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Key Problems of Restoring Damaged Critical Railway Infrastructure During Military Crisis Situations

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Abstract

This study addresses key issues related to the technical protection and restoration of critical railway infrastructure in the Czech Republic when dealing with military and non-military crisis situations. These issues can be divided into problems of organizational nature and technical problems. The study demonstrates how these key issues can be resolved and what steps are required. Ensuring the operational readiness of railway infrastructure is an integral part of successfully managing crisis situations and securing military transport, as well as transport for the national economy and the population.

KEY WORDS: *Temporary bridge; crisis situation; recovery of transport infrastructure; critical infrastructure*

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1. Introduction

The growing prevalence and impact of security threats, both military and non-military in nature, underscore the need to build society's physical, social, economic, and environmental resilience. Disruption of transport infrastructure resulting from activated threats can have a long-term negative impact on the functioning of society (ensuring the mobility of the population, the smooth operation of supply chains, the state's defense capabilities, and the fulfillment of international commitments regarding mobility across the territory of the Czech Republic). Ensuring comprehensive protection of railway infrastructure against all threats is not economically, personnel-wise, or technically feasible, therefore, attention is focused primarily on protecting critical railway infrastructure elements that handle the largest volumes of transport and are of international significance. For that reason, attention must be paid to the system's capacity for rapid railway infrastructure restoration. Current challenges in railway infrastructure restoration primarily lie in establishing a new system for the protection and restoration of railway infrastructure and resolving issues regarding the usability of temporary railway bridges for medium and large spans. Resolving these issues will contribute to the ability to recover quickly from impacts by establishing missing restoration requirements, increasing the resilience and robustness of railway infrastructure, and limiting the socioeconomic impacts resulting from its disruption. These key issues, once resolved, will help ensure long-term crisis and defense planning for the restoration of railway infrastructure in the event of military and non-military crises, as well as the design of an educational system to prepare students for future careers in the transportation sector and provide ongoing professional development [1,2].

Railway infrastructure is a critical component of the Czech Republic's national economy. Its functionality is essential for ensuring national defense, crisis management, and the daily lives of the population. The current system for restoring railway infrastructure in the Czech Republic is inadequate and does not allow for a rapid response to crisis situations. Therefore, given the current security situation in Europe, it is necessary to give this issue the attention it deserves and not to underestimate the situation. It is necessary to develop new technical, organizational, personnel, and economic measures to ensure the protection and rapid restoration of damaged railway infrastructure. These measures are essential for restoring infrastructure operations within a matter of days to a few weeks. The current reactive system is capable of ensuring restoration within months, which is at odds with the requirements for a resilient and safe society. Resolving these key issues will contribute to increasing of the Czech Republic's resilience to the impacts of crisis situations. The Czech Republic is crisscrossed by infrastructure networks, including its transport network, particularly its road and rail networks. Transport is essential for all sectors of the national economy and is classified as critical infrastructure. With the adoption of the new

Directive (EU) 2022/2557 on the resilience of critical entities, pressure will increase to ensure the uninterrupted provision of services that are essential for the economy and society as a whole. At the same time, critical entities will need to strengthen their resilience to ensure the continuity of their services [3,4].

Transportation is a critical sector for national security. Without it, it would be impossible to transport emergency response forces and equipment to the scene of an incident, fulfill defense missions during military conflicts, or ensure the viability of regions. Therefore, every country's transportation system must be designed so that all modes of transport are fully prepared to carry out emergency missions. Undoubtedly, a key challenge is ensuring the operation and passability of the transport network under all types of events, which is one of the fundamental prerequisites for successfully managing crisis situations. This issue is also addressed by EU Directive 2016/797 on the interoperability of the railway system in the EU, which also addresses the continuity of operations even in the event of a disruption. Despite this, the railway infrastructure recovery system is currently non-functional, lacking systematic strategic planning for response and recovery, as well as interoperability among the responsible entities [5].

