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Traffic Safety
Preliminary Communication
U. D. C.: 625.15/.16.001
Accepted: Oct. 14, 2000
Approved: Sep. 2, 2003

AN APPROACH TO THE SAFETY PROBLEM OF RAILWAY-ROAD CROSSINGS IN THE TRANSPORT SYSTEM

ABSTRACT

The paper presents an approach to the problem of railway-road level crossings. The goal is to improve safety in the transport system network, which includes a considerable number of »inadequately protected« crossings. The single crossing, in its abstract sense, is considered to be a system consisting of four subsystems: the external world, the crossing in its strict sense of the word, the railway and the road. The system analysis of the problem is based on an exhaustive set of bibliography, listed at the end of the paper. This analysis leads to many findings and those exerting the greatest impact are selected as the basis for the synthesis. The synthesis proposes a triangle of variables: time period, critical points on the railway network and the value of the risk indicator. This simple model may include also other variables by converting relevant values. The main result is the risk indicator over the network. It can be used for various scenarios, thus enabling their mutual comparison as well as application in investment studies.

KEYWORDS

safety, transport system, railway-road crossings, system analysis, risk

1. INTRODUCTION

The paper deals with a problem of railway-road level crossing, which represents a problematic obstacle in safe and smooth traffic operation, both for the road and railway systems [18], [19], [20], [29], [30], [33], [36]. The proportion of accidents at railway-road level crossings is not very high for the society, but these accidents are very dangerous. The risk of fatal outcome in an accident at a level crossing is twenty to forty times greater than in an average road accident [22], [23]. Intensive users (mostly car drivers) are highly exposed to the risk, and the population living in the vicinity of level crossings is the most endangered one. Special cases are multi-fatality accidents [4] and especially accidents involving school buses. In the case of a school bus accident, the emotional component often triggers public campaign requiring higher safety level, which often results in institutional improvements.

The paper is based on a variety of bibliography sources; a full set of 119 items can be found in [36]. Due to the limited space in this paper, the references given relate only to the most interesting reading. However, this selection does not deny the importance of the rest of the works listed.

From the railway point of view, these accidents represent the greatest part of fatalities on railways in general. The two different standpoints (the road and the railway one) can be explained by an adequate approach. Having this in mind, the system analysis is proposed starting from the abstraction of the railway-road interaction system, divided into four subsystems [15] at the lower system level: the road, the railway, the external world and the railway-road level crossing in the strict sense of the word.

The objective of the study is to find the basic relations relevant for planning and decision-making with regard to the improvement of safety items at railway-road level crossings within a transport system as a whole. Therefore, a very wide and complex analysis is necessary [16]. The goal is to find an abstract model, putting together the essential relations. The model developed can be as detailed as necessary; it can be adjusted in accordance with available resources, but even in a simpler form, it can reflect the development trends and requirements in a balanced society.

2. THE SYSTEM APPROACH

Level crossings of roads and railway lines are frequently called railway level crossings or just road crossings (from the railway point of view). The system of such crossing is described by the following main components:

– relations to the external world,

- relations to road traffic in connection with an actual crossing,
- relations to railway traffic in connection with an actual crossing,
- micro-space around the crossing in the strict sense of the word, influenced by various spatial functional segments, devices, procedures and system relationships characterising the behaviour of participants and devices.

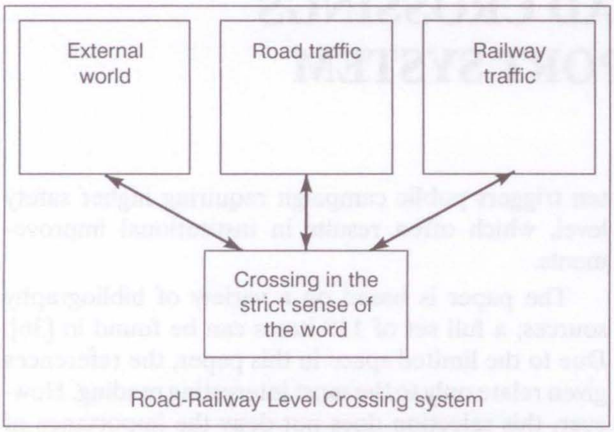

Figure 1 - The four subsystems

The system analysis should include the safety of road and railway operation and reliability of signalling-safety equipment also from the viewpoint of the new intelligent system solutions.

