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APPLICATION OF ADVANCED OPTOELECTRONIC SENSORS IN ROAD TRAFFIC SAFETY ASSISTANCE SYSTEMS FOR HEAVY-DUTY VEHICLES

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Abstract – Oversized transport, involving the carriage of loads exceeding legally permissible standards, constitutes a significant organizational and operational challenge. Of key importance is not only compliance with formal requirements, but also the identification and mitigation of risks for drivers and other road users. This article presents a procedural framework designed to support carriers in the preparation and execution of such transport operations. It emphasizes that routine practices and reliance on professional experience may lead to underestimating risks, while standard preparatory procedures do not always ensure safe transport execution.

Key words – safety, electronic sensors, road traffic, transport

JEL Classification – L90, R41

INTRODUCTION

Oversized transport represents a specialized branch of road freight, encompassing the carriage of loads whose dimensions or weight exceed legally established standards. The execution of such logistics operations entails overcoming numerous organizational, technical, and formal challenges. A critical aspect remains the necessity of obtaining appropriate permits for movement on public roads, a process involving complex administrative procedures. However, even with full compliance with legal and formal requirements, the organization of oversized transport continues to generate significant risks for drivers as well as other road users.

These hazards arise, among others, from the limited maneuverability of vehicles, reduced visibility, extended braking distances, and the need to adapt road infrastructure to accommodate loads of non-standard dimensions. In practice, some carriers tend to underestimate these factors, relying on personal experience or falling into routine, which may lead to dangerous situations. Such consequences, varying in severity, are unavoidable in daily transport operations and therefore necessitate a systemic approach and the application of novel risk mitigation methods.

The objective of this study is to present a procedural framework that enables the identification of potential threats and the implementation of preventive measures aimed at enhancing transport safety. The author focuses on organizational and technical solutions that can support carriers and freight forwarding entities in the effective execution of oversized transport operations. It is emphasized that standard preparations—such as route reconnaissance or road infrastructure analysis—are not always sufficient and must be supplemented with additional safety procedures.

SYSTEM RESEARCH METHODOLOGY

The purpose of developing the methodology was to ensure the coherence and transparency of the analysis of processes related to the use of advanced optoelectronic sensors in support systems for heavy transport safety. The adopted research methodology integrated theoretical, diagnostic, and technical approaches, as well as the assessment of the practical aspects of implementing LiDAR systems in heavy-duty vehicles.

Research Assumptions

The main research objectives were formulated as follows:
- What are the key risk factors in oversize transport operations requiring technical support through sensor systems?
- To what extent can optoelectronic sensors (e.g., LiDAR TF350) contribute to reducing hazards arising from limited visibility and maneuverability of vehicles in motion?
- What technical and environmental conditions determine the operational effectiveness of these sensors in road traffic?

Stages of the Research Procedure

The research was conducted in four main stages:

Stage I – Literature and Legal Analysis

A comprehensive review of the literature and legal acts concerning the safety of oversize transport was performed, including applicable regulations (e.g., those governing pilotage procedures and the use of monitoring systems on road convoys).

Stage II – Identification of Hazards and Risk Factors

Based on the literature and expert consultations, the most frequent sources of risk were identified: human, technical, environmental, and organizational factors. A set of risk factors was compiled, followed by an indication of optimization areas with the use of optoelectronic sensor systems.

Stage III – Development of the Support System Model

At this stage, a conceptual model of the support system utilizing the LiDAR TF350 sensor was developed. The sensor's technical parameters, mounting conditions, and resistance to environmental factors were analyzed, along with its operational interactions:
- installation on the vehicle's front section,
- mounting on the telescopic mast of the pilot vehicle.

Stage IV – Analysis of Results and Implementation Conclusions

An analysis of the system's impact on convoy safety and the potential for adapting the solution under real operational conditions was conducted. The results were compared with current technical standards and transport safety procedures.