There is no system of effectively functioning coordination mechanisms guaranteed by experts with the relevant expertise in the individual ministries. It is necessary to create an effectively functioning system that will ensure the ability to restore the railway network within days, or at most within a few weeks. This is in contrast to the current situation, where, according to experts, restoration capabilities are measured in many months. The seriousness of this situation is underscored by the fact that the Czech Republic is not realistically capable of ensuring allied transport and guaranteeing the operability of the railway network within days. For many years, rapid restoration has essentially been impossible to guarantee in terms of time. Personal interviews indicate that representatives of the General Staff of the Czech Armed Forces are aware of the seriousness of the problem. The course of the military conflict in Ukraine has shown that the railway constitutes a vital transport infrastructure that cannot be dispensed with. The Czech Republic must once again devote the necessary attention to this issue and develop it further. Otherwise, basic transportation functions will not be ensured at all times and in all situations, which runs counter to the goal of building a resilient and safe society, as outlined in the Czech Republic's strategic documents. This problem can be addressed by designing a functional system for the protection and restoration of critical railway infrastructure. This approach can be used to address all crisis situations, with certain variations in terms of management and cooperation. Ensuring the functionality of the national economy, which is dependent on transport systems, the defense capabilities of the Czech Republic, and meeting the needs of the population must be a key priority and not only at this time [6–9].

This is critical national infrastructure, and its protection and restoration in crisis situations must be approached with due respect and the support of society as a whole. There are essentially two existing approaches to restoring railway infrastructure. The currently prevailing passive/reactive approach, where the resumption of operations cannot be guaranteed within a specific timeframe and is expected to take months. The second option is to have a system and capabilities for rapid restoration and to carry it out within days or, at most, a few weeks, which requires a shift in approach toward realistic capabilities based on adequate resources, personnel, means, and a management system, that is a proactive system based on building crisis preparedness. This shall ensure that, following rapid recovery, a transition can be made to permanent recovery, carried out using conventional methods permitted by the prevailing situation.

When large railway bridges are destroyed, a problem with their restoration using temporary bridge structures arises, because it is no longer possible to restore all types of bridges using the temporary structures. This applies in particular to the temporary bridge structure ŽM16, which can be used to restore both large railway bridges and road bridges. But this temporary structure is not adapted to the requirements of current transport construction or the demands of the traffic throughput. We believe that these shortcomings can be eliminated by defining the current requirements for modifying the ŽM16 temporary bridge structure and assessing how the structure can be modernized so that it meets the present-day requirements for the restoration of critical infrastructure. It is therefore necessary to address the issue of rapid restoration of destroyed railway bridges in crisis situations, which entails technical, material, personnel, organizational and financial measures so that the requirements for traffic throughput in military crisis situations are met, including ensuring allied transport not only through the territory of the Czech Republic [10–13].

The aim of this article is to highlight the major challenges involved in ensuring the protection and restoration of critical railway infrastructure during military and non-military crisis situations, namely a dysfunctional system and technical difficulties associated with the use of temporary bridge structures for the restoration of medium-sized and large bridges.

2. Method of Investigation

Interviews conducted with experts at Správa železnic, s.o., particularly those with a military background who had previously worked on railway protection and restoration and served in the Railway Corps (dissolved by the Czech Armed Forces at the end of 1993) and its successor organization Stavební obnova železnic (dissolved without replacement in 2018), the issues outlined in this article were confirmed. The development of the situation, including potential impacts and concerns regarding the dissolution of Railway Construction and Restoration and the subsequent collapse of the system, was described even before the dissolution in the Ministry of Defense of the Czech Republic's journal Vojenské rozhledy (Military Review). The texts are cited in the references [6–9].

The key points can be summarized as follows:

1) The most pressing problem is the creation of a new and functional system for the protection and restoration of railways (critical railway infrastructure) during crisis situations.

2) Resolving the technical issues related to the use of the ŽM 16 temporary bridge system for the restoration of medium-size and large bridges. This is a demountable structure with standardized interchangeable parts that can be easily assembled according to relevant requirements and parameters, with a single-span length of up to 102 metres, which this structure allows.

3. Expected Phases of Developing a New Protection and Recovery System

Phase I. Identification, analysis, and assessment of risks of the capabilities, interdependencies, resources, and management system for the protection and recovery of the railway network in military crisis situations

1) Systematic assessment of threats and vulnerabilities in the railway infrastructure from the perspective of forces, interdependences, resources, and the management system ensuring the protection and restoration of railways in situations related to military conflict, armed attack, or hybrid threats [14].

2) Analysis of the capabilities and capacities of entities responsible for protection and restoration (e.g., Správa železnic (Railway Administration), Ministry of Defense / Czech Armed Forces, Ministry of Transport, Spárva státních hmotných rezerv (Administration of State Material Reserves)), assessment of the interdependence between individual entities and protection and restoration resources (e.g., availability of specialized equipment, logistical capabilities, communication channels).