The external world has a decisive role in the presented abstraction of the system. The society would support effective spending of money with the purpose of minimising risks in all its activities, but the infrastructure owner prefers to minimise the risk in its own infrastructure. The two divergent goals should be adjusted.

The road car driver is part of the road subsystem. At the same time, he is the weakest item within all the subsystems. His behaviour strongly influences the micro design of the crossing. The railway subsystem has its train whose mass, speed, and other parameters require an absolute priority in the crossing.

The crossing in the strict sense of the word involves a number of problems concerning the risk and adequate safety protection (design [17]). The behaviour of the car driver belongs to the road subsystem, while the signalling-safety equipment is related both to the railway and to the road subsystems. Similar questions are raised with the expected implementation of intelligent systems. All the mentioned items represent only several relations, which must be examined within each subsystem and integrated in the interaction with other parts.

The efficiency of such system abstraction lies in its analytical and integrative power. It allows an analysis within each subsystem, and at the same time, the essential relations can be elaborated on the level of the whole system.

3. CONCEPT OF THE RISK INDICATOR

The proposed indicator of risk quantifies an undesired uncertainty. It is expressed as a function of occurrence probability for a definite event, and of severity of consequences. There are more definitions in various fields: finance, economy, statistics, decision theory, and insurance [1], [2], [3], [34]. An example of such a definition is: "risk is a convolution of exposure, hazard, and magnitude of losses".

For an individual, the ideal level of safety could be a situation without any risk of personal accident, injury, and material damage. Unfortunately, in reality, there is no "ideal" safety at all, because the danger is present everywhere and it cannot be avoided. Therefore, a "real" safety is a concept – indicating a situation in usual life at the socially accepted level of risk. [1]

In transportation, risk is observed in interaction with parts of the transport system. In general, injuries, deaths, losses in assets, systems, and functions are possible [39]. There are various aspects depending on transport modes, activities, and the observed statistical classes. E.g., each individual may have his own acceptable level of risk, which differs from those of the others. Something similar can be implemented with each professional group (car drivers, train crew, engine drivers, passengers, etc.).

In Fig. 2 the concept of risk is detailed. In the case of railway-road crossing the calculation is performed as follows. The road traffic flow over the crossing is exposed to hazard (collision with the train). Due to the situation (train traffic, crossing safety class, micro conditions, road user's characteristics etc.) an expected rate of accidents can be found. Further, possible damage can be calculated in accordance with the statistical data and evaluated as a loss.

This is a concept where for each crossing x a value $r_x(f_x h_x i_x j_x)$ can be found. The value of i stands for the

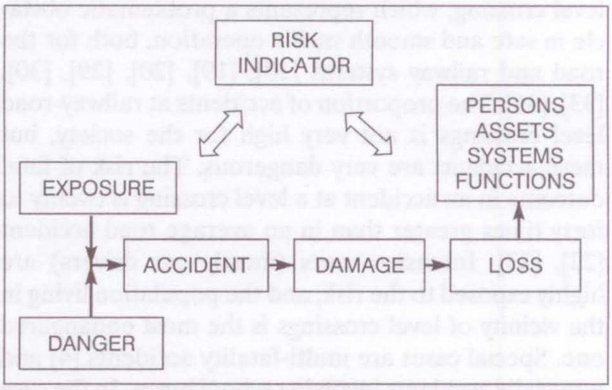

Figure 2: A block diagram of the risk indicator

number of observed units, j for the user's repetition frequency, f for the coefficient of expected accident per exposure rate, and h for the evaluated losses. Instead of i and j a representative exposed flow may be used. If the crossings are observed in safety classes z the relevant $r_z(f,h)$ may be used for each safety class.