Diagram – Research Process Map (Fig. 1)

Below is a simplified schematic of the logical sequence of the research procedure:

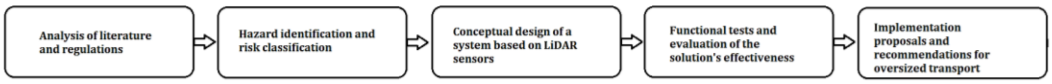

Fig. 1. Diagram – Research Process Map

Research Tools and Methods

- **Qualitative and quantitative analysis** – identification and probability assessment of risk types.
- **Comparative method** – juxtaposition of conventional and modern support systems.
- **System modelling** – creation of a transport process model incorporating LiDAR technology.
- **Expert verification** – consultations with practitioners from the transport sector and traffic safety engineers.

Expected Outcomes

The application of the above methodology enabled:
a) Systematization of risk factors in oversize transport operations.
b) Development of a logical model for integrating LiDAR sensors into heavy vehicles.
c) Identification of practical recommendations concerning the implementation of driver-assistance systems under real road conditions.

1. PREPARATORY PROCEDURES IN ROAD TRANSPORT PRIOR TO VEHICLE OPERATION ON PUBLIC ROADS

Securing Cargo in Road Transport [7, 15] constitutes one of the key elements of the logistics process, determining both the safety of carriage and the protection of the goods transported. In the case of conventional load units such as Euro pallets, a relatively simple yet effective solution involves the use of an aluminum spacer beam, commonly referred to as a stop bar. Positioned behind the last row of pallets, it effectively prevents them from shifting deeper into the trailer during maneuvers, braking, or travel over uneven road surfaces. This method is widely applied due to its ease of installation, low cost, and proven effectiveness in the transport of homogeneous cargo.

Another frequently employed solution in road transport is the use of maritime containers, which serve as universal loading units enabling the carriage of general cargo such as textiles, electronic equipment, or foodstuffs. Owing to standardized dimensions and technical parameters, containers can be seamlessly transshipped across different modes of transport—from seagoing vessels onto road semi-trailers adapted for their carriage, i.e., so-called container chassis. The container's design incorporates special corner castings located at its bottom edges, which ensure secure and stable placement on the trailer. In turn, container chassis are equipped with locking mechanisms, known as twist-locks, which, once properly engaged, immobilize the container, eliminating the risk of displacement or detachment during transport. This solution guarantees a high level of safety while simultaneously expediting loading and unloading processes.

Modern engineering solutions [16] applied in road transport encompass a broad spectrum of trailer structures and securing systems, enabling the safe carriage not only of solid or bulk cargo, but also of liquids and live animals. Each trailer type is specifically designed to match the requirements of a given cargo category-ranging from specialized tankers with anti-slosh systems, to silos for the transport of granular materials, and livestock trailers adapted for the carriage of animals under welfare-compliant conditions. As a result, the logistics process becomes not only operationally efficient, but also compliant with road traffic safety requirements and technical standards.

Within the domain of oversized transport, the selection of an appropriate transport unit [14], the proper securing of cargo, and its accurate placement on the trailer constitute a complex issue requiring in-depth analysis. Each transported object is characterized by individual parameters-such as geometric dimensions, total mass, or the specific distribution of its center of gravity-which necessitate preparatory measures executed with a high level of precision.

Upon acceptance of a client's order, the first stage of the organizational procedure involves a detailed analysis of the cargo's characteristics and the planned route of carriage-from the loading site to the final unloading point. These data are absolutely essential for the subsequent step, which is obtaining the relevant permit for oversized transport. In practice, it frequently occurs that the actual dimensions of the cargo deviate from those provided in the client's documentation. Even small components protruding beyond the main contour-such as valves, handles, latches, or installation conduits-may significantly increase the actual dimensions and alter the classification of the transport. To minimize the risk of such discrepancies, it is recommended to obtain detailed technical documentation from the client, including construction drawings and photographs depicting the cargo in its entirety.

An equally crucial element of preparation is the precise identification of the loading and unloading points. This information is of fundamental importance for assessing the feasibility of transporting the set along the designated route, particularly with respect to restrictions arising from road infrastructure, such as bridge load capacity, lane widths, or permissible clearance heights under viaducts. In the context of Category V permits, it must be emphasized that the transport route is defined in a clear and binding manner, and its unauthorized modification-especially in the form of unplanned detours-is inadmissible and may result in serious legal and organizational consequences.

