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Road Overbridges of Car Lift Type for Crossing Railway Tracks in Densely Built-Up Areas of Modern Cities



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ABSTRACT

The theoretical prerequisites for construction of road overbridges of car lift type for crossing railways by automotive vehicles are suggested. A technical solution has been proposed that makes it possible to ensure the crossing by cars of «problem» railway crossings during periods of their long-term closure for road traffic. The same solution can be used to organise a road overbridge in other locations where there is no railway crossing. The technical solution itself is based on the use of overhead road overpasses and is a «simplified» version of the solution implemented by Elon Musk and his company in Los Angeles based on a tunnel, moving platforms and freight elevators. For development of car lift type road overbridges, computational methods of theoretical mechanics, technical diagnostics and monitoring, as well as the theory of queuing should be used to estimate the number of cars passed through it when crossings are closed. It is proposed that the structures of the overbridge should be «built-in» into the landscape, equipped with alternative sources of energy supply and technical means of control, diagnostics and monitoring of rolling stock and of location of direct intersection of automobile and railway roads (an intelligent monitoring zone). The proposed promising technical solution in the form of a road overbridge makes it possible to increase comfort of road transportation and improve traffic safety at level crossings.

Keywords: *transport, level crossing, traffic safety, car lift type road overbridge, traffic optimisation, information services at level crossings.*

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Background. Points of intersection of highways and railways at the same level, or level crossings [1], according to statistics, are the most frequent places of occurrence of violations in operation of the railway transport system. These data are relevant for the whole world, and not only for a single country or region [2; 3]. In Great Britain alone, on an area of 243 809 km^2, there are about 6 thousand level crossings (approximately a level crossing per 40 km^2) [4], and in the EU countries there are over 100 thousand level crossings [3], of which about 49 % are unguarded. Level crossings are places of increased safety risk for both road and rail users.

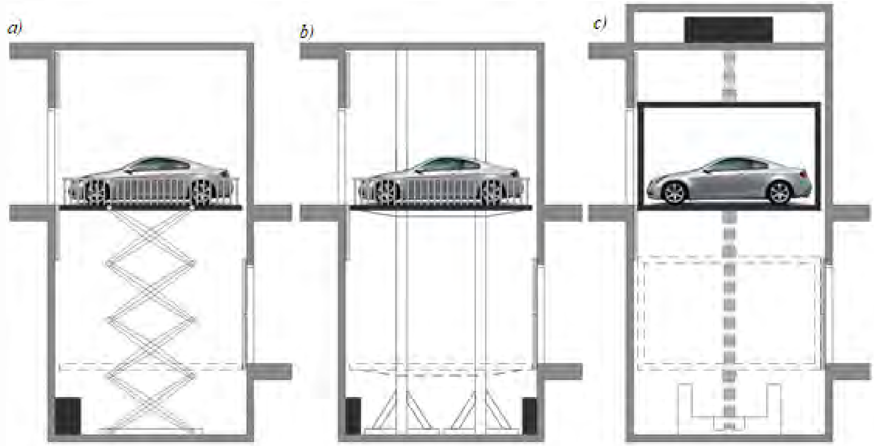
The causes of violations at level crossings are extremely varied, but they can all be reduced to errors in operation of the man-machine system: actions of drivers of road vehicles can be provoked by the incorrectly understood actions of railway transport while the drivers are in the waiting mode for permission to pass through the level crossing, and that is the cause of violations of traffic rules by them. At this point, they become sources of dangerous impact for the railway system.

Violations often occur due to the fact that the crossing is closed for movement of vehicles in advance and also does not open immediately. At the same time, depending on the category of the railway line, track development and the maximum permissible speeds of train movement, waiting time can vary significantly. Crossings can often be located in areas of existing urban infrastructure and cause significant interruptions in traffic. For example, a crossing on St. Petersburg–Moscow line, where high-speed Sapsan trains run, in Kolpino (St. Petersburg) is notorious, as it closes 20 minutes before the train enters the crossing and opens only 20 minutes after it passes. If we consider that the consecutive two train schedule is set for Sapsan trains, the breaks for following the crossing become close to half an hour [5]. Once in a traffic jam, the driver becomes a hostage of the situation and is forced to waste time, as well as to lose the stability of the psychological state, which undoubtedly has an impact on the transport system.

