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The application of open transmission standards for safety improvement in railway systems

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ABSTRACT

The paper deals with additional applications of open radio transmission standards in railway systems related to safety of trains. Presented in the paper new proposition is conception of anti – collision system, which assumes safety routes both in the normal and extraordinary conditions. This solution based on wireless transmission standard and allows to significantly reduce the probability of accident (collision) especially in serviced or modernized railway lines.

KEYWORDS: railway safety, SIL wireless transmission, open transmission standards

1. Introduction

Currently used railway data transmission generally based at wire solutions. With reference to such type of transmission it is essential adequate infrastructure. It is very important in rail line of special significance. The problem can appears in regional rail lines or in solutions which are unprofitable from point of economic view. Since several years we can see dynamic implementation of wireless transmission in rail applications. The wireless transmission or radio network can be used everywhere, where is the problem with construction of section of the traditional overhead lines. Over the years, there were many conceptions and solutions which increase functionality (moving block distance) [10] or safety (additional warning system for drivers who are closing to level crossing, [1], [2,9]). Such proposition can use public transmission standard like WiFi or WiMax but also dedicated for rail GSM-R. In the case of a dedicated GSM-R it is important, that public standards do not introduce interference, [8]. The use of these standards is important with reference to line in faze of modernization and regional lines without remote control of dispatcher centre. All of the solutions must meet dedicate rail standards, [4]. In the Fig. 1 the applications of open transmission standards is shown, with location of proposed additional system.

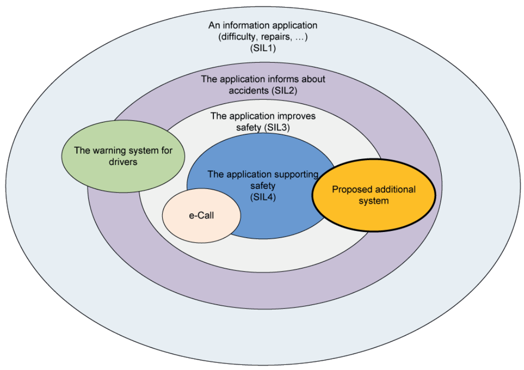

Fig. 1. Concept of location [own study]

The safety has priority meaning and is connected with investments in main rail lines. The problems can appears in a regional lines. The authors proposed the conception which can increase the safety in railway movement, especially at rail line about less importance. The elements of such proposition is transmission between trains with information about position which basis of GPS. In addition, the conception assume sending additional information like speed, distance and movement direction. In the dangerous situation (possibility of the collision at the same track) such solution allow to begin the safety procedure. For analysis of this proposition authors proposed Markov process, which are one of the analysis methods for rail systems, [9]. This allows the estimation of characteristic parameters.

2. Open radio transmission in rail applications

The application of radio transmission in rail systems allow to working out and implementation new solutions. The open transmission with public standards gives the new possibilities of optimal and functional railway control and management. It also gives the protection and management for the same level of safety, which is defined in EU standards. Details of radio transmission include special standard PN-EN 50159: 2011 (Railway Applications – Communication, Signaling and Processing Systems. Safety – Related Communication in Transmission Systems). This standard includes information concern safety of transmission and communication. The possibility to use the open radio transmission to increase the safety in rail transport was shown in papers [3,5]. In the Fig. 2 is shown the conception of warning system for drivers closer to cross level.

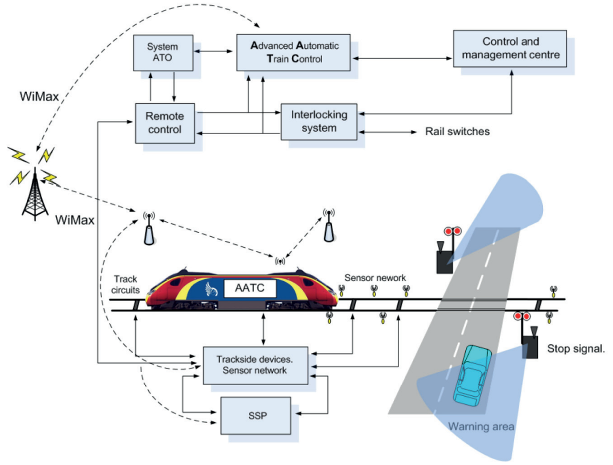

Fig. 2. The conception of the additional warning system [own study]

Evaluation of the impact of additional messages on driver behavior shown in paper [7]. An additional element which can increase the safety in rail movement is system based at wireless solutions like WiMax, WiFi, or public radio transmission. In a case of regional lines, where speed is less than 120km/h, such solution can be very helpful. Assuming, that minimal block distance between trains is 1.6km, using transmission with distance of 10km it may be sufficient, Fig. 3.