3) Assessment and prioritization of risks to forces, interdependencies, resources, and the management system for protection and restoration during military crisis situations.

Phase II. Identification, analysis, and assessment of risks to the capabilities, interdependencies, resources, and management system for the protection and restoration of the railway network in non-military crisis situations

1) Assessment of crisis preparedness (documentation, crisis measures, cooperation, responsibilities, management system, and communication during crisis management) of key entities operating and using the railway infrastructure (e.g., Railway Administration, Ministry of Transport, core Integrated Rescue System units, Administration of State Material Reserves) with regard to the functionality of the railway protection and restoration system in the event of non-military threats - identification of risk areas [15,16].

2) Analysis, evaluation, and prioritization of risks to forces, interdependences, resources, and the management system for the protection and restoration of the railway network during non-military crisis situations.

Phase III. Synthesis of the results of the identification, analysis, and assessment of risks to forces, interdependencies, resources, and the management system for the protection and restoration of the railway network in crisis situations:

1) Identification and evaluation of common and distinct features of technical, personnel, and organizational preparedness for the protection and restoration of the railway network during military and non-military crisis situations.

2) Synthesis of relationships, competencies, and responsibilities among entities in addressing military and non-military crisis situations.

3) Interoperability of entities in the protection and restoration of railway infrastructure.

Phase IV. Proposal for technical, personnel, economic, and organizational measures to protect and restore the railway network in crisis situations:

1) Proposal for technical measures (technologies for on-site detection and repair of damaged sections of the railway network, ensuring transport safety).

2) Proposal for personnel measures (determining the number and qualifications of personnel required for the protection and restoration of railway infrastructure, proposal for the content of ongoing staff training, planning of workforce capacity and backup teams to ensure continuity of work during restoration).

3) Proposal for economic measures (cost estimates for establishing a railway protection and restoration system and maintaining the system’s functionality).

4) Proposal for organizational measures (requirements for planning documentation, establishing decision-making processes, response times, planning and availability of reserve capacities, communication procedures between entities). Proposed measures for entities will be developed as alternative options, each of which will contribute to strengthening the resilience of the railway infrastructure with an emphasis on securing civilian and military transport needs within the territory of the Czech Republic during the activation of crisis situations.

Phase V. Proposal for technical, personnel, economic, and organizational measures to protect and restore the railway network in crisis situations.

4. Modernization of a Key Temporary Bridge Structure

Analytical methods focus on defining the modernization of the ŽM16 temporary bridge structure, which currently constitutes crucial material resources for the restoration of large railway bridges in crisis situations. The temporary bridge structure can be used for road and rail transport, but currently has many technical limitations in the restoration of critical infrastructure. These limitations are linked to the time of its creation in the 1960s [10–13].

Fig. 1. The ŽM 16 bridge structure at the training base of the Ministry of Transport of the Czech Republic

For the Czech Republic, it is crucial to address the modernization of the temporary railway bridge ŽM16, which due to its quantity constitutes a significant portion of the state reserves held by the Administration of State Material Reserves (SSHR). The temporary bridge is well-suited not only for rail transport but also for road transport. Currently, however, it has limitations due to the era in which this temporary bridge was created. The modernization of the ŽM16 bridge structure is important for the Czech transport infrastructure, because it will contribute to increasing not only the resilience of critical infrastructure but also the Czech Republic's defense capabilities in crisis situations of a military nature, as well as in crisis situations of a non-military nature. In the event of targeted destruction of bridge structures, it is important to restore the transport network and make it passable using all available means, particularly temporary bridge structures [10,13].

Given the current limitations of the ŽM16 structure, it is necessary to define the boundary conditions for both the existing and the modernized structure. Based on our expert assessment, it is necessary to address the following key requirements for the modernization of this structure so that it meets 21st-century standards for use in both military and non-military emergency situations [7,10–13].

1) A new fatigue-resistant crossbeam and related deck sections must be designed for the road version of the bridge, enabling traffic on the bridge in two full-width lanes.

2) It is also important to design structural elements and modifications for the implementation of the ŽM16 structure as a continuous girder with at least two spans, as most current bridge structures are built as continuous girders with narrower piers, which do not allow for the incorporation of this structure as a simply supported girder, since a temporary pier made of PIŽMO would need to be constructed next to the existing pier.

3) An important part of the modernization is also to design support elements for the overhead contact line, because there is currently insufficient backup for diesel traction as in the past, and it is necessary to plan for electric traction and the use of a large number of electric locomotives during the infrastructure renewal.

