	4	An event (disturbance) that has a high probability of occurring (the chance of occurring is between 61% and 80%, e.g. once a week on average).
Very large	5	An event (disturbance) the occurrence of which is associated with a very high probability (the chance of occurrence is between 81% and 100%, e.g. at least twice a week).

Source: own study.

A scale of possible consequences of a given threat that could affect the functioning of the city's logistics system was also created. This table allowed for assigning a numerical value on a scale of 1 to 5 to different levels of consequences of a given event, with the scale reflecting the increasing seriousness of the consequences, from minor disruptions to catastrophic consequences that could lead to paralysis of the transport system, critical infrastructure or rescue services. Table 4 presents the scale of consequences along with their description.

Table 4.
The scale of the risk effect

Effect	Scale	Description
Slight	1	The occurrence of an incident may cause minor, almost imperceptible disruptions to the functioning of the city's logistics system, e.g. short-term difficulties in local traffic or minor problems with access to municipal services. The incident may involve limited losses for residents and local service operators. The impact on the continuity of public transport or the operation of emergency services is minimal and easy to control without major involvement of city resources.
Small	2	The incident causes noticeable, but still limited disruptions to the functioning of the city's logistics system. It may concern, for example, local flooding or temporary difficulties in the logistics service of city facilities, which requires a response from services and intervention by the authorities. The scope of the problem is manageable with the involvement of moderate financial and organizational resources. Residents may feel the effects, but it does not cause long-term paralysis of the infrastructure.
Medium	3	The occurrence of an incident leads to more serious difficulties in the implementation of the basic tasks of the city's logistics system, e.g. disruption of traffic on main communication routes, limited availability of emergency services, or interruptions in the delivery of supplies. It requires coordinated action by city services and engages a significant part of the available resources. Residents and entrepreneurs clearly feel the effects of an event that may negatively affect mobility and safety.
Major	4	An event has a very large impact on the functioning of the city's logistics system. Examples include the closure of key road sections, the collapse or flooding of areas important for the flow of people and goods, or restrictions on the operation of critical infrastructure. The city must engage significant funds and resources to control the situation, and restoring the logistics system to full efficiency requires time and costs. The effects may also include interruptions in the supply of municipal services or the isolation of some areas.
Catastrophic	5	An event leads to a complete disruption of the continuity of the city's logistics system, e.g. interruption of main communication routes, paralysis of emergency services, cutting off districts from infrastructure and resources. The effects are long-term or difficult to reverse, and their removal involves huge financial, time and logistical outlays. The functioning of a city in crisis may be significantly limited or suspended, which affects social and economic life.

Source: own study.

Thanks to this solution, it was possible not only to define the effects of specific threats, but also to compare them in a systemic approach. This table was the basis for building a risk matrix, a tool supporting the process of crisis management and planning preventive actions in urban systems.

As part of the risk analysis conducted within the logistics system of the surveyed municipalities, a list of identified threats was developed, along with assigned values for the probability of occurrence and an assessment of potential consequences. The aim of this analysis was to indicate the most critical factors that could disrupt the continuity of public services, transport infrastructure, and crisis response systems. Table 5 presents twelve key threats that may occur in connection with land deformations, flooding, water accumulation, inefficiencies in the emergency response network, and information-related issues during crisis situations. Each of these threats was assigned a rating in two dimensions: probability and impact. The product of these elements was used to determine the risk level. This result served to assess the degree of threat posed by a given phenomenon to the urban logistics system.

Table 5.
Determining the risk level

No.	Threat	Probability	Scale	Risk level
1	Terrain deformation (sinkhole) in an urbanized area	3	4	12
2	Terrain deformation (sinkhole) in a forest/uninhabited area	4	2	8
3	Flooding of a main road (treated as flooding)	1	4	4
4	Occurrence of flooding on the main road	1	5	5
5	Flooding of urbanized areas	3	4	12
6	Obstruction of evacuation routes	1	4	4
7	Damage to the water and sewage network	1	3	3
8	Flooding/inundation of an area in an economic zone	1	4	4
9	Landslide in an economic zone	2	4	8
10	Lack of information or disinformation during a crisis	4	3	12
11	Insufficient number of rescue services	2	4	8
12	Secondary threat, e.g. contamination of groundwater	3	5	15

Source: own study.

The next stage of conducting the risk analysis was to develop a table describing the risk levels in the context of the functioning of the city's logistics system. Table 6 organizes the risk into four levels, from low to very high, indicating both its acceptability and the consequences for the continuity of city services, infrastructure and coordination of rescue operations. Each level contains a detailed interpretation, thanks to which it was possible to assign appropriate categories to previously identified threats.