For areas of interaction between road and railway transport, like those described in the example, construction of multi-level interchanges is the best solution from the standpoint of both reliability, safety, and speed of passage. However, this solution has two significant, even deterministic, disadvantages. The first one is associated with economic aspects and high costs of construction of multi-level interchanges. The second one is associated with the peculiarities of urban planning and with the fact that in a number of areas with an established infrastructure, sometimes construction of multi-level interchanges becomes inappropriate from the purely technical point of view. It should be noted that according to [3], the main directions of development in the field of traffic safety at level crossings are focused on increasing the number of technical means of automation of level crossing control, however, the potential of modern information systems has been somehow overlooked [6–8].

One of the solutions to optimise traffic at level crossings is integration of data from railway systems for organising and controlling traffic, as well as from means automation and telemechanics into mobile navigation systems and building routes for road traffic, considering the predicted closing and opening times of crossings [9; 10]. If it is impossible to obtain data from the railway transport system, then there is an option for implementing a forecasting system with its own sensors installed near the crossing. Such a solution allows to provide traffic participants, both motor transport drivers and locomotive drivers, with a forecast of the situation at the crossing and with a forecast of size of traffic and with information on the traffic itself in the area of intersection of the road and the railway. This forecast by itself is the most valuable information for ensuring traffic safety: the number of accidents and crashes is guaranteed to decrease, as road users will receive information «about the near future» and will choose acceptable actions.

Another promising option for organizing traffic at level crossings is the use of specialized freight elevators and road overbridges designed for the motor vehicles could cross the intersection of the road and railways. Such car lift type road overbridges can be installed not only in the immediate vicinity of the crossings, but also be built in the existing urban infrastructure environment, considering the most intense traffic areas. The car driver will have a choice to use this transport infrastructure object (similar to an alternative that he has in large cities: to travel by free either by toll roads). When developing a design, it is necessary to consider the methods of theoretical mechanics



Pic. 1. Variant of lifting devices: a) scissor car lift; b) column car lift; c) car lift [compiled by the authors].

to choose engine power for lifting cars to a certain height, as well as methods of the theory of queuing to estimate the number of cars that will use that opportunity when the level crossings is closed. This, however, will require simulating operation of the overbridge for various road scenarios.

This innovative solution requires further study and analysis.

The *objective* of the study described in the article is to examine the features of arrangement of road overbridges, considering implied innovations and the prospects for their mass implementation. The study has used the *methods* of theoretical mechanics, technical diagnostics, and monitoring, as well as the theory of queuing to estimate the number of cars served when level crossing is closed. The study has resulted in development of an innovative solution for railway crossings, based on the use of car lift type road overbridges.

It should be noted that such a solution can be considered as the analogue of the invention of The Boring Company by Elon Musk, implemented in Los Angeles, where freight elevators are also used, but to deliver cars underground to special moving platforms, and further movement is carried out through a tunnel [11; 12]. This solution, however, turns out to be quite expensive, in contrast to the one proposed by the authors.

Road overbridges

A car lift type road overbridge might be a special design that combines an overhead overpass and structures for vertical ascent to it at both ends using a freight elevator.

The construction of the presented structure does not require changes in development in the area of intersection of the road and railway, as well as construction of approaches, which is extremely important in the conditions of the existing development and does not affect the architectural appearance of the city.

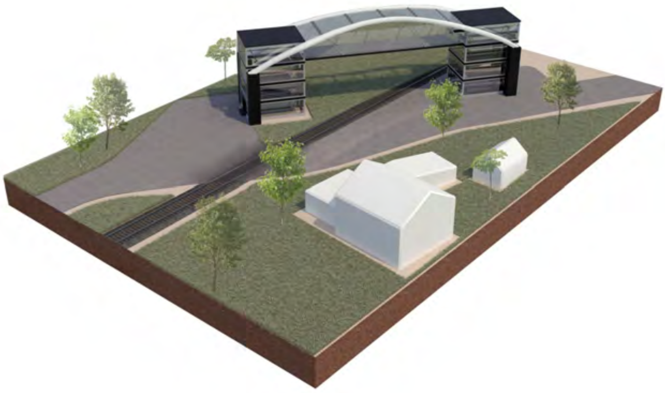
It is possible to use special lifts or elevators, which are widely used in major cities around the world as devices for delivering a car to the overbridge. In many cities, the lack of free space is increasingly felt, and placing cars underground with the help of a lifting mechanism does not disturb the surrounding architecture. Car lifts are also used in shopping centres with rooftop parking, and in residential buildings with parking lots in the basement.

