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OPERATIONAL CHALLENGES IN AIR TRANSPORT OF OVERSIZED CARGO

Summary. This article explores the formal and legal framework governing the air transport of oversized cargo, emphasizing applicable regulations and available aircraft types. Drawing on insights from a semi-structured in-depth interview (IDI) with an industry expert, the study outlines the key stages of the transport process and identifies potential hazards that may arise at each step. Particular attention is given to operational challenges such as regulatory compliance, appropriate aircraft selection, and coordination of logistics. In response, the paper proposes targeted preventive and corrective measures aimed at minimizing disruptions and enhancing the safety and efficiency of operations. The results not only offer practical guidance for industry professionals but also serve as a foundation for future research focused on developing tailored risk assessment tools and methodologies suited to the specific demands for non-standard air cargo transport.

Keywords: air transport of oversized cargo, legal and technical conditions, operational challenges, hazard identification

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1. INTRODUCTION

The transport of oversize cargo plays a significant role in the modern economy due to the growing number of investments and projects that require the movement of structural components, infrastructure elements, or industrial machinery with non-standard dimensions and weight [8]. Oversize cargo is defined as freight that, due to its characteristics – external dimensions, weight, or packaging form - cannot be transported using standard means of transportation [5, 9, 28]. It is important to note that the interpretation of this concept may vary depending on the mode of transportation because of differing legal regulations, infrastructure specifics, and available means of transport [25]. A shipment considered as oversized in one transport mode may fall within standard parameters in another [8]. A general classification of oversized cargo is presented in Figure 1.

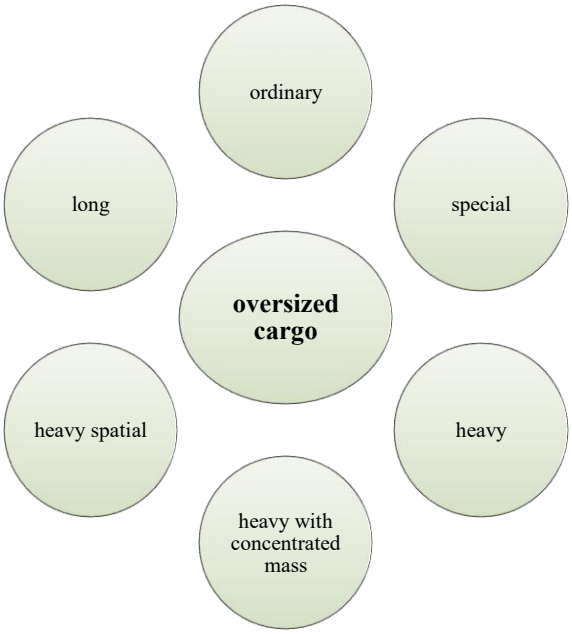

Fig. 1. Types of oversized cargo
Source: own work based on [15]

Oversized loads can be categorized based on their shape, weight, and dimensions. The main types include:

- ordinary – this group includes steel structures, small machinery, and industrial equipment. Although they exceed standard transport dimensions slightly, they usually weigh no more than 25 tons and are transported using specially marked road vehicles,
- special – these loads significantly exceed vehicle dimensions and require dedicated transport routes and specific road traffic arrangements. They can reach considerable sizes in length, width, and height,
- heavy – refers to large-scale equipment or components like tanks, silos, or tram carriages. Their weight typically ranges from 70 to 100 tons,
- heavy with concentrated mass – these are extremely heavy relative to their size, with weights reaching up to 200–300 tons. Examples include transformers or turbines. Transport usually requires multi-axle trailers or rail solutions,

- heavy spatial – due to their extreme size and weight (up to 900 tons and 40 meters in height), these can only be moved by sea or inland waterways. Examples include port cranes or large pipe systems,
- long – these are characterized by exceptional length (up to 40-60 meters), while their other dimensions often fall within standard ranges. Typical examples include poles, wind turbine blades, or industrial reactors [14].

Oversized cargo transport can be transported using various modes of transportation. The literature discusses selected aspects of such operations in the context of road [6, 7, 12, 13, 14, 27], rail [18, 19], maritime [3, 16], and inland waterway transport [11, 24]. It is noticeable that literature is dominated by studies focused on road transport. Significantly, less attention has been devoted to issues related to transporting such cargo by air [8, 9], which, despite its limitations, plays an important role in the global supply chain. Air transport is sometimes the only solution in regions with insufficient road and rail infrastructure [20]. It is particularly popular in situations where delivery time is crucial (e.g., in the case of critical failures).