In parallel with the formal procedure, the coordination of logistics activities by the freight forwarder plays a crucial role. In cases where the dimensions or mass of the cargo require support in the form of road piloting, the forwarder is obliged to arrange an appropriate escort. If the carrier does not possess the necessary resources, the task should be entrusted to a specialized subcontractor. Effective organization of piloting constitutes one of the key safety elements in oversized transport, safeguarding both the carrier and other road users.

Once the application for the relevant permit has been submitted to the competent administrative authority, the subsequent critical stage in the organizational process of oversized transport is the selection of an appropriate means of transport. For the carriage of heavy loads, it is necessary to employ a transport set equipped with a tractor unit and a multi-axle trailer. This configuration allows for even weight distribution, thereby ensuring compliance with axle load limits, which are explicitly stipulated in the issued permit. In situations involving lightweight cargo of considerable dimensions, the use of standard flatbed trailers is the more advantageous solution. This is because employing low-bed trailers in such cases increases the risk of the transported object colliding with elements of road infrastructure, such as crash barriers, traffic cones, or direction signs.

Following the compilation of the required documentation, the provision of suitable transport equipment, and the completion of a passability analysis of the designated route, the process advances to the execution stage loading the cargo at the scheduled time. Entry of the driver into the premises of the loading or production facility necessitates familiarization with the regulations applicable within that area. Such regulations typically specify detailed provisions concerning permissible speed limits [2], rules governing internal traffic organization, and designated parking areas for vehicles.

At the same time, occupational safety requirements are gaining increasing importance, covering not only the use of safety helmets and high-visibility vests, but also protective footwear, goggles, and work gloves. Failure to comply with these requirements, which may appear secondary at first glance, in practice results in refusal to perform the loading operation and removal of the driver from the facility grounds. The consequence may be the loss of a specific order, and in the case of carriers engaged in long-term cooperation, the termination of an extended contractual relationship. The timeliness of loading and unloading processes thus constitutes a fundamental component of the operational reliability of a transport enterprise.

The subsequent stage involves preparing the transport set for proper loading. In the case of self-propelled machinery, steel ramps are employed, serving as bridges between ground level and the trailer surface. The entry is executed by an operator designated by the loading facility, while the truck driver remains responsible for supervising the entire process. For structures or machinery lacking self-propulsion, lifting devices such as overhead cranes or mobile cranes are employed. In certain circumstances, the driver may be required to remain inside the vehicle cabin during the lifting and placement of the cargo. In such instances, it is essential to establish in advance, with the person responsible for signaling or attaching the cargo (the rigger), the precise location of the elements on the trailer surface. To enhance transport safety, the use of anti-slip mats is recommended; these should be placed at all contact points between the cargo and the trailer platform.

Once one or more elements have been properly positioned, the next stage is cargo securing. Numerous securing methods exist, the selection of which depends both on the specific characteristics of the cargo and the professional practice of the driver. The responsibility for carrying out this task correctly rests entirely with the driver of the transport set, who drawing on personal experience applies the means and techniques deemed most adequate and effective. The most commonly known and widely used securing devices include transport straps, tensioned chains, anti-slip mats, various types of edge protectors and corner fittings applied in cargo lashing, as well as protective nets [11].

In addition to securing devices, various auxiliary tools and elements are also employed to facilitate and support the fastening of cargo. The most widely known is the plastic cable tie, used by drivers primarily to bind excess transport straps or chains. In similar applications, grey duct tape is also frequently encountered. A practical tool often used is the nail puller (commonly known as a crowbar). Drivers employ it as a lever to achieve tighter strap tension, since muscular strength alone is not always sufficient. For attaching a protective net to the trailer, plastic ties may prove inadequate; a more reliable solution is the use of metal carabiners combined with a steel cord, which eliminates the risk of the net tearing during transport.

Once the cargo has been properly secured, preparations for departure must be undertaken. At this stage, the driver should perform the following checks:

- Installation of warning boards adjusted to the cargo width,
- Inspection of the lighting system, including the vehicle, the trailer, and the aforementioned boards,
- Verification of communication devices (in particular, ensuring the correct operation of the CB radio for contact with the pilot),
- Cargo security inspection – a responsible driver should re-confirm that the load is properly secured and that no loose objects remain on the trailer that could cause damage while driving.