Table 61.
Defining risk levels

Risk	Description
Very high risk	This is a completely unacceptable level of risk from the point of view of the functioning of the city's logistics system. It can result in serious disruptions in services for residents, blocking key roads, interruptions in access to public services and hindering the work of rescue services. The consequences require huge financial, organizational and time expenditures, and their elimination can be long-term. In such a situation, it is necessary to immediately implement remedial actions to reduce the threat to an acceptable level and restore the continuity of the city's functioning.
High risk	This is also an unacceptable risk, which can lead to the temporary immobilization of key components of urban infrastructure, such as traffic intersections, economic zones or service junctions. Such disruptions cause difficulties in transport, coordination of rescue operations and in providing basic services to residents. It is recommended to implement comprehensive preventive measures and risk management procedures to limit its impact and enable the maintenance of basic urban functions.
Medium risk	At this level, the risk does not pose a direct threat to the continuity of the city system but can clearly affect the quality and efficiency of city logistics, including the operation of technical services, crisis communication or public information systems. The occurrence of such risks may result in lower social satisfaction and a deterioration of the image of the local government unit. It is necessary to constantly monitor these factors and implement actions to limit their impact on the operational functioning of the city.
Low risk	This is the level of risk considered acceptable in the daily functioning of the city's logistics systems. The potential effects are small and temporary, and their impact does not require serious interventions or reorganization of services. Despite this, it is necessary to conduct constant observation and maintain readiness to act, especially in the event of changes in environmental conditions or the emergence of new risk factors.

Source: own study.

Based on the obtained results, a risk matrix was created, which allows for a graphical arrangement of individual threats depending on their probability of occurrence and the scale of potential effects. Placing threats in the appropriate fields of the matrix allowed for an intuitive determination of which of them require immediate preventive actions and which should only be monitored.

The conducted risk analysis allowed for the identification and assessment of key threats affecting the functioning of logistics systems in the studied municipalities. Both natural events, such as sinkholes, floods or floodlands, and systemic factors, such as disinformation or insufficient number of rescue services, were considered. Based on the developed risk matrix, it was possible to indicate areas requiring urgent intervention and those that should be systematically monitored.

4. Results and discussion

The results of the Servqual analysis conducted among two key stakeholder groups, residents and firefighters of the Volunteer Fire Departments, reveal both similarities and differences in the perception of the quality of the logistics system functioning in crisis situations. Both residents and members of the Volunteer Fire Department assessed the quality of services provided in the areas of: information and communication, safety and preparedness, response and effectiveness of actions, and support and social involvement. Despite the common thematic scope, the results showed different perceptions and priorities of each group.

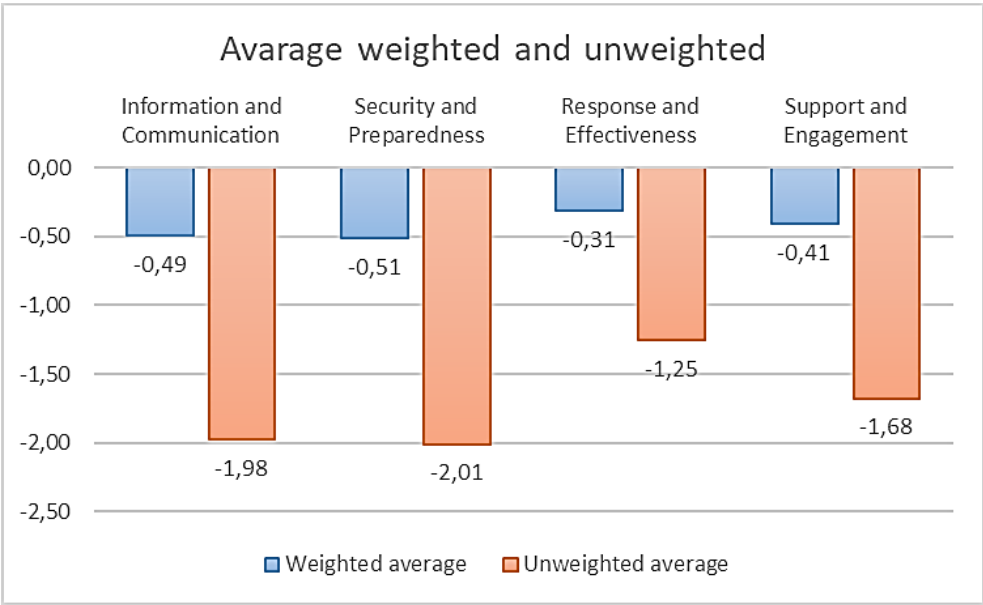

Figure 3. Weighted and unweighted average for residents.