A car lift (Pic. 1) is a structure consisting of a support system and a drive mechanism. The device operates as follows. The car drives onto the platform, gauge sensors (they are located at the ends of guardrails) read the correct position of the car, and the support system starts moving, raising the car to the required height.

In scissor lifts (Pic. 1*a*), the platform moves with the help of levers located under it and shaped as scissors. The cylinders acting on the levers force them to unfold, which allows to lift the platform up.

The disadvantage of using scissor lifts is the lack of walls at their platform. That is, passengers who left (accidentally or intentionally), as well as the driver himself, are not protected by anything from falling or getting injured on such a lift. In addition, the installation will not budge if the machine has entered the site incorrectly.

Pic. 2. Variant of location of an overbridge with a one-way traffic zone (view from the car) [prepared by the authors].

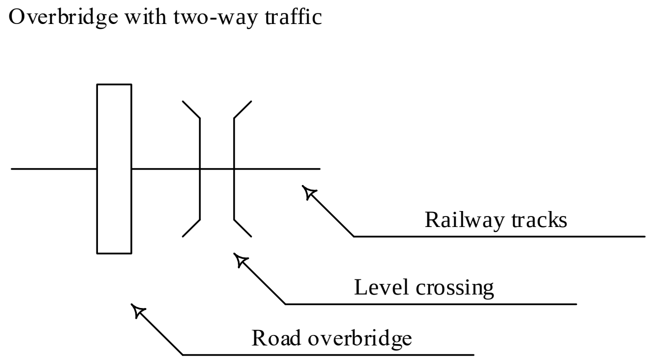


Pic. 3. Variant of location of the overbridge with a one-way traffic zone (bird's-eye view) [prepared by the authors].

This will lead to additional movements (manoeuvring) of the car on the platform of the lift, which will increase time the lift is occupied and time of a car's crossing the railway line. It will be difficult to implement this design, since it is not able to withstand the lifting of a car of more than 3 tons to a height of 7 meters (which is necessary to ensure the clearance conditions regarding dimensions of the structure).

The lift option in Pic. 1*b* is a structure of two (each of which is located opposite respective side of a car) or four (each two of them are located opposite respective side of a car) guide columns, located perpendicular to the platform. In this case, lifting is produced by hydraulic cylinders. They move the carriages, attached to the platform with a special system, which includes traction chains and block-and-tackle mechanisms. The standard value of the height to which the car can be lifted is 7 m. But, unfortunately, all other disadvantages of the first version of the lift (Pic. 1*a*) are consistent with that version as well.

The most perfect option, devoid of the indicated disadvantages, is a car lift (Pic. 1*c*)



Pic. 4. Symbols.

which is the same freight elevator capable of lifting a load to the required height, the mass of which should not exceed 3,5 tons. With this version of the lift, it is not necessary to monitor the sensors and rearrange the transport to a «more comfortable» position. In this case, when the car enters the elevator cabin, the ascent starts immediately after the doors are completely closed.

The design of the road overbridge can be adapted to the landscape and easily fit into it (Pics. 2, 3), and the overbridge can be built both with a single tunnel for traffic, and with two tunnels (they can be located both parallel and above each other).

It is advisable to use such a crossing elevator as an engineering structure that provides an «additional service» for road transport, and not as an ordinary means of crossing the railway. At the approaches to the elevator, control zones might be installed that work in automatic mode (according to the type of operation of the approach zones for road transport at airports or according to the type of operation of toll zones on dedicated high-speed highways). At the same time, it is possible to organize an electronic queue to access an elevator fixing different priorities, for example, for ambulances. It is convenient and simply necessary in connection with the universal usage of mobile applications to develop and implement mobile applications to increase comfort of using the provided service, to provide advance planning and traffic optimisation.

Queuing scenarios in direct proximity to the overbridge and level crossing

The operation of an overbridge with one and two tunnels is determined by the peculiarities of formation of flows of vehicles interested in its use on both sides of the overpass from the side of the highway. In fact, the proposed technical solution is either a single-channel or two-channel queuing system (QS) [13; 14].