After completing these straightforward procedures, the driver can be confident that no critical step has been overlooked and may proceed to introduce the transport set into public traffic. Following the first stage of travel, it is advisable to re-check the arrangement and fastening of the securing devices during a scheduled pause. Straps or chains may become loosened in transit, particularly when traveling across uneven road.

2. HAZARDS ASSOCIATED WITH OVERSIZED TRANSPORT

The rapid development of civilization, the two world wars, and the subsequent arms race fueled the growth of road transport, a trend observed since the 20th century. The expansion of new road networks and the improvement of transport means in terms of speed, mobility, and comfort are advantages appreciated by every driver spending most of their time behind the wheel. However, in introducing increasingly advanced conveniences for heavy transport, insufficient attention has often been paid to the emerging hazards.

Excessive weight, protruding elements, driver fatigue, and weather conditions there is an abundance of factors [9] influencing safety, and not all of them can be anticipated. To conduct a reliable analysis, the issue must be broken down into its causal components. The first of these, beyond human control, is nature. Weather and seasons cannot be adapted to individual preferences, but it is possible to prepare for the occurrence of nature-related hazards. The most important step in this respect is weather monitoring. While it may appear straightforward, the choice of an appropriate source is essential. Practically any mobile application provides access to short-term forecasts, which are freely available to most mobile phone users.

In addition to natural hazards, attention must also be paid to technical risks. At present, modern electronic solutions allow for quicker and earlier diagnosis of mechanical failures. This is not only safer, but also more convenient for the user. Nevertheless, new solutions inherently generate new problems.

Faulty electronic systems are frequently reported, often misleading the user, while service technicians encounter greater difficulty repairing such systems than addressing mechanical failures. Electronic malfunctions remain beyond human control; however, mechanical failures can be mitigated through regular vehicle maintenance. The most common malfunctions, along with methods to reduce their occurrence, are presented in Table 1 below.

Table 1. Most Common Failures and Preventive Measures. Author's Own Elaboration

Failure	Preventive Measure
Tire Blowout	Regular inspection of tread depth and tire pressure, adjusted relative to the load carried by the vehicle (heavier machinery requires increased pressure, whereas for lighter cargo, the values should be reduced). At the beginning of each working day, the driver should inspect the entire set and check the condition and appearance of the tires.
Damaged Suspension	Driving on deteriorated roads and unusual noises emanating from the undercarriage should be reported by the driver to the freight forwarder, who will then arrange diagnostic testing of the vehicle upon return from the route.
Brake System	Any signal from the vehicle's onboard computer indicating a malfunction of the ABS system, improper filling of the air tank, or any other brake system warning must be reported immediately. The driver must not continue the journey under such technical conditions, as in extreme cases this may result in wheel lock and ignition.

The human factor constitutes one of the fundamental elements shaping road transport safety [1-2], particularly in the context of oversized transport. Both the freight forwarder and the transport organizer must bear in mind that the driver is a human being subject to biological limitations, not a machine capable of continuous operation. Drivers experience fatigue and stress, and may also suffer from health-related issues, all of which directly affect their ability to concentrate and respond in traffic situations. From the client's perspective, timely delivery of cargo is of critical importance; however, it is the responsibility of the freight forwarder to establish transport schedules that are not only realistic but also safe, and to do so with full accountability.

The most common organizational error involves assigning drivers to mixed work patterns, requiring alternation between daytime and nighttime driving. Such practices disrupt the biological rhythm, cause sleep disturbances, and lead to chronic fatigue, which may result in decreased work efficiency and, more importantly, a heightened risk of falling asleep at the wheel and causing an accident.

Equally important is the driver's psychological well-being [10], as duties should be carried out under conditions that enable sustained concentration and the minimization of stress.

Excessive workload, generating time pressure and the necessity to perform an excessive number of tasks, leads to violations of traffic regulations, risky maneuvers, and reckless behavior.