4. THE FINDINGS

All findings resulting from the system analysis are categorised according to their importance. First, a set of the most important findings is defined, and then the second step is to define also the sets of findings of minor and low importance. The criteria for the "importance" are:

- the findings have an important socio-economic, safety, or financial role and appear at least once in the system analysis tree-structure;
- the findings have a less important role but often appear in the system analysis tree-structure;
- the findings have a structural or integration role important for the model.

A summary of the most important findings can be given as follows:

4.1. External world

- the area close to the railway-road level crossing with the most exposed population may have a decisive impact on the way the problem is solved [12], [17], [23];
- the socially accepted level of individual safety in transport must be balanced to other fields of human activities [1], [23];
- the level railway-road crossings present an economic impedance to the increased road traffic flows;
- the multi-fatality disasters trigger changes in the safety institutions [4], [27];
- the state level of yearly financing improvement for railway-road crossings is often proportional to the fatality rate;
- due to the lack of ideas, the international professional audience needs common efforts or a research network [7], [16];
- the society must take care of stimulating safer transport modes (which means stopping the shift from railway to the less safe road transport mode [1]).

4.2. Railways

- the train mass, speed, and braking parameters are decisive in the safety design of a railway-road crossing;
- the train path has to be privileged in safety improvement on railway-road crossing; in connection with traffic control, better warning of detected danger is possible;
- the reasons for the increase of road flows do not come from the railway [32] and consequently the railway share on railway-road level crossing with regard to the costs for solving the problem should be negligible - various sources estimate this from 0 to 5% of the costs [23];
- it would be even less fair if the railway were burdened by the increase in the costs, which would eventually affect the rail fares, thus repelling passengers from the safer railway transfer making them to shift to the more risky road transport [1];
- the reliability of signalling and safety equipment is high and the related problems are small compared with other problems (e.g. unreliability of car drivers);
- the balises are considered to be the basic detector of the train locations;
- the so-called "hidden error's heritage and long history" within the safety and signalling equipment, seem to be a potential for disasters [5].

4.3. Road

- road vehicle drivers and pedestrians (road users) have the main responsibility - therefore all kinds of influence are suitable: education, warning, and law enforcement [22], [23], [39];
- essential behavioural decisions depend on risk acceptance of the road motorists;
- traffic rule violation is the prevailing reason for drivers' involvement in accidents; [6], [23];
- the increase of road traffic flows means greater exposure on railway-road crossings, therefore the road economy has to finance the solving of related risks [14], [23], [25];
- road traffic control is responsible for proper guiding of road vehicles;
- after multi-fatality disasters, and especially if school buses are involved, the public realises how big the risk is and often triggers a campaign for improvements [4];
- the evaluated damage and indirect cost of injuries and fatalities are very high; from year to year the society is becoming more and more aware of these costs [8], [15], [36];
- it is useless to plan safety improvement on railway-road crossings by means of the law and without determining the funding at the same time. A juridical obligation for any road or railway entity means nothing, if there is no investment money ensured by the same law.

4.4. Railway-road crossing in a narrow sense

- video surveillance and enforcement drastically reduce the number of accidents in tests;
- elimination of crossings (to convince the opponents, obtain permissions, and close the crossing) is a hard job, often a "discouraging" one. For a long term the closure can be efficient in 25% cases [28], [11];
- low-cost train detection may reduce the cost of active warning protection;
- intelligent solutions have to be incorporated in the railway information system as well as in the road and vehicle systems; [13], [26], [33];
- the Slovenian Railways estimate that the cost of one average level-separated crossing construction is 1,600,000 SIT at the 1999 price level [21];
- the equipment redundancy can be used to cover the less reliable human actions [20];
- the average number of crashes into the level crossing gates in Slovenia is 205 per year [11]; these may be considered as potential near-miss accidents with higher losses.