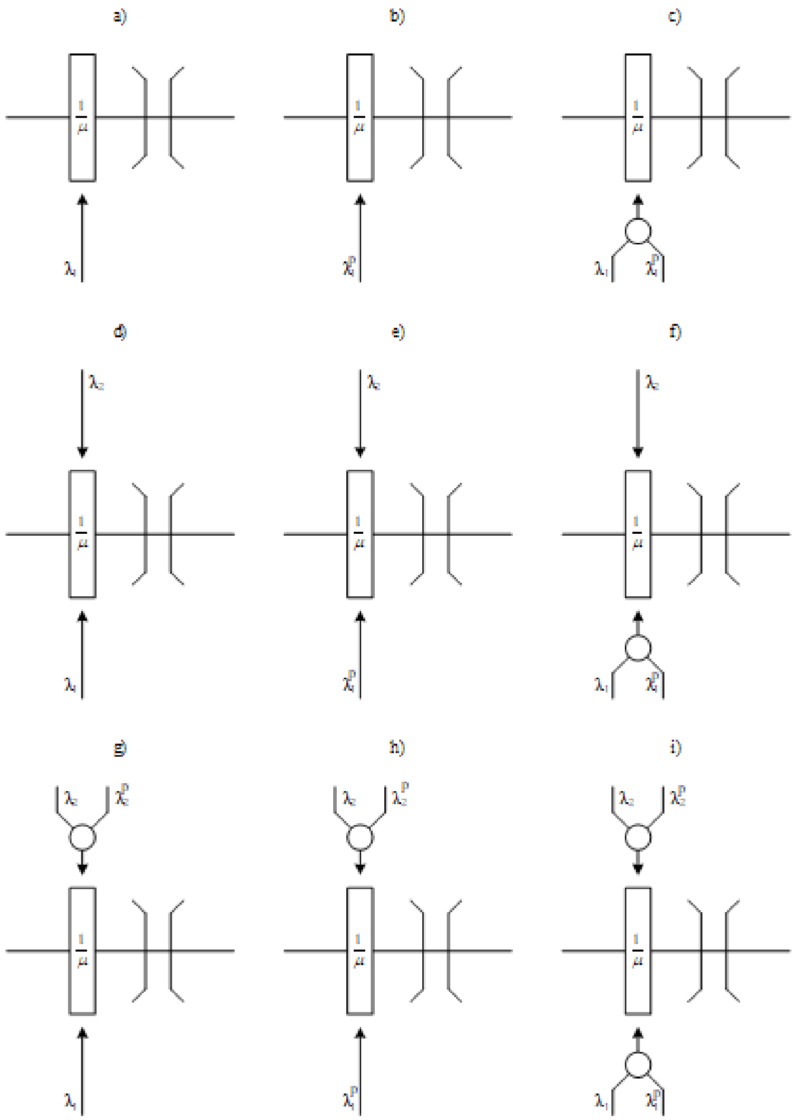
With both options of organizing an overbridge for road transport, its operation is restrained during the periods when the level crossing is open for road traffic, when there are no road traffic accidents that impede the passage through the railway, etc. It is practicable to consider QS only in the periods from level crossing closure till its opening for road traffic. More precisely, from some forecast moment, which allows to activate the work of the overbridge for road transport in advance. There is also a case when during traffic jam at the level crossing overbridge can be operated to meet a high-priority application, but this case is proposed not to be considered in view of the absence of classical QS in this case, since in case of a traffic jam, a high-priority application can be served instantly, and simultaneous arrival of high priority vehicles at both sides of the overpass are unlikely. However, in this case, the technical solution will do its job, skipping first a transport object, then the second one.

Applications regarding the considered technical object «overbridge for road transport» at time of its operation, in the most general case, have the following parameters:

• applications with the same priority and intensities λ_1 and λ_2 arrive from both sides of the overbridge.

• on both sides, a high-priority application with intensity λ_1^p and λ_2^p is possible.

• average service time of each application is determined by time parameters of a vehicle's ascent, its movement over the railway bed and



Pic. 5. Scenarios of queuing at a two-way overbridge [prepared by the authors].

descent, and is expressed in the general case by the value $\frac{1}{\mu}$.

Let us consider two versions of scenarios of queuing near the overbridge when it is intended for two-way, and for one-way traffic (with the possibility of reversing).