As a consequence, such situations may escalate into serious threats to the life and health of all road users. Negligence on the part of the driver does not manifest solely in the manner of operating the vehicle; a key aspect also lies in the proper securing of the transported cargo [9, 11]. Standard authorizations such as a driving license of the appropriate category and the Driver Qualification Certificate (Code 95) do not ensure full preparedness for the carriage of oversized loads. Regular refresher training in the proper fastening and securing of cargo is indispensable, with particular emphasis on heavy, irregular, and atypical loads lacking standard securing points. Vocational training should encompass not only theoretical knowledge but also practical instruction under the supervision of experienced drivers, which in many cases proves more valuable than the qualification course itself.

Other road users also remain a significant source of risk for transport safety. These include pedestrians, who irresponsibly enter the roadway in prohibited areas, as well as drivers of passenger cars or delivery vehicles, whose careless and often unpredictable behavior causes numerous collisions and accidents. The most common causes of road incidents attributable to other drivers include: failure to yield at intersections, improper use of acceleration lanes on expressways and motorways, sudden lane changes without signaling, the mistaken belief that merely activating a turn signal confers right-of-way, or intentionally cutting off heavy vehicles in order to force them to brake. Some of these incidents arise from recklessness, while others stem from the intent to obtain undue compensation or to carry out acts of illegal "road justice." In such cases, adherence to the principle of limited trust and the promotion of a culture of safe driving are the primary recommendations.

Environmental hazards must also be taken into account. The development of road infrastructure, including the construction of new sections of motorways and expressways, often entails interference with forested areas and habitats of wild animals. Despite the application of engineering solutions such as wildlife crossings or fencing systems, the risk of animals straying onto the roadway persists. For this reason, drivers - particularly those operating heavy vehicles - should exercise caution, adjusting speed to visibility and weather conditions.

One of the most serious and persistent risk factors in transport remains driving under the influence of alcohol or intoxicating substances [10]. According to data from the Etransport portal, in 2024 the number of apprehended intoxicated drivers amounted to 92,324, while the number of accidents caused by them totaled 1,201. Although these statistics show a slight improvement compared with previous years, the issue continues to represent a serious threat to road traffic safety. In addition to routine police checks, sobriety controls are increasingly being carried out within production and logistics facilities where loading and unloading take place. Employers also play an important role, as through random checks prior to departure and observation of drivers' behavior, they can effectively eliminate individuals posing potential hazards [10].

Although driver assignments and the specific nature of work in international transport complicate such measures, a responsible company policy in this regard constitutes an essential element in enhancing safety.

In summary, the human factor in road transport encompasses psychophysical, organizational, and social dimensions. Its consideration in the planning of oversized transport operations, along with the implementation of preventive measures, not only enhances safety but also fosters the development of a transport culture grounded in responsibility and professionalism.

3. APPLICATION OF ADVANCED OPTOELECTRONIC SENSORS IN SAFETY ASSISTANCE SYSTEMS

One of the key issues determining safety in the transport of oversized cargo is the risk of damage to road infrastructure and other vehicles, which in turn poses a direct threat to the health and lives of road users. Parameters such as the length and width of the transport set are relatively easier to control through proper route organization and cooperation with escort vehicles. Escort drivers, who hold specialist qualifications in the handling of oversized transport, provide active support by maintaining appropriate distances, maneuvering, and guiding the convoy in a manner that ensures safe passage around road obstacles, narrowings, and infrastructure elements.

A far greater challenge for transport organization is posed by the height of the load. This results from the presence of numerous obstacles [12-13], such as viaducts, traction and power lines, and natural environmental elements, e.g., tree branches. Although most potential hazards may be identified during a preliminary route inspection carried out by the person responsible for preparation, there remains a risk that the measurements and observations will not reflect the actual conditions at the time of transport. Road infrastructure is subject to dynamic changes caused by atmospheric factors (wind, heavy precipitation, temperature fluctuations), mechanical damage, or natural material degradation. The collapse of structural elements onto heavy or passenger vehicles not only disrupts traffic flow but also creates a tangible risk of fatalities.