Air transport in the context of oversized cargo represents a unique case. It involves numerous operational challenges that far exceed standard logistics procedures. First of all, restrictions related to the dimensions of cargo doors, the maximum lifting capacity of aircraft and the availability of specialized transport units (such as Antonov An-124 or Boeing 747-8F) require precise planning and often the involvement of a dedicated fleet. Additionally, it is necessary to use advanced loading and unloading techniques that take into account not only the mass and volume of the cargo, but also its weight distribution and impact on the stability of the aircraft. Problems also arise in obtaining appropriate permits, coordinating with airports that have appropriate infrastructure, and ensuring compliance with international safety and security regulations. As a result, the effective implementation of this type of transport requires close cooperation between logistics operators, air carriers and regulatory authorities [8]. Aircraft have limited transport capabilities due to the dimensions and load-bearing capacity of their cargo holds. According to [7], in aviation, the criteria for transporting oversized cargo are strictly defined, and such transport requires special loading procedures and appropriate aircraft selection to match the characteristics of the cargo. Furthermore, it is emphasized that such transport depends mainly on aircraft size. The maximum load a plane can carry corresponds to the parameters of the cargo hold's width, height, and length. For heavy cargo, it is crucial to consider that the aircraft must still be able to take off. [25] highlight that in practice, if the cargo does not fit into a standard air container (ULD – Unit Load Device) or on a typical air freight pallet, and requires a specially chartered cargo aircraft, it is considered oversized. In addition to unusual dimensions, oversized air cargo may be characterized by:

- excessive weight, meaning it exceeds the maximum payload of a standard cargo deck or requires special loading procedures,
- irregular shape, meaning it cannot be easily loaded or secured in a standard cargo compartment.

The literature emphasizes that the concept of oversized cargo in air transport does not formally exist; however, in industry practice, it is used to describe shipments requiring a customized logistical approach [10]. Oversized cargo transport is a comprehensive service that requires precise planning, organization, and coordination at every stage – from order acceptance, through loading, to final delivery. The safety of operations is the paramount goal of the entire logistics process.

The aim of this article is to analyze the formal and technical conditions, identify the key stages, and highlight the operational challenges, and potential risks involved in organizing air transport of oversized cargo. The article describes the legal acts regulating this type of transport and the means of transport used within it. The identification of key stages, challenges and potential operational risks was based on the results of a semi-structured, in-depth individual interview (IDI) with an aviation industry expert with extensive professional experience in the execution of oversized air cargo operations.

2. CONDITIONS OF AIR TRANSPORT OF OVERSIZED CARGO

The successful execution of operational challenges related to the air transport of oversized cargo is influenced by various factors, including legal, technical, and organizational conditions. Given that ensuring safety at every stage is paramount, adherence to applicable legal regulations is essential. These include international conventions, national aviation transport laws, and guidelines issued by aviation organizations. Additionally, it is necessary to consider the technical limitations of this transport mode, such as airport infrastructure parameters and aircraft specifications. A critical aspect is the selection of an appropriate means of transport, considering technical parameters like payload capacity and cargo hold dimensions. This section will discuss the legal acts governing air transport, technical and operational constraints associated with oversized cargo transport, and the characteristics of cargo aircraft utilized in such operations.

Regulations governing the air transport of oversized cargo encompass international, European Union (EU), and national laws, necessitating close collaboration among carriers, freight forwarders, and relevant supervisory authorities. The foundational legal instrument for international air cargo transport, including oversized shipments, is the Convention on International Civil Aviation (commonly known as the Chicago Convention). This convention establishes global principles concerning aviation safety, airspace management, and aircraft certification. Additionally, the Montreal Convention addresses the liability of air carriers for damages arising from cargo transport, including potential damage to oversized items. For the transport of dangerous goods, the International Civil Aviation Organization (ICAO) provides Technical Instructions that detail requirements for the safe international transport of such goods by air. Complementing these, the International Air Transport Association (IATA) issues the Dangerous Goods Regulations (DGR), which offer comprehensive guidelines on the classification, packing, marking, labeling, and documentation necessary for the air transport of hazardous materials. Within the EU, the air transport of oversized cargo is regulated by Regulation (EC) No 1008/2008, which outlines common rules for the operation of air services within the Community. In the context of oversized operations, Regulation (EU) No 965/2012 is particularly significant, as it establishes technical requirements and administrative procedures related to the safe operation of aircraft. In Poland, air transport operations are governed by the The Act of 3rd July 2002 – Aviation Law which specifies requirements for transport operations, carrier certification, and procedures for obtaining permits for non-standard transports.