4) It is also necessary to analyze, from the perspective of fatigue life, the potential reinforcement of welds using new HFMI (High Frequency Mechanical Impact) technologies).

5) Last but not least, these new findings must be incorporated into the methodological and technological procedures for the construction of temporary bridges. As part of the modernization of structural design solutions, it is necessary to utilize theoretical knowledge of the behavior of steel bridge structures under load (FEM models), experimental tools consisting primarily of strain gauge measurements of stress on real structures in situ, the use of the MMM (Metal Magnetic Memory) testing method, and experimental dynamic loading of structural details in laboratories (fatigue tests). During the modernization, emphasis must be placed on the use of new technologies to improve strength and fatigue characteristics, including the use of higher-strength steels such as STRENX/S690Q and the use of so-called "hammering" of welds using the HFMI method [7,8,10,13].

The goal of the ŽM 16 temporary bridge modernization project is to enhance its performance characteristics, which plays a crucial role in protecting and restoring critical infrastructure and quickly restoring traffic in damaged sections. Improving the performance of ŽM16 as part of the modernization will help ensure the continuity of the transportation infrastructure (in the event of damage to or destruction of a key bridge), enable the rapid restoration of traffic, ensure connections between settlements and industrial zones, and provide access to critical infrastructure (e.g., hospitals, power plants).

In crisis situations, this modernization will enable emergency services (firefighters, medical personnel, police, and the military) to reach disaster areas more quickly, ensuring the evacuation of people or the delivery of supplies in the event of a collapse of standard transportation infrastructure.

Reducing the downtime of critical transport network connections during the repair or construction of a new permanent bridge shortens the period during which the road is out of service and minimizes economic and safety impacts. Increasing the resilience and flexibility of the transport network enhances the transport infrastructure's resilience to sudden outages or attacks. State agencies or the Czech Armed Forces can prepare deployment scenarios in advance (as part of crisis planning and critical infrastructure protection), and supplement crisis plans (NATO, EU) with these temporary bridge structures to improve defense planning, e.g., within the framework of Host Nation Support or EU/NATO civil protection; rapid network restoration is fundamentally anticipated in the event of a military conflict.