In light of these hazards, the development and implementation of innovative technical solutions enabling early detection of obstacles in the vertical route profile [4, 8] becomes fully justified. One proposed solution is the use of a detection system based on LiDAR technology [5-6], designed to alert the driver of potential collisions within sufficient time to initiate defensive action, including the safe stoppage of the transport set. Depending on convoy configuration, the measuring sensor may be installed either on the heavy vehicle itself or - allowing for greater reaction time - on the lead escort vehicle. The system design should incorporate a telescopic boom, enabling the adjustment of sensor height to the actual dimensions of the transported cargo, while maintaining the necessary safety margin.

An equally important aspect is the device's resistance to environmental factors. Uninterrupted operation is required across a wide temperature range, with complete protection against dust and water ingress, as well as resistance to prolonged exposure to precipitation. At the same time, the device must not generate secondary hazards for road traffic, particularly with regard to light beam emissions. The application of the LiDAR TF350 laser sensor appears to be an optimal solution due to its technical specifications: a detection range of 350 meters, high measurement precision (error margin of 0.1 m), and an IP67 protection rating, ensuring complete dust resistance and short-term immersion in water. An additional advantage is photobiological safety (Class 1, EN60825), which guarantees no adverse effects on human health.

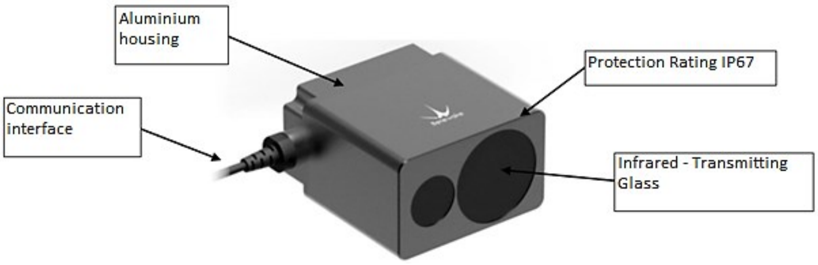

Fig. 2. External Structure of the LiDAR TF350 Laser Sensor [5]

The basic parameters of the LiDAR TF350 sensor (Fig. 2) are as follows [5]:

- Dimensions: 78 × 67 × 40 mm
- Weight: 225 g
- Supply voltage: 5–24 V
- Communication: 4–20 mA analog signal
- Operating angle: 0.5°
- Operating temperature range: −25°C to +60°C
- Storage temperature range: −40°C to +85°C

An analysis of the technical specification clearly indicates that the LiDAR TF350 meets the requirements imposed on systems supporting safety in oversized transport. Its implementation can significantly reduce the risk of collisions with road infrastructure elements and thereby contribute to improving the safety of both the transported cargo and other road users.

The project assumes the development of a durable, safe, and aerodynamic method of integrating the LiDAR TF350 sensor with the upper fairing of the tractor unit. A key requirement is the possibility of both embedded installation (Fig. 3, Fig. 4) and rapid disassembly in the case of temporary applications (Fig. 5). This is achieved through the concept of a telescopic boom with magnetic mounting. The device must retain full functionality under road operating conditions, including vibration, extreme temperatures from −30°C to +60°C, humidity, precipitation, and exposure to road salt.

For this reason, a hermetically sealed housing with an IP67 ingress protection rating was designed, complemented by optical protection in the form of a transparent polycarbonate window, as well as the incorporation of anti-vibration elements and a de-icing system. The primary installation concept assumes integration of the LiDAR within the fairing, placed in a specially prepared compartment equipped with a transparent optical window. An alternative solution involves mounting the sensor on a telescopic boom, enabling a wider field of view-an important feature for measurements requiring greater flexibility in sensor positioning. Cable routing is planned through rubber grommets into the vehicle cabin, using industrial-grade M12 connectors along with surge protection devices and EMC filters, thereby enhancing the system's resistance to electromagnetic interference.