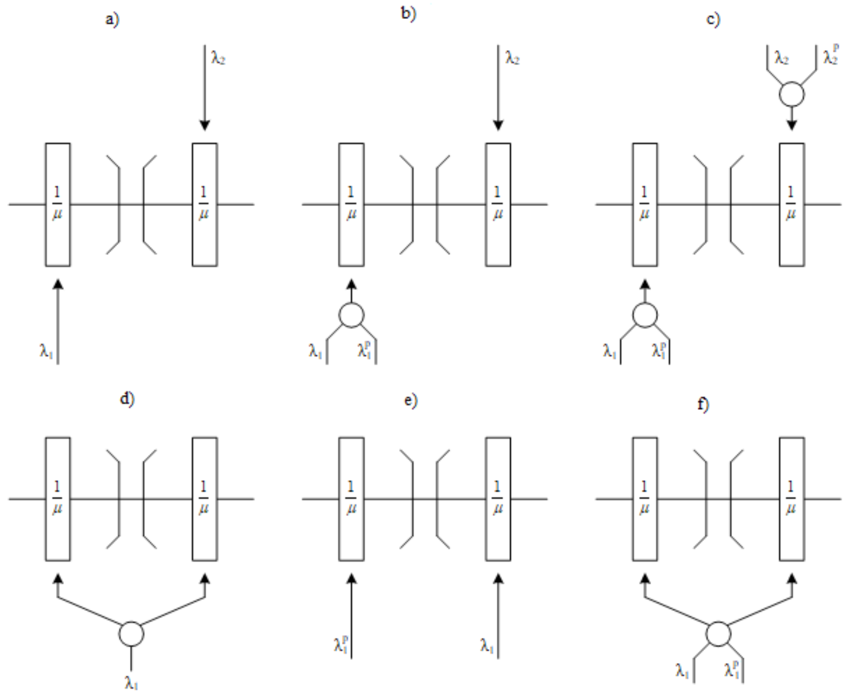
Pic. 4 shows the symbols.

Let us describe the case of a two-way overbridge (Pic. 5). First, we will assume that the cases of considering flow from each side are equivalent and exclude from consideration one of «symmetric options» (for example, when there is a flow on only one side or only on the other side). Then nine different situations can be distinguished.

The first scenario shown in Pic. 5*a*, characterizes the case when a queue of low-priority applications is formed only on one side of the overbridge.

The second scenario (Pic. 5*b*) describes the case of a high-priority application from one side of the overbridge in the absence of traffic from the other (in fact, it is similar to the first scenario).

The third scenario (Pic. 5*c*) describes the situation of formation of both low-priority and high-priority applications from one side of the



Pic. 6. Scenarios of queuing at a one-way (reversible lane) overbridge [compiled by the authors].

overbridge in the absence of traffic from the other.

The fourth scenario (Pic. 5*d*) characterizes the situation when low-priority applications are formed on both sides of the overbridge. This case seems to be the most interesting. In case of formation of applications from both sides of the overbridge, it is required to establish a priority for the traffic from either side. This priority can be set based on the number of applications and constraints regarding the operating time τ. We can suppose that traffic lights are installed on both sides of the overbridge to regulate queuing. Then it is advisable, considering time τ, to adjust the operation of traffic lights in such a way that during time τ the same number of cars will pass in both directions. In this case, for a small value of τ, the priority of one of the queues can be selected and the green light for this queue can be turned on for time $\left(\frac{\tau}{2}-\frac{1}{\mu}\right)$ and for the same time it then can be turned on for the second queue. If time τ is so short that only a small number of cars can be allowed to pass, the traffic priority should be set according to the preliminary applications of drivers. If time τ is long (exceeds 10–20 minutes), then the traffic lights can be switched several times, keeping the total travel time in each direction as $\frac{\tau}{2}$.

The fifth scenario (Pic. 5*e*) shows the presence of two streams of applications on both sides of the overbridge, one of which is high-priority, the second is low-priority. In this case, high priority applications are served separately. It should be noted that within the flow of high-priority applications there may be own priorities, however, it is advisable not to consider them, assessing only the possibilities of total operation of the overbridge according to this scenario.

The sixth and seventh scenarios (Pic. 5*f, g*) describe identical situations when low-priority applications are formed on one side of the overpass, and low- and high-priority applications on the other. In this case, priority is given to high-priority applications, and once they are fulfilled, the overpass begins to operate according to the fourth scenario already discussed above.

The eighth scenario (Pic. 5*h*) describes a situation similar to the previous two situations, with the only exception that high-priority applications are formed on both sides of the overbridge, but low-priority applications are also formed at one side. In this case, first, high-priority applications are executed from both sides, and then – low-priority applications from that given side. When high-priority applications are executed, the flows can be considered equivalent, and the execution of applications can be further based on the queue length with the corresponding service time for each application.

The ninth scenario (Pic. 5*i*) covers the most common case of formation of both types of applications at both sides of the overpass. Operation is similar to the algorithm described above for serving high priority applications from both sides and low priority applications from both sides.