In the cases of constructing level-separated crossings (e.g. in urban areas) special gates with flexible steel chains may be used. They are able to absorb a crash of 2000 kg mass at 70 km/h, swinging four meters.

The numerical values taken for various safety classes are as follows: the obligatory STOP sign halves the risk, video surveillance and prosecution lower the risk 4.4 times, signalling lights 3.5 times, and gates 8.5 to 10.5 times compared to the risk at the level crossings equipped only with Andrew's Cross. The best results are obtained with the double half-gate, the four quadrant technique and video surveillance. Such system lowers the risk 50 times (tests have shown a reduction of number of accidents by 98%).

All risks concerning road drivers are high compared to the risk of technical equipment failure. Therefore, the driver problems mask the equipment problems.

The systematic analysis results in details regarding the level separation, which are not so much known in the professional literature. (E.g.: the level separation cannot be characterised as 100 % safe; such absolute safety simply does not exist). Extensive spending in level separation, if the budget is limited, can leave many risky crossings neglected. Moreover, the high construction costs may increase the fare and have a reverse impact; the passengers tend to shift from a safer mode back to the more risky road).

In literature, some very interesting concepts can be found, which are not directly implemented here. Several can be mentioned, like threshold [25], [23], safety efficiency [25], risk homeostasis, near-miss accidents, corridor study [24], low-cost [9], etc. The "threshold" concept tries to determine when to start the level separation, "safety efficiency" suggests a measure of investment projects in safety improvement, a "risk homeostasis" theory gives an assumption that the driver behaves more risky if he feels safer, a 10 to 100 "near-missed" events suggest that a serious accident will happen, the "corridor" approach says that a study on a single crossing cannot be as correct as the whole "corridor study", the "low-cost" improvements are applicable for crossings with very low traffic flow, etc.

5. SOME GENERAL OBSERVATIONS

The railway-road level crossing problem has been studied thoroughly for a long time and no strikingly new findings can be reported at present. After the advent of intelligent transport systems, the "steady" problem of level crossings became "dynamic" again. Many questions, unpredictable progress, and research opportunities have been arising in the field of future technical development and use of ITS in connection with level crossings. The ITS makes the situation complex, raising some more questions about the level crossing automatic safety equipment [7], [13], [26], [33]. It is proposed that the ITS options can be observed as an upgrade of active protection.

The institutional safety management shows a new trend by putting safety closer to the integral quality management. Especially, it is expected that concept of safety and railway operation must be integrated.

The costs of level separation of railway-road crossings has to be covered by the road, if requested as result of the increase in road traffic flow. The level separation has to be economically justified. The level separation is not the question of safety. The juridical aspect is very clear: any type of sign makes the crossing protected [24]. The hazard occurs, in a great majority of accidents, as a result of some kind of traffic rule violation by the road user. The costs of level separation of railway-road crossing constructed for high-speed train operation has to be covered through the economy of better services [35].

6. SYNTHESIS

The most important findings form the basis for the model design. Taking into account the aim of the research and the relatively complex problem structure, the synthesis task is to search for a simple model capable of incorporating as many essential relations as reasonable.

The individual fatality risk per year is taken as the most suitable variable. It helps to avoid problems if motorization, fuel consumption, or travel time and distance indicators are used. Compared to fatality, other indicators may significantly differ from source to source, for they are not so precisely defined as the fatality. Beside transport, the fatality is often used in other fields, such as health, safety at work, urbanism etc, thus enabling comparison in the safety level taken from different sources.

The next important dimension is time – usually given in years. Big economies often observe e.g. 30-50 year period. Annual values are suitable, because many statistics, plans, and investments are well defined on a yearly basis, as well as data on fatalities and damages.