Beyond legal regulations, technical considerations are crucial in organizing air transport. Table 1 presents selected limitations encountered in air transport, along with their brief descriptions.

Tab. 1

Limitations in the execution of oversize air cargo transport
Source: own work based on [9, 21]

Limitation	Description
Cargo aircraft capacity and payload	Selecting an appropriate aircraft is crucial to accommodate the cargo's specific requirements, such as its weight, dimensions, and center of gravity distribution. The aircraft must be capable of carrying the load without risk of damage or overloading
Airport capability to handle cargo aircraft	An airport's ability to manage oversized cargo operations depends on factors like runway length, pavement strength, and the availability of infrastructure such as cargo terminals and technical equipment necessary for handling large shipments
Transporting oversized items to suitable airports	Coordinating road or maritime transport is necessary to deliver oversized cargo to an airport equipped with the required infrastructure, such as appropriate loading facilities and handling equipment
Delivering cargo from airport to final destination	Ensuring the availability of suitable transportation and infrastructure is essential for moving the cargo from the airport to its destination, considering potential logistical challenges in road transport

Therefore, it can be concluded that despite the existence of clear legal regulations, the air transport of oversized cargo involves numerous technical challenges that must be addressed to ensure the safety and timeliness of operations. A critical factor is the selection of an appropriate aircraft whose technical specifications align with the requirements of the cargo being transported. Table 2 presents the technical data of selected cargo aircraft that are or can be utilized in oversized cargo transport operations. Parameters such as internal cargo hold dimensions and maximum payload capacity are essential for determining the capabilities of each aircraft. Additionally, the size of the cargo doors plays a crucial role, particularly when handling non-standard goods, as it directly influences loading operations [4].

It can be observed that aircraft adapted for the transport of oversize cargo exhibit exceptional capabilities in efficiently carrying large masses during single air operations. In the context of such transports, one of the most important cargo aircraft capable of meeting this challenge was the Antonov An-225 'Mriya'. Unfortunately, this aircraft was destroyed due to military actions in Ukraine in 2022. The loss of the An-225, one of the most recognizable and largest of its kind, creates a significant void in the global fleet for transporting non-standard freight [23].

In addition to the aircraft mentioned in Table 2, specialized air transport operations also make use of aircraft from the Airbus Beluga family, which were specifically designed to transport components used in the production of Airbus planes [26]. Although the Belugas (both the A300-600ST version and the newer A330-700L) are primarily used for internal operations

by Airbus, their transport capabilities make them suitable for carrying oversized cargo for external clients, especially in situations requiring transport tailored to large, specific loads. It is worth noting that in 2022, Airbus established the Airbus Beluga Transport (AiBT) line for transporting special cargo outside the Airbus production network. However, in January 2025, the company announced the suspension of AiBT's operations, marking the end of this short-lived venture focused on specialized oversized cargo transport services [22]. Despite the closure of AiBT, the Airbus Beluga remains a key tool for transporting aircraft components and other specialized cargo.

Tab. 2

Cargo parameters of the largest transport aircraft
Source: own work based on [9]

Aircraft model	**Cargo hold dimensions [m]**			**Cargo door dimensions [m]**		**Maximum payload [t]**
	width	**length**	**height**	**width**	**height**	
Antonov 225	6.40	43.00	4.40	6.40	4.40	250.00
Boeing 747 cargo	3.17	49.00	3.04	3.40	3.04	111.00
Antonov 124	6.40	36.50	4.40	6.40	4.40	110.00
McDonnell D.MD11	3.50	48.00	2.31	3.55	2.59	80.00
McDonnell D. DC10	3.17	37.25	2.23	3.55	2.59	66.00
Boeing 767 cargo	4.00	30.00	2.50	2.54	3.40	60.00
Boeing 767	4.00	30.00	2.50	3.40	2.59	54.00
Ilyushin Ił-76	3.46	20.00	3.40	3.44	3.40	45.00
Airbus A300 cargo	4.77	39.00	2.23	2.56	3.58	45.00
McDonnell D. DC 8	3.17	31.54	2.30	3.35	2.03	44.00