From a mechanical perspective, installation is foreseen within a compartment of approximate dimensions 220 × 220 mm and a depth of 150–220 mm, with these values to be adjusted according to the specific fairing model (Fig. 3, Fig. 4). The optical window, manufactured from polycarbonate or PMMA with a thickness of 6–8 mm, is coated with anti-reflective and anti-fog layers, while its 5° inclination facilitates water runoff. The sensor itself is mounted on an aluminium plate with elastomer washers, reducing resonance generated during vehicle operation. Environmental protection includes a de-icing system in the form of a heating foil controlled by a thermistor and integrated into the sensor assembly. Heating power within the 10–30 W range ensures optical transparency is maintained under winter conditions. Additional provisions include drainage of the cable compartment and supplementary sealing to minimize the impact of dust and road salt.

The system is powered by the vehicle's electrical installation (12/24 V DC) via an isolated DC-DC converter adapted to the LiDAR's requirements and equipped with overcurrent protection. Communication is carried out via wired Ethernet with optional Power over Ethernet (PoE) capability. Diagnostic signals, such as overheating or sensor malfunction, may be transmitted both to the driver's cabin and to the telematics system.

The installation procedure involves preparation of the fairing (cutting and reinforcement of the compartment), installation of the mounting plate with anti-vibration washers, placement of the sensor, cable connection, and installation and sealing of the optical window. Electrical connections are secured against vibration, and all wiring is properly labelled for maintenance purposes. The final stage includes sensor calibration, communication testing, verification of the de-icing system, and road testing.

Routine system maintenance is scheduled every six months and includes inspection of seals, heater and electrical connection testing, as well as cleaning of the optics. Additionally, the system should allow for software updates both over-the-air (OTA) and manually. The entire solution complies with safety and electromagnetic compatibility requirements, while integration of the sensor into the fairing minimizes aerodynamic disturbances to the vehicle. The design also incorporates power supply redundancy to enhance the reliability of critical systems.

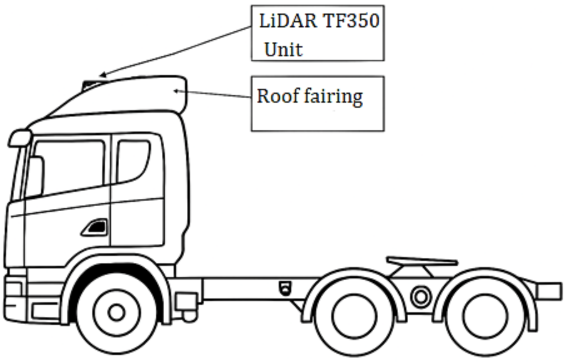

Fig. 3. Model with Sensor Integrated into the Tractor's Roof Fairing. Author's Own Elaboration

Fig. 4. Visualization of Sensor Placement within the Roof Fairing. Author's Own Elaboration

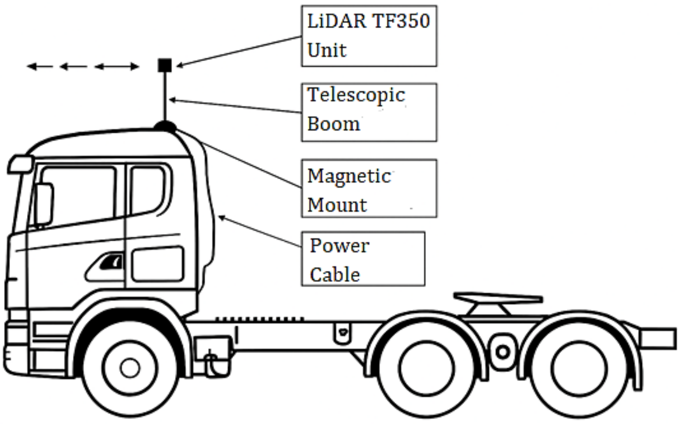

Fig. 5. Model with Sensor Mounted Using a Telescopic Boom. Author's Own Elaboration

CONCLUSIONS

The issue of road transport safety has a long history, reaching back to the very beginnings of motorization. Despite technological advances, the introduction of modern safety systems, and the tightening of regulations and sanctions, the risk of road accidents remains unavoidable. A significant proportion of incidents results from deliberate violations of applicable rules by drivers, most commonly through speeding or disregarding prohibitions and mandatory traffic regulations. It must be emphasized, however, that some accidents arise from causes beyond the driver's control, such as physical exhaustion, sudden health problems (e.g., heart attacks, epileptic seizures), or other random factors.