Source: own study.

According to figure 3 for residents, the largest differences between the perceived and expected assessments (both in weighted and unweighted averages) are visible in the dimensions: safety and preparedness (–2.01 unweighted, –0.51 weighted) and information and communication (–1.98 unweighted, –0.49 weighted). This indicates a strong sense of lack of transparency of the authorities' actions, insufficient information about threats and limited access to emergency plans. Residents also show dissatisfaction with the level of safety and feel that local government authorities are insufficiently prepared to deal with crisis situations.

Figure 4. Weighted and unweighted average for OSP.

Source: own study.

Figure 4 shows that OSP firefighters also indicated safety and preparedness (–2.02 unweighted, –0.49 weighted) and information and communication (–1.96 unweighted, –0.51 weighted) as the strongest quality gaps. Although the numerical differences are slightly different than in the case of residents, the data indicate deficiencies in procedures, coordination, and access to current guidelines. OSPs also note a limited level of support and involvement from residents. The differences in mean values (both arithmetic and weighted) show that although both groups recognize the existing deficiencies of the crisis management system, their expectations and assessment of the system's functioning differ slightly depending on the role they play.

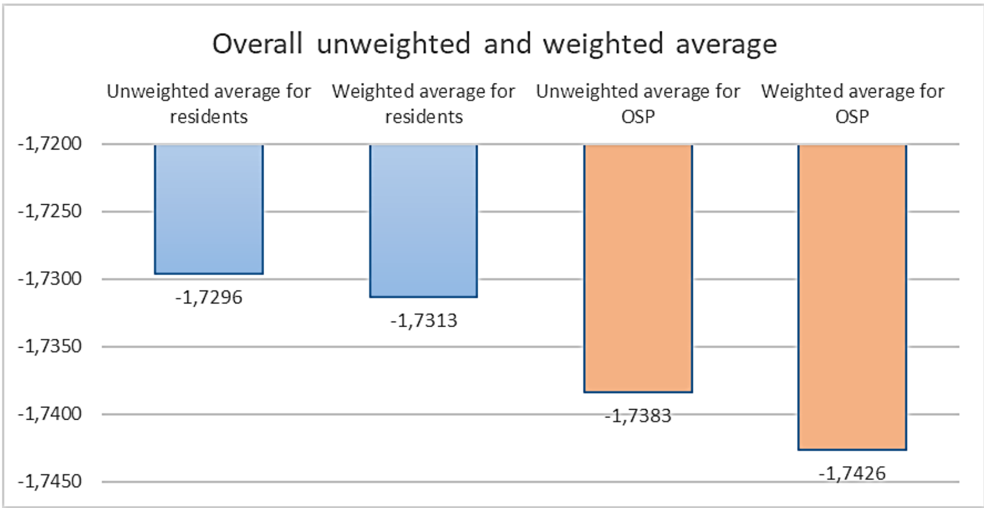

Figure 5. Weighted and unweighted total average.

Source: own study.

In the comparative analysis of Servqual results for the studied groups, both similarities in the level of general dissatisfaction and significant differences in the way of perceiving individual aspects of the quality of crisis management are visible. It is worth paying attention to the values of the general averages, both weighted and unweighted, which are presented in figure 5. In the case of residents, the unweighted average was -1.7296, and the weighted average was -1.7313. In turn, for the OSP firefighters, these values were slightly lower, the unweighted average was -1.7383, and the weighted average was -1.7426. Although these differences are small, it can be seen that firefighters assessed the quality of services related to crisis management slightly more severely. This may result from their daily contact with threats and the operational nature of their work, which allows them to notice more weak points in the operation of the system.