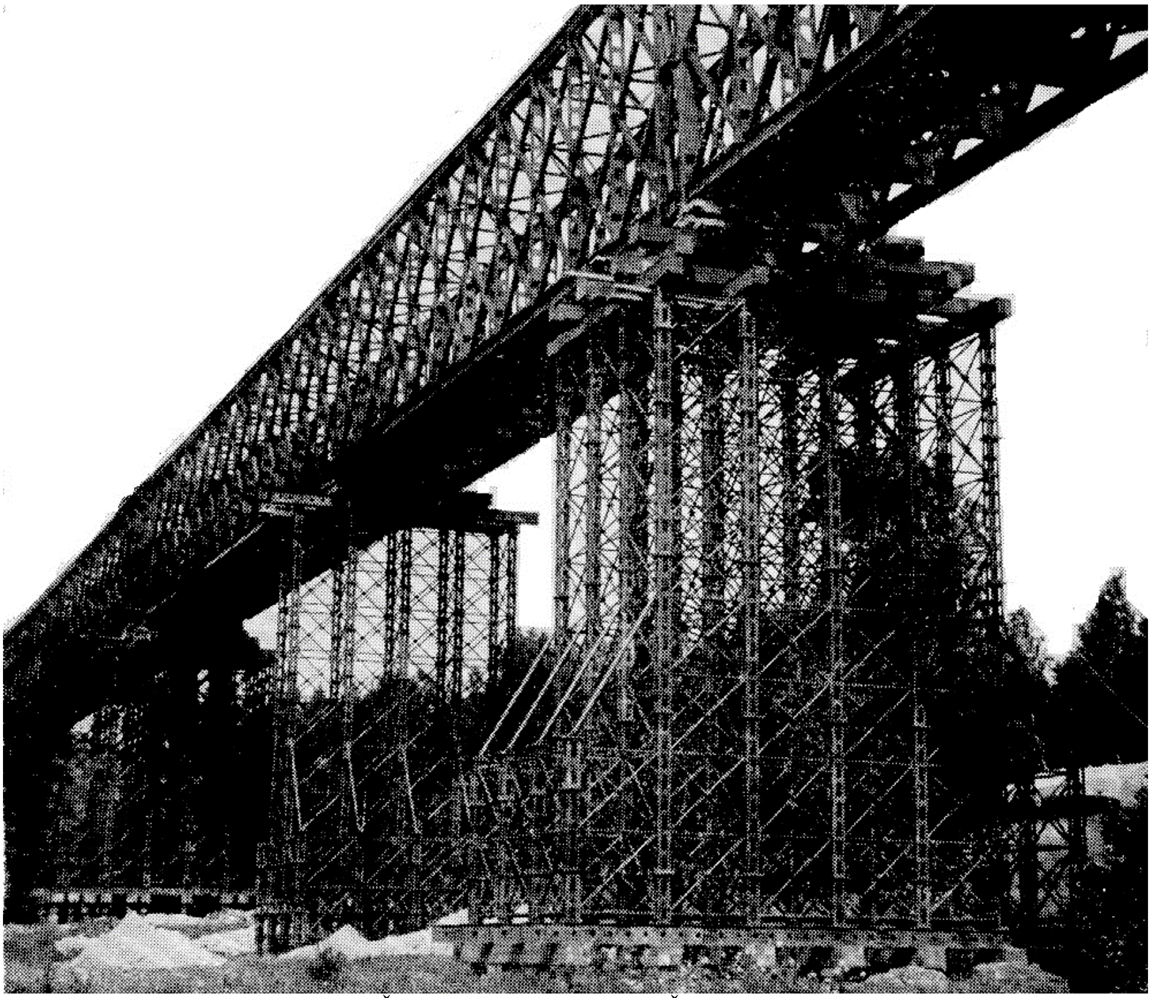

Fig. 2. Temporary bridge structure ŽM 16 supported by the PIŽMO pier

Problem-Solving Phases. The objective is to enhance the functional properties of the ŽM16 temporary bridge to safeguard critical transportation infrastructure during crisis situations. This process can be structured into several logically sequential phases that enable the achievement of the expected objectives in an effective and measurable manner [10–13].

Phase 1 - Analysis of the current state and project preparation, which requires conducting a situational analysis, i.e., mapping the current condition of structures used in practice and updating available legislation (standards, drawings), and creating digital drawing documentation: technical inspection of the ŽM16 components in use, their condition, and the impact of degradation factors (bridge deck, main girders, fasteners, etc.); creation of digital documentation (creation of 2D drawings of components); creation of FEM models of the existing structure, evaluation of limit states; analysis of material wear and corrosion (identification of problem areas, including fatigue risks); analysis of existing regulations related to temporary bridges, comparison with current requirements (applicable standards and regulations, technical data sheets, etc.).

Phase 2 – Modernization design. This key phase involves structural modifications, material innovations, and technological improvements, including: fatigue analysis based on theoretical calculations and experimental measurements;, design and manufacture of new ŽM16 components (preparation of manufacturing documentation, purchase of test lab samples, purchase of new bridge components); creation of FEM models of the new modified structure, evaluation of limit states (analysis of proposed modifications); production of results (utility and industrial design, functional samples), application of new technological processes and new diagnostic methods (HFMI, MMM).

Phase 3 - Design verification, final evaluation, and documentation The final phase will focus on verifying the results and activities achieved in the project, preparing documentation, and proposing amendments to relevant regulations and standards: assembly of the new, modernized ŽM16 at the Kojetín training center, verification of properties through experimentation, final calculations and assessments (impact of HFMI, FEM fatigue calculations), preparation of proposed amendments to regulations (assembly proposal, proposed changes to regulations related to ŽM16).

Limitations. The current system for the protection and restoration of railway infrastructure is based on general principles used in crisis management and the requisitioning of material resources as a part of economic measures for crisis situations. The system is currently characterized by a high degree of uncertainty, significant delays, and lengthy restoration periods for railway infrastructure, which exacerbates the impacts of the crisis. The responsible authorities are not devoting adequate, coordinated attention to remedying this situation; therefore, the current level of progress is at zero, or partially at the first stage of progress [3,4,11,12,15,16].

The modernization of this temporary bridge structure is the only economic and realistic solution for the restoration of large bridge structures in the Czech Republic. Given the possibilities of the Czech Republic, the development and production of a new temporary bridge structure is unrealistic both in terms of time and money.