Oversized transport generates additional areas of risk. Professional drivers, operating under time pressure, high stress, and repetitive tasks, are more exposed to conditions conducive to hazards. Particular risks are associated with the transport of heavy, oversized, and irregularly shaped cargo, which pose a substantial danger both to the carrier and to other road users. For this reason, strict adherence to safety procedures is essential from the moment an order is accepted until the vehicle enters public traffic.

The safe execution of oversized transport requires a multifaceted approach, encompassing:

- **technical preparation** – selection of the appropriate means of transport, proper cargo distribution and securing, inspection of the vehicle's technical condition (including the drive system, tires, engine, and electrical installation);
- **human factor** – systematic training and professional development of drivers, tailoring tasks to their competencies and experience, monitoring psychophysical condition, and preventing occupational burnout;
- **compliance with legal regulations** – adherence to both road traffic rules and transport law, including route planning, permit acquisition, and proper documentation;
- **use of modern technologies** – implementation of planning, monitoring, and warning systems within the transport process;
- **coordination and cooperation** – information exchange between carriers, authorities, and road administrators, as well as the use of industry information sources, including digital tools and social media.

Oversized transport, despite its inherently high level of risk, can be executed safely provided that the process is properly planned and supervised. For experienced carriers, it represents a recurring task with varying parameters; however, its overall scale is increasing in parallel with economic growth and the demand for transport in the industrial and energy sectors. As the number of operations rises, so too does the probability of adverse events. Therefore, safety in oversized transport should remain a subject of continuous analysis and the implementation of innovative solutions, ensuring that economic development is balanced with social responsibility in protecting the life and health of road users.

ZASTOSOWANIE ZAAWANSOWANYCH CZUJNIKÓW OPTOELEKTRONICZNYCH W SYSTEMACH WSPOMAGANIA BEZPIECZEŃSTWA RUCHU DROGOWEGO POJAZDÓW CIĘŻAROWYCH

Transport ponadnormatywny stanowi wyspecjalizowaną gałąź transportu drogowego, obejmującą przewóz ładunków o wymiarach lub masie przekraczających obowiązujące normy prawne. Realizacja tego typu operacji logistycznych wiąże się z koniecznością pokonywania licznych wyzwań organizacyjnych, technicznych i formalnych. Kluczowym aspektem pozostaje konieczność uzyskania stosownych zezwoleń na poruszanie się po drogach publicznych, co wiąże się ze skomplikowaną procedurą administracyjną. Jednak nawet przy spełnieniu wymogów prawnych i formalnych, organizacja transportu ponadnormatywnego nadal generuje istotne zagrożenia dla kierowców oraz pozostałych uczestników ruchu drogowego.

Niebezpieczeństwa te wynikają m.in. z ograniczonej manewrowości pojazdów, utrudnionej widoczności, zwiększonej długości drogi hamowania czy konieczności dostosowania infrastruktury drogowej do przejazdu ładunków o niestandardowych wymiarach. W praktyce część przewoźników bagatelizuje te czynniki, opierając się na własnym doświadczeniu lub popadając w rutynę, co może prowadzić do niebezpiecznych sytuacji. Takie następstwa, choć różnego stopnia, są nieuniknione w codziennej praktyce transportowej, dlatego wymagają systemowego podejścia i zastosowania nowych metod minimalizacji ryzyka.

Celem niniejszego opracowania jest przedstawienie schematu postępowania, który pozwala na identyfikację potencjalnych zagrożeń oraz wdrożenie działań prewencyjnych mających na celu zwiększenie bezpieczeństwa przejazdu. Autor koncentruje się na wskazaniu rozwiązań organizacyjnych i technicznych, które mogą wspierać przewoźników oraz podmioty branży spedycyjnej w skutecznej realizacji przewozów ponadnormatywnych. Podkreślono przy tym, że standardowe przygotowania, takie jak objazd planowanej trasy czy analiza infrastruktury drogowej, nie zawsze są wystarczające i wymagają uzupełnienia o dodatkowe procedury bezpieczeństwa.

Słowa kluczowe: bezpieczeństwo, czujniki elektroniczne, ruch drogowy, transport.

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