The third dimension is the number of critical points. All critical points on a railway network compose a set. This set can be easily enumerated, much easier on the railway than on the road network, which is often more complex. We are talking about "points" because the crossings are traditionally observed as the points of a network, in contrast to the sections (road and railway). An advantage of such data presentation is the method of compressed data recording, while the other advantage is its flexibility: with the same input set the crossings can be modelled as redesigned, closed, with changed safety class, level separated, redefined for pedestrians only, etc. If necessary, thus we may include the points of interaction with the neighbouring road and rail sections, forbidden but trespassed crossings, etc.

Each critical point defined by the input set of observed critical points on the railway network has all the attributes necessary for calculations. The safety classes can be defined according to a study structure. Each point can belong to only one class at a time. If there is a change, e.g. after an investment in safety improvement, the point can be moved from one safety class to another – simply moved from one subset to another. Among input data per each crossing, the improvement is defined by expected investment cost, coefficients of expected lower fatality and risk, etc.

Many other items can be added and inserted into the model by using proper conversion of values. (E.g.: the calculation of losses, the evaluated damage on assets, functions, and systems or estimated socio-economic cost of injuries and fatalities). If there are no specific reasons, we assume linear relations for the whole model.

Looking for the socio-economic optimum, combined measures can be examined within definite budget limits, with various technical solutions, as well as the expected socio-economic costs of accidents. By considering the requests and applying the input data, this approach enables to find – what is the best imple-