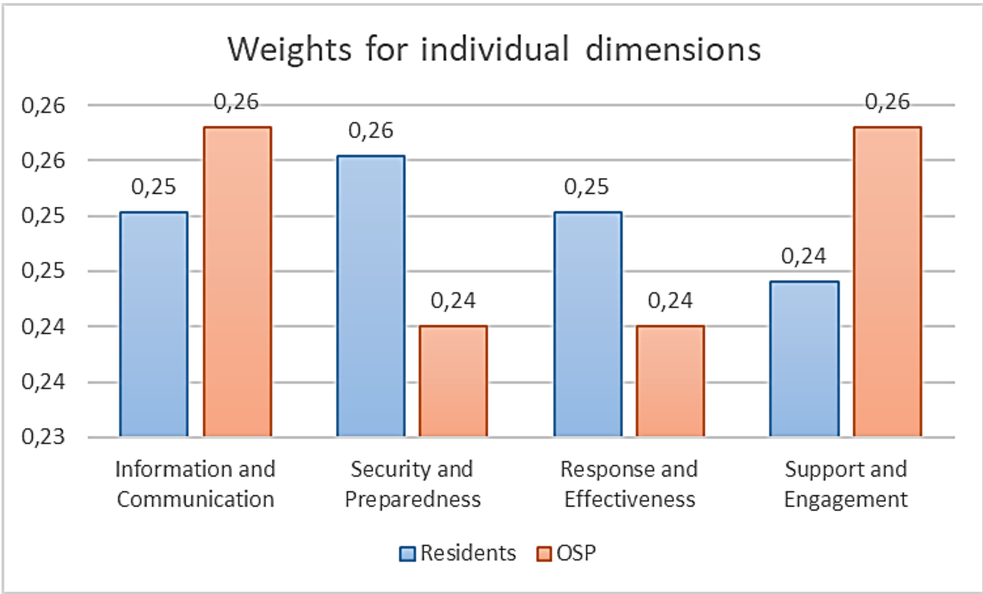

Figure 6. Weights for individual dimensions.

Source: own study.

The differentiation between groups is also visible in the weights assigned to individual assessment areas, as presented in Chart 6. The weights were assigned subjectively, aiming to reflect the dimensions that the surveyed stakeholder groups might emphasize more strongly. For residents, the greatest importance was attributed to the aspect of Safety and Preparedness, reflecting their need for protection during crisis situations and readiness for immediate response. The next most important areas indicated were Response and Effectiveness and Information and Communication, while the least important were Support and Engagement. A different prioritization appeared among firefighters. For them, the highest weights were assigned to the dimensions of Information and Communication and Support and Engagement. This distribution shows that, from their point of view, key elements include efficient information exchange, cooperation between units and residents, and active involvement of the local community in crisis response actions. The lowest weight was assigned to aspects related to safety and preparedness, which results from the fact that they themselves are responsible for these areas and more often notice their systemic limitations.

The results clearly indicate that both the local community and operational units perceive significant shortcomings and deficits in the functioning of the crisis management system, especially in areas related to communication, safety, and operational readiness. Residents of the surveyed areas place particular emphasis on improving the quality of communication with local authorities and increasing the transparency of undertaken actions. They feel a lack in terms of the speed of service response and the availability of emergency plans, which translates into a low sense of security in the face of threats. On the other hand, volunteer firefighters, as individuals responsible for direct response to crisis events, point to the lack of up-to-date operational procedures, insufficient equipment resources, and problems with coordination between units and communication with residents.

The compilation of results from both groups shows that their perspectives are not contradictory but complementary, together forming a complete picture of the needs, expectations, and challenges facing the urban logistics system. The key value of the analysis was the inclusion of both unweighted averages, which show the overall level of satisfaction, and weighted averages, which capture the importance assigned to specific areas. This approach made it possible to identify those elements of the system that are of the greatest importance to stakeholders and which require urgent intervention. The conclusions drawn from the analysis and interpretation of the chart results clearly indicate the need for an integrated approach to crisis management, encompassing not only operational aspects, such as equipping services and improving procedures, but also communication and participatory activities. Only through the combined efforts of authorities, residents, and emergency services can resilient, flexible, and efficient logistics systems be built, capable of effectively responding to disruptions and minimizing their social, economic, and infrastructural impacts.

The conducted risk analysis allowed for the identification and systematization of threats affecting the functioning of urban logistics, with particular attention to the effects resulting from mining activities in the studied areas. The risk assessment was carried out based on a risk matrix, founded on two axes: the probability of threat occurrence and its potential consequences for the logistics system. The matrix is presented in table 7.

Table 7.
Risk matrix

Scale of effect	Catastrophic	**5 (Threat.4)**	**10**	**15 (Threat.12)**	**20**	**25**
	Serious	**4 (Threat.3, 6, 8)**	**8 (Threat.9, 11)**	**12 (Threat.1, 5)**	**16**	**20**
	Moderate	**3 (Threat.7)**	**6**	**9**	**12 (Threat.10)**	**15**
	Small	**2**	**4**	**6**	**8 (Threat.2)**	**10**
	Minor	**1**	**2**	**3**	**4**	**5**
		Very small	Small	Medium	Large	Very large
		Scale of probability (chance) of occurrence				

Source: own study.