5. Conclusions

Currently, there is no comprehensive, systematic, and coordinated system for the protection and restoration of critical railway infrastructure in crisis situations; therefore, it is necessary to develop a new approach to railway protection and restoration that is appropriate for the present day. There are only partial fragments of solutions among the interested entities. The current approach to ensuring the functionality of critical railway infrastructure is based on essential supplies, which are governed by specific rules - the most important rule being that securing essential supplies during crisis situations is carried out, to the greatest extent possible, in the usual manner for periods outside of crisis situations, i.e., ensuring it through normal commercial supplier-customer relationship, which is a prerequisite for a functioning national economy. This assertion is further supported by the fact that no time standards have been established for the restoration of railways in crisis situations. This fundamentally limits the speed of restoration. The real-world consequence in crisis situations is the impassability of key railway lines for a period of 4 to 6 months, which is unacceptable for the recovery of the territory and the security of the Czech Republic. Consequently, we cannot guarantee NATO allied transport through the territory of the Czech Republic, to which we are bound. It is fortunate that the current system’s ineffectiveness has not been put to the test by a large-scale emergency that would have exposed its dismal state.

The Ministry of Defense/Czech Armed Forces has not explicitly committed to prioritizing rail transport, although certain small steps toward greater use of the railways, as was the case in the past, are beginning to emerge. There is no doubt that ensuring the operational readiness of rail transport in every situation will contribute to fulfilling alliance commitments. Currently, the Czech Armed Forces are concerned only with the protection and restoration of military sidings, which represent only a marginal part of the system; without the functionality of key railway infrastructure, these sidings will be unusable and will not fulfill their purpose. Therefore, it is necessary to change the perspective on the problem and address it more comprehensively. From the state’s perspective within the crisis management system, this shortcoming must be eliminated and the problem resolved. The set goals are ambitious, but their benefits will create a new, comprehensive, multidisciplinary, and proactive approach to the protection and restoration of railway infrastructure by linking individual ministries and organizations, establishing technical and personnel parameters for restoration, and proposing adjustments to procedures, including the estimated economic costs associated with setting up the system.

It is necessary to establish a practical system that guarantees the rapid restoration of railways in crisis situations, is capable of responding to a changing security environment and the resulting threats, and ensures critical transport for the national economy, the armed forces, and the population, even in light of transport restrictions and priorities. Implementing this will resolve a long-standing problem. The proposals contribute to strengthening resilience and security, the ability to respond quickly and in a coordinated manner to prepare for and address impacts on railway infrastructure, i.e. strengthening crisis management in the transport sector, and to strategically enhance resource planning for the restoration of railway infrastructure. [1–5,15,16]

The state material reserves concerning the restoration of critical railway infrastructure contain several hundred meters of the ŽM16 temporary bridge structure. The State Material Reserves Administration stores this key material for the Czech Republic. The modernization of the ŽM16 temporary bridge structure is therefore important, because it will contribute to increasing not only the resilience of critical infrastructure, but also to the defence capability of the Czech Republic in crisis situations of military nature, as well as crisis situations of non-military nature.

The novelty of this solution lies primarily in the modernization of the ŽM16 bridge structure, which currently cannot be used as a continuous girder; in its road version, it cannot be used as a two-lane bridge; it is not possible to install overhead catenary wires in the structure using standard methods; and no calculations have been performed for the currently required operational loads. In practical terms, this means that the structure of which the Czech Republic has a large number in its state reserves is difficult to use in crisis situations. It thus prevents the rapid restoration of impassable routes within days or a few weeks, which is unacceptable for the Czech Republic. Consequently, we cannot guarantee the transportation needs of the national economy and the population, nor can we ensure NATO allied transport across the territory of the Czech Republic, to which we are bound. The shortage of two-lane temporary road bridges is a well-known fact, and even the Road and Motorway Directorate purchases overly expensive structures abroad that fall far short of the performance parameters achievable by the ŽM16 design.

The modernization proposal is the only reasonable economic option for addressing the problem. Developing an entirely new design and manufacturing it is essentially unfeasible under Czech conditions. We can no longer assume, as we have in the past, that a ready-made, functional system ensuring the operation of critical infrastructure costs nothing and will never cost anything. Given the amounts allocated to security, this will certainly not be a staggering sum, and it represents a very rational approach that the Czech Republic urgently needs. The purpose of the proposal is to contribute, within the Czech Republic, to a truly functional system guaranteeing the rapid restoration of large bridge structures, which are a key element in the restoration of land transport infrastructure, particularly railways and roads, during crisis situations. From the state's perspective, this shortcoming must be eliminated and this problem resolved within the crisis management system. Crisis situations cannot be successfully managed without land-based modes of transport, which is currently a widely accepted fact among experts in crisis management and safety.

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