In summary, understanding technical details is key to aligning the right aircraft with the requirements of a transport assignment. The cargo hold dimensions and door sizes directly impact loading operations, determining the feasibility of loading specific cargo and influencing the choice of compatible airports. The payload capacity further helps in assessing the maximum weight that can be transported, which is critical for effective transport planning. Thus, selecting an aircraft involves careful consideration of these specifications to ensure the success of oversized cargo transport. To further explore how such operations are organized and managed in practice, the following section presents the qualitative research methodology applied in this study.

3. MATERIAL AND METHODS

To identify key stages and hazards in oversize air cargo transport, a qualitative research method was employed, which included a semi-structured in-depth interview (IDI) with an expert in the field. This method, widely used for obtaining detailed, qualitative insights into complex phenomena [1, 2], was the most appropriate choice for this study, as it allowed for a deep exploration of the respondent's experiences and perspectives on organizing non-standard cargo transportation.

The interview process was guided by a pre-prepared list of questions, but allowed for flexibility, enabling the expert to freely elaborate on relevant topics. This approach provided rich insights into new areas that emerged during the conversation, ensuring the researcher could address a range of issues beyond the initial framework [17]. The interview allowed for a deeper understanding of the specific challenges and logistical complexities involved in the transportation of oversize goods.

The respondent was a highly experienced professional from the air cargo logistics industry, bringing years of hands-on expertise in organizing air transport operations. The expert's practical knowledge offered invaluable information about the challenges involved in planning and executing air transport for oversized cargo. This conversation also helped gain an understanding of the respondent's subjective views on the operational complexities of both air and ground logistics in this specialized area.

The semi-structured interview consisted of 12 open-ended questions, covering the following key areas:

- verification procedures for transport orders,
- analysis of legal and technical requirements,
- planning of air and ground transport operations,
- use of loading and unloading equipment and techniques,
- risk management and emergency procedures.

The open-ended nature of the questions allowed the respondent to freely share experiences and views, facilitating a detailed exploration of critical issues surrounding oversized cargo transport. The interview, which lasted about 45 minutes, took place online via Microsoft Teams, with a friendly and open tone to ensure the respondent felt comfortable sharing detailed and honest responses. Due to confidentiality agreements, some sensitive operational details were not disclosed, and certain answers were generalized.

The collected data were subjected to content analysis, aimed at extracting the main thematic categories and conclusions. This approach facilitated a comprehensive analysis of the expert's insights and the identification of key elements influencing the studied processes.

4. RESULTS AND DISCUSSION

Based on the semi-structured in-depth interview conducted with an expert from the aviation industry, it was possible to reconstruct in detail the various stages, challenges, and risks associated with organizing oversize cargo transport by air. The interviewee, who has extensive experience in planning such operations, presented both standard procedures and specific cases that illustrate the complexity of the discussed issue.

The transport process begins with the analysis of the feasibility of accepting the shipment. This is a crucial moment where the parameters of the cargo, such as its weight, dimensions, and safety requirements, are analyzed. Simultaneously, the technical capabilities of the infrastructure at both the departure and destination airports are verified, along with regulatory aspects such as oversized cargo transport regulations, the need to obtain permits, and the availability of flight slots. At this stage, it is also essential to comply with international regulations, such as those from ICAO (International Civil Aviation Organization) and IATA (International Air Transport Association). As the respondent noted: '*Before we undertake the operation, we must thoroughly analyze whether it is even feasible – it's not just about the size, but also regulatory issues and airport capabilities*'. At this point, a preliminary cost estimate and a provisional schedule for the execution of the order are also prepared. Often, initial technical consultations with the cargo sender, end client, and customs services are required at this stage.