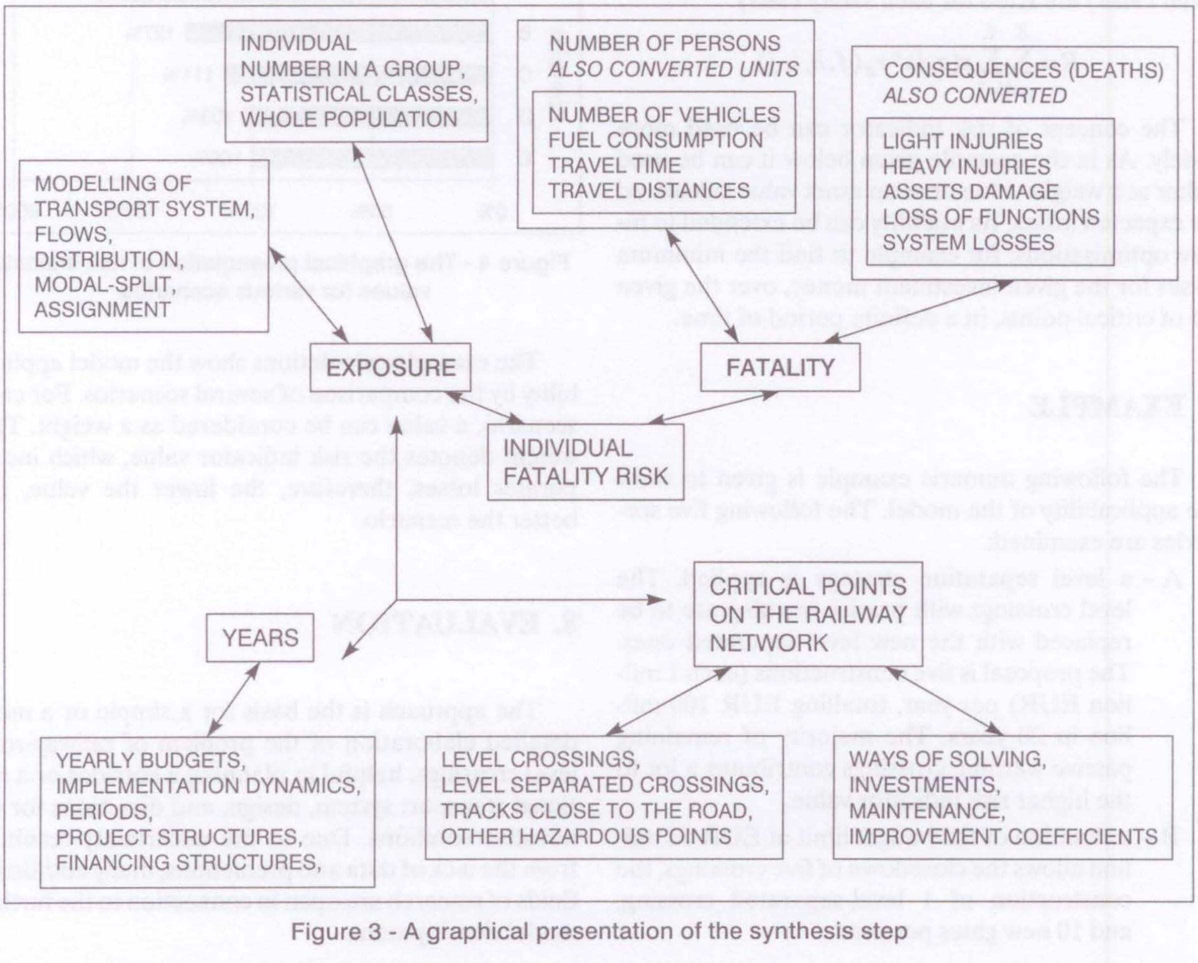

Figure 3 - A graphical presentation of the synthesis step

mentation dynamics of level separation versus automatic safety equipment, looking for the minimum expected fatalities or the maximum socio-economic benefits.

The available data from statistically significant sources may help to explain indirect costs of injuries, assets damage, etc, and link them to the fatality rate – as the most precisely given data. In contrast, the personal injury data are not suitable, they may be classified by various rules, which can be changed during the evaluation time period. When converting the values concerned, we have to accept local or typical data, linking the input data with the fatality rate.

The following notation is used in calculation formula of the risk indicator value R: The time period (years) $l=1,\dots,L$, safety class type $z=1,\dots,Z$, risk indicator per unit for each crossing $r_x(f,h,i,j)$, with occurrence frequency f, estimated losses h, exposure i (number of repeated uses by each unit j), number of observed units j, number of points $x(z,l)$ in each safety class z per year l. Input data and necessary conversion factors are mostly taken from the literature concerning large networks.

Due to the lack of particular data for each crossing, only safety classes are used in the example below. For each safety class a representative $r_z(f,h)$ is used (if given i and j are fixed for each safety class).

$$R=\sum_{z=1}^{Z}\sum_{l=1}^{L} x(z,l)*r_z(f,h,i,j)$$

The concept of risk indicator can be used more widely. As in the example given below it can be used either as a weight value or as an exact value calculated for expected losses. Its usability can be extended in future optimisations; for example to find the minimum losses for the given investment money, over the given set of critical points, in a definite period of time.

7. EXAMPLE

The following numeric example is given to show the applicability of the model. The following five scenarios are examined:

- A – a level separation strategy is applied. The level crossings with passive warning are to be replaced with the new level-separated ones. The proposal is five constructions (each 1 million EUR) per year, totalling EUR 100 million in 20 years. The majority of remaining passive warning crossings contributes a lot to the higher risk indicator value.
- B – a situation of the budget limit at EUR 52 million allows the closedown of five crossings, the construction of 1 level-separated crossing, and 10 new gates per year.
- C – a mixed scenario includes the closedown of five crossings, the construction of two level-separated ones, and 20 new gates a year which is estimated to cost EUR 101 million.
- D – a scenario composed of the close-down of five crossings, the construction of two level separated ones, and 20 new gates a year; this seems to be the most probable scenario. It is improved by the ITS additions from six year onwards, by using better coefficients and consequently resulting in the lower risk value.
- E – scenario concerning only new gates. 38 gates a year may replace all risky Andrew's crossings in 20 years and will require EUR 101 million.