While Pic. 5 shows scenarios for formation of applications to use overbridge with two-way traffic, Pic. 6 shows scenarios for formation of applications for a one-way road overbridge (with the possibility of reversing traffic). We can say that this option for organizing the overpass can be considered based on individual cases of the first option. For this reason, no additional description might be provided.

The calculation of the given QS can be carried out by means of simulation (not presented in this work).

Additional functionality of the road overbridge

The car lift type road overbridge is a unique technical solution that allows to integrate convenient means of crossing railways into the areas with an already established infrastructure. The technical solution itself can not only be implemented with a design that fits perfectly and does not violate the main «line» of the landscape, but also be provided with developed functionality that allows you to make not just a structure for solving a single task, but also to build a multipurpose facility. The buildings and objects of transport infrastructure should long ago cease to be considered only as static objects, «tuned» purely to solve a single narrow problem. They should be considered as objects created by man for ease of use, minimization of costs of both time and money, to increase the efficiency of operation of the transport complex and to obtain more comfortable use of the transport system by the end user. Technical objects should be as close as possible in their properties to the properties of living objects from the biological world and endowed with some «technical senses»: «technical hearing», «technical vision», «technical intelligence». In addition, it is necessary to achieve maximally «green» technical solutions using alternative energy sources, classifying energy consumers, and implementing such technical solutions that have a reduced carbon footprint [15].

The proposed «simplified» copy of the technical solution of Elon Musk company is a basic system that can be easily expanded and enlarged to a multifunctional complex with the following features:

• The roof of the complex is covered with solar panels to organise energy supply not only from the local power grid, but also from an alternative source, and in fact the structure itself is a «micro-power plant» with energy storage devices (it is quite possible that there will be enough energy to power the automation objects, as well as neighbouring residential buildings).

• It is possible to combine its functions with electric charging for modern electric vehicles from sources of «micro-power plant».

• Diagnostic equipment can be installed under the floor of the structure respecting clearance conditions for rolling stock traffic to check the workload of wagons, the state of the contact network (if the road is electrified).

• Equipment for monitoring the integrity of wagon seals, recognition of wagon numbers, flaw detection of axle boxes can be installed on the sides of the structure (it is possible to use the technology of surface acoustic waves for monitoring).

• In the area of intersection of the road and railway (at the level crossing itself), devices for control, technical diagnostics and monitoring of the state of the level crossing, etc., are installed.

Such functionality makes it possible to integrate into a single facility a complex technical «organism» that solves various tasks and ensures the fault tolerance, safety of the transport system, and comfort of movement of car users.

Conclusion

The implementation of road overbridges in «critical zones» of the intersection of roads and railways can significantly optimise traveling in large cities and regions with an established infrastructure. At the same time, it is possible to integrate the technical solution with mobile applications and navigation services in such a way that queues for using the overbridges are formed in advance and considered for routing and route optimisation purposes. The social effect of the use of car lift type road overbridges in the conditions of dense urban development in modern cities can also be of great importance.

The proposed solutions can be either separate mobile applications or integrated services as part of existing navigation and banking systems. Such integration makes it possible to simplify the user's interaction with the transport system, reduce time spent on operations, provide more comfortable travel, and, ultimately, optimise user's time and financial costs.

It should be emphasized once again that car lift type road overbridges are not a mass technical solution, but a toll increase in comfort of transportation and a means allowing prompt passage of emergency vehicles. In addition, such a technical solution, having modular design and suitable for rapid deployment, can be useful for long-term planned work, for example, related to reconstruction of crossings, their closure for a long time, etc. The presented structure for one- and two-track railway lines can be erected as simply as possible. The travel time is determined by a value $\frac{1}{\mu}$ that depends significantly on the types of car lifts installed, speed of entering the lift, ascending, driving along the corridor, descending, and exiting the lift and, according to preliminary estimates, should not exceed 1 minute. To avoid long queuing, it is advisable to provide possibility to pre-book the service; in some cases, to optimise location of vehicles, it is advisable to build specially equipped waiting lots in front of car lift. All this, of course, requires further detailed study, considering building conditions directly at a construction site and economic effect calculated additionally (which is influenced by capital investments, service costs, user demand, the ability to attract advertisers when using mobile applications, etc.).

In conclusion, it should also be noted that the suggested technical solution might be met with caution by specialists responsible for making decisions on the construction of innovative transport facilities, and will quite naturally require further study, but merits attention thanks to its potential positive effects.

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