The next stage is transport planning, which requires the involvement of a team of specialists from various fields – from engineering to logistics. Key decisions here involve selecting the appropriate aircraft that can accommodate the cargo while meeting requirements related to the center of gravity, floor load capacity, and cargo space. '*We need to choose the right aircraft based on weight and dimensions. Then we have to plan the route, check where we can land, whether the runways are long enough, and whether the airport can handle such operations*' emphasized the respondent. At this stage, ICAO's safety guidelines for air operations and IATA's standards for documentation and cargo transport are also taken into account. Additionally, an essential element is considering customs procedures and other legal regulations related to international freight transport, which may include requirements for customs clearance, shipping documentation, as well as specific security and cargo control requirements depending on the country of origin and destination of the cargo. In some cases, additional transport permits are required, including those from customs authorities, agencies responsible for checking exports and imports, and external services dealing with international transport control.

One of the critical stages in organizing oversized cargo transport by air is the coordination of ground transport, which is carried out by external logistics companies. Although the air operator is not directly responsible for organizing this, it is essential to ensure precise synchronization of the cargo delivery to the airport with the flight operation schedule. As the expert emphasized: '*If the truck is delayed, and the loading window on the tarmac is already open, everything is delayed, and time is money in this case'*. At this stage, it is crucial to check whether the transport vehicles are suited to the specifics of the cargo – this includes both low-bed trailers and technical equipment such as cranes needed for loading. It is also necessary to verify whether the delivery is planned well in advance and in accordance with the airport's infrastructure requirements. If needed, support may be provided to the client or transport company in adjusting the timing and organizing airport passes or escorts. '*Sometimes, the loading has to be postponed because, for example, the convoy cannot enter the airport grounds during peak hours*' the interviewee pointed out.

The next stage is the technical inspection and loading of the cargo onto the aircraft. This is one of the most demanding phases of the entire process because each loading operation must be carefully planned in terms of the aircraft's balance, allowable floor load, and cargo securing during the flight. Before loading, a detailed inspection of the shipment's condition is carried out, checking the state of packaging, securing devices, and support points. As the expert noted: "*The biggest challenge is not the weight itself, but the center of gravity – we must precisely plan the cargo placement to avoid disturbing the aircraft's balance. Sometimes we use roller systems*

or special ramps to load the cargo onto the aircraft'. This process involves technical teams from the air carrier, freight operator, and often independent inspectors who oversee the safety of the entire operation.

Next comes the flight execution. Although it may seem that the flight itself is the simplest stage, in reality, it requires ongoing monitoring of numerous variables. '*On paper, it looks simple – you fly from point A to point B. But along the way, the weather can change, there may be turbulence, and we have to avoid certain airspace zones. Sometimes, during the flight, we must adjust altitude or the route. We are in constant contact with the pilots and air traffic control'* the expert shared. These types of flights are often classified as special cargo operations and are carried out under strict air traffic control supervision. In emergency situations, such as deteriorating weather conditions or technical failures, procedures are in place to divert to backup airports, which must also be pre-approved.

The final stage is unloading and handover of the cargo to the recipient. This operation follows a similar procedure to loading, maintaining all safety protocols and technical checks. Once the aircraft has landed, the cargo is transferred to the designated area, where a final inspection is carried out, and the delivery documentation is signed. '*At the end, everything must match – the weight, the technical condition. Sometimes the recipient has their own inspectors overseeing the unloading. We must ensure that the cargo has arrived in an undamaged state',* the expert emphasized. Only after confirming the cargo's compliance with the documentation and its proper technical condition is it handed over to the end client or further transported by road to its destination.

The expert's statements clearly show that oversized cargo transport by air is a complex, multi-stage process requiring not only advanced technical and operational knowledge but also a high level of coordination, flexibility, and risk management skills. Each stage – from the feasibility analysis to the final unloading – presents potential challenges, and failing to anticipate them can lead to serious consequences. As the respondent concluded: '*This is not an ordinary shipment – every detail matters. Sometimes, even the smallest mistake can impact the entire operation.'*

Based on the conducted semi-structured interview with an expert from the aviation industry, it was possible to reconstruct in detail the stages and activities involved in organizing the transport of oversized cargo by air. This information has been visualized in a diagram (Fig. 2), which depicts the six main stages of the process, and the key actions carried out within them.