It is important to note that the scenarios are intended to show the wide applicability of the model. A future investment feasibility study can compare options with characteristics suitable in particular situation. The input data are used for the Slovenian Railways network and combined with values for the missing data taken from references. The comparison is therefore valid only for the given scenarios and cannot be generalised.

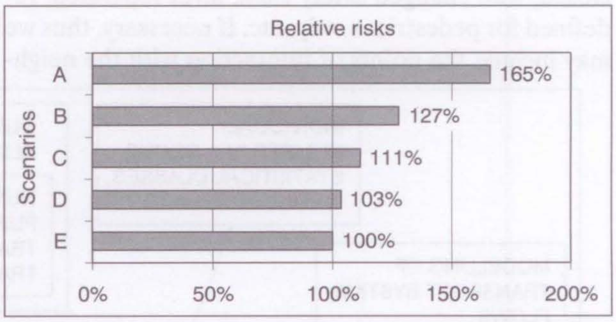

Figure 4 - The graphical presentation of risk indicator values for various scenarios

The example calculations show the model applicability by the comparison of several scenarios. For each scenario, a value can be considered as a weight. This weight denotes the risk indicator value, which incorporates losses, therefore, the lower the value, the better the scenario.

8. EVALUATION

The approach is the basis for a simple or a more detailed elaboration of the problem of railway-road level crossings, helpful in planning a corridor or a national transport system, design, and directions for innovative solutions. Due to the uncertainty resulting from the lack of data and predictions, many additional fields of research are open in connection to the further model development.

A well-grounded basis is presented for the most effective spending of a limited budget for the infrastructure owner. For the given money per year during a defined period, it can be found what number of crossings have to be consolidated, how many level crossings have to be equipped and to what extent the level separation can be performed.

Wide applicability of the proposed approach can be shown by a set of scenarios. In the above example, some frequently posed questions are worked out. The usual dilemma when to separate the level crossings on a network can be presented by two extreme scenarios: to invest all the available money to build a separation or to implement automatic gates. A variety of »mixed« scenarios can be defined. For a definite network (input data) with a large number of Andrew's crosses and a limited budget, an intensive spending in level separation may lead to higher risk over the whole transport system – because a significant number of risky level crossing will remain. Surely, for a single separated crossing the risk indicator value is negligibly low, but the real danger for the whole network comes from the »inadequately protected« crossings contributing a lot to the overall risk.

8. CONCLUSION

The presented system approach to the problem of railway-road level crossings in a transport system is able to achieve the pre-requested results. The introduced risk indicator can be used in decision-making by scenario-weighted comparison as well as in real problem evaluation. The analysis-synthesis gives the essential relations useful for the model design. The basic relations among the risk indicator, time and critical points on the railway network offer a simple and transparent tool, but a tool still flexible enough to incorporate many other items.

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POVZETEK

PROBLEMATIKA VARNOSTI CESTNO - ŽELEZNIŠKEGA KRIŽANJA V TRANSPORTNEM SISTEMU

Članek obravnava problem nivojskih križanj železnice in ceste. Cilj je izboljšati varnost transportnega sistema, ki vključuje precejšnje število nezadovoljivo zavarovanih križanj. Nivojsko križanje sestavljajo štirje manjši deli: okolje, samo križanje, železnica in cesta. Analiza problema je osnovana na izčrpni bibliografiji, ki je navedena na koncu članka. Ugotovitve analize, ki imajo največji vpliv, so bile osnova za končne sklepe. Gre za preplet treh dejavnikov: časa, kritičnih točk na železniški mreži in tveganja. V ta model lahko vključimo tudi ostale dejavnike. Zaključek analize podaja dejavnike največjega tveganja na železnici, ki se lahko uporabijo za različne scenarije, omogočajo njihovo medsebojno primerjavo in se upoštevajo pri investicijskih študijah.

KLJUČNE BESEDE

varnost, transportni sistemi, cestno-železniško križanje, sistemske analize, tveganje

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