The analysis revealed that out of all the assessed cases, as many as four threats received a very high risk level, indicating their critical importance to the functioning of the municipal logistics system. The most serious identified threat turned out to be secondary contamination of groundwater, which received the highest risk score of 15 points. Although this threat does not occur suddenly, its long-term effects can be difficult to reverse, and their impact on residents health and the natural environment is potentially catastrophic. Almost equally serious were the risks of flooding in urban areas and the occurrence of land deformations (sinkholes) within urban infrastructure. The consequences of these include potential loss of transport infrastructure, threats to residents' health and lives, and the disruption of key communication routes. A high level of risk was also recorded in the case of lack of information or misinformation during crisis situations. Although intangible, this area was assessed as significant from the perspective of crisis management. Inconsistent, incomplete, or false messages can lead to information chaos, reduce the effectiveness of emergency services, and worsen public trust in local authorities. This aspect was highlighted by both residents and firefighters in the conducted surveys. On the other hand, physical risks with lower probability or limited impact, such as land deformations in undeveloped areas, flooding of lower-ranking roads, or landslides outside strategic zones, were assigned medium or low risk levels. However, it should be noted that their occurrence can have a cascading effect, and their cumulative impact may lead to more serious issues within the logistics system, for example, by hindering evacuation or restricting access for emergency services.

The analysis also revealed that systemic threats, including the shortage of emergency resources and the lack of coordinated procedures, represent real barriers to efficient crisis response. An insufficient number of trained personnel and a lack of technical resources confirmed by survey results among volunteer firefighters significantly reduce the operational and logistical efficiency of municipalities during emergencies. The risk matrix became a tool that enabled not only the classification and prioritization of threats, but also the identification of areas requiring immediate remedial action. The analysis confirms the rationale for undertaking preventive measures in areas with the highest risk levels and highlights the need to implement integrated response procedures between emergency units, local administration, and the local community.

5. Conclusions

The issue of urban logistics system resilience in crisis situations, despite its growing importance in the face of climate change, unpredictable environmental hazards, and increasing urban development challenges, remains a relatively underdeveloped area in the academic literature. Studies on urban logistics typically focus on its functionality, efficiency, and management under normal conditions, while knowledge regarding how these systems operate under disruption and what characteristics enhance their resilience to crises is still insufficiently explored. This article addresses that research gap by focusing on the conceptualization of urban logistics resilience and the relational aspects of resilience-building through stakeholder collaboration.

The empirical research conducted provided qualitative data on the perception of logistics system resilience from two selected stakeholder groups: residents and volunteer firefighters (OSP). Conclusions drawn from both analyses were used to formulate practical recommendations for local governments on strengthening the resilience of local systems. However, it is important to highlight certain limitations that affect the generalizability of the results. Firstly, the study was conducted in a single region characterized by specific spatial and environmental conditions linked to mining activity and the consequences of mine closures. As such, the findings may be limited to post-industrial municipalities with similar characteristics, and their application to other regions should be approached with caution. Secondly, the study included only two stakeholder groups. While residents and volunteer firefighters are crucial to the local resilience system, they do not represent the full spectrum of entities involved in urban logistics. Future analyses should be extended to include groups such as: local government and crisis administration officials, employees of municipal utility companies, public transport operators, local entrepreneurs, as well as non-governmental organizations involved in relief efforts.

Moreover, the exclusive reliance on questionnaire-based surveys may be considered a methodological limitation. Although surveys allowed for the collection of comparable data from a large number of respondents, they did not enable an in-depth exploration of the motivations, experiences, and assessments of individual groups. Supplementing the research with interviews, field observations, or stakeholder workshops could enrich the interpretation of results and enhance the exploratory value of the study.

In future research projects, it would also be beneficial to incorporate GIS-based tools. Spatial analysis could help identify critical bottlenecks in transport infrastructure, locations most at risk of disruption to logistics services, or relationships between urban layouts and crisis management effectiveness.

While the current research makes a valuable contribution to the development of knowledge on urban logistics resilience, it remains exploratory in nature due to its limited territorial scope and stakeholder sample. The results obtained may serve as a starting point for more comprehensive research projects that would include a broader range of urban system participants and apply diverse data analysis methods.

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