The primary objective of this research was to identify the key stages involved in the air transport of oversized cargo, as well as to highlight potential risks associated with each stage. The diagram developed in this study serves as an illustrative tool to present these key stages, offering a clear overview of the various tasks and processes involved in the transport of oversized cargo.

Insights gained from the expert interview further contributed to identifying critical stages in the process. The expert's extensive experience provided valuable perspectives on the operations and challenges involved, allowing for a deeper understanding of the intricacies of each stage in oversized cargo transport. This information was essential for recognizing where potential hazards may arise, even if they are not immediately apparent during the process.

Additionally, Table 3 presents a summary of the potential hazards associated with each identified stage. Alongside these hazards, recommended preventive measures and corrective actions are outlined. These recommendations aim to mitigate the impact of such challenges, offering practical solutions for optimizing operations and ensuring the safe and efficient transport of oversize cargo.

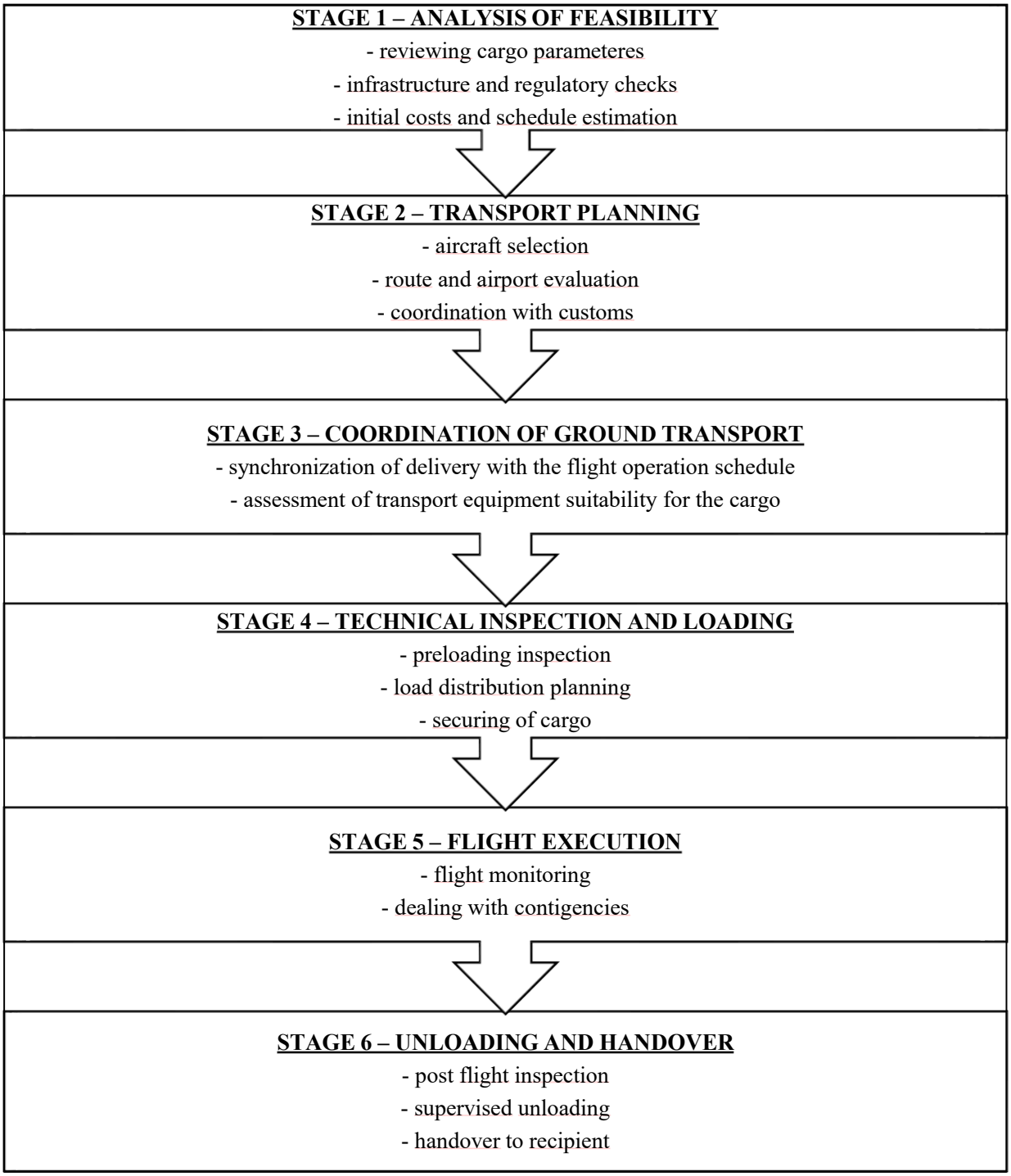

Fig. 2. Stages of oversized cargo transport by air
Source: own work

Tab. 3
Potential hazards, recommendations, and preventive actions in oversize cargo transport by air
Source: own work

Process stage	Potential hazard	Recommendations/preventive actions
Analysis of feasibility	- Non-compliance with international regulations (ICAO, IATA) - Incorrect assessment of infrastructure capabilities	- Early involvement of technical and legal experts - Consultations with airport authorities and customs services
Transport planning	- Incorrect selection of the aircraft - Insufficient runway length or weight limitations	- Use of specialized tools for load and route simulation - Verification of infrastructure requirements for each airport along the route
Coordination of ground transport	- Delivery delays - Lack of coordination between the air operator and the ground carrier	- Early synchronization of schedules - Constant operational communication and escalation mechanisms in case of delays
Technical inspection and loading	- Disruption of the aircraft's center of gravity - Damage during loading	- Preparation of a detailed cargo placement plan - Use of certified loading equipment and supervision by independent inspectors
Flight execution	- Changing weather conditions - Unforeseen airspace restrictions	- Preparation of alternative emergency airports - Ongoing analysis of weather conditions and flight plans
Unloading and handover	- Incorrect unpacking or damage to the cargo - Incomplete documentation	- Involvement of recipient's technicians in the unloading process - Double-checking of documents and final cargo quality inspection

The conducted analysis enabled the identification of the main threats associated with organizing oversized cargo transport by air. The risks outlined in Table 3 highlight the complexity and multi-stage nature of the process, emphasizing the critical need for careful planning, coordination, and technical supervision. The compiled findings provide a practical framework for improving the efficiency and operational safety of air transport operations involving non-standard cargo, supporting both strategic planning and real-time decision-making in complex logistics environments.

5. CONCLUSIONS

This paper has thoroughly examined the formal and legal framework surrounding oversize cargo air transport, emphasizing the applicable legal acts and the available means of transport. The analysis reveals the complexity of managing oversized cargo transport, with an emphasis on the intricate balance between legal compliance, operational logistics, and the selection of appropriate transport means.

The study identified the key stages of the transport process and the hazards associated with each stage, highlighting the critical importance of coordination between various stakeholders, including cargo shippers, logistics operators, airport authorities, and customs. The identified possible hazards – ranging from regulatory compliance issues to the physical and logistical challenges of handling oversized cargo – underscore the need for meticulous planning and risk management strategies. In particular, the complexities introduced by legal regulations and infrastructure constraints must be addressed to avoid operational disruptions.

Furthermore, the article proposes practical recommendations for mitigating the identified risks. These recommendations include adopting preventive measures such as early-stage regulatory compliance checks, ensuring compatibility between transport vehicles and cargo, and maintaining clear communication channels between all involved parties. Corrective actions for operational errors, such as delays or equipment mismatches, are also outlined, aiming to optimize the efficiency and safety of the transport process.

The findings not only provide insights into current practices but also highlight significant opportunities for future research. Specifically, the need for developing systematic risk assessment methodologies tailored to oversized cargo transport becomes evident. Such methodologies could facilitate more accurate identification and management of risks, ultimately improving operational efficiency and safety in this specialized field.

Although this study offers practical insights into the organization of oversized cargo transport by air, it is important to recognize its limitations. Relying on a single expert interview, the study introduces a level of subjectivity, and the insights derived are not fully representative of the broader industry landscape. Future research, incorporating multiple perspectives from different stakeholders within the air transport and logistics sectors, could lead to a more comprehensive and nuanced understanding of the challenges and best practices in managing oversized cargo transport by air.

In conclusion, while the regulatory and logistical complexities involved in oversized cargo air transport are significant, effective risk management strategies, supported by robust legal frameworks and operational tools, can significantly enhance the efficiency and safety of these specialized operations.

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