Installed additional panel in indicating cab can give information about approaching train, or the approach to another, Fig. 4. Additional information allow to identify train and show the number of the track.

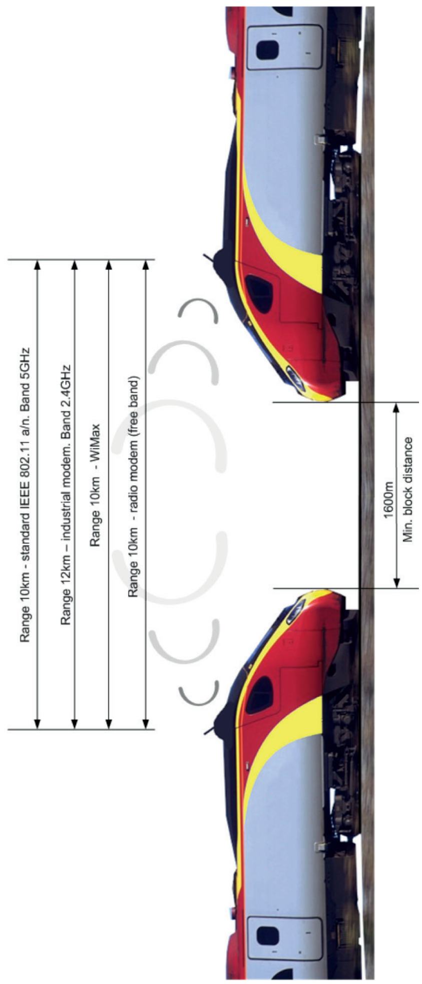

Fig. 3. The network range [own study]

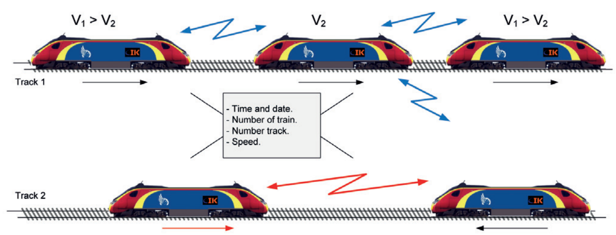

Fig. 4. The conception of addition system [own study]

The proposed solution does not interfere with the existing railway infrastructure, and is not a part of the control management of rail traffic. It can only be an additional system, which allow to better evaluation of the situation by the train driver on the trail. Current solutions allow for the preview only in dispatcher centre. An algorithm of such solution is presented in Fig. 5. It is assumed, that the time of one cycle is equal ~ 500ms.

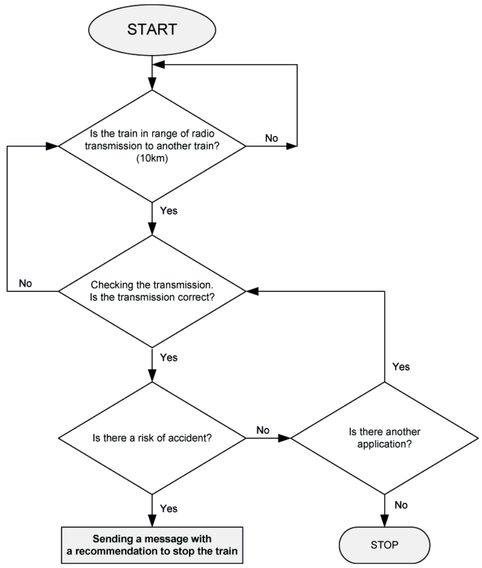

Fig. 5. An algorithm [own study]

3. Markov models for conception

In order to mathematical analyze the Markov processes were proposed. Due to special characteristics of railway control and management systems and restrictive regulations the Markow processes comply with the railway standards, [9]. These processes are the tool for safety analysis. Figure 6 shows the model of a situation where there is no extra addition system.

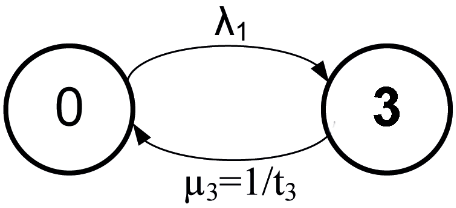

Fig. 6. Model without addition system [own study]

In the model from Fig. 4 we can distinguish:
- 0 - state of correct work,
- 3 - state of dangerous situation.

An undesirable state in such model is state 3. Solving the differential equation the model from Fig. 6. we can write the availability formula:

$$A = 1 - \lim_{t \to \infty} P_{dangerous}(t) = 1 - P_3 = \frac{\mu_3}{\lambda_1 + \mu_3} \quad \textbf{(1)}$$

where:
λ_1 – the intensity of critical applications,
μ_3 – time to return to the full efficiency.

In order to make the comparison, in the Fig. 7 is shown the model with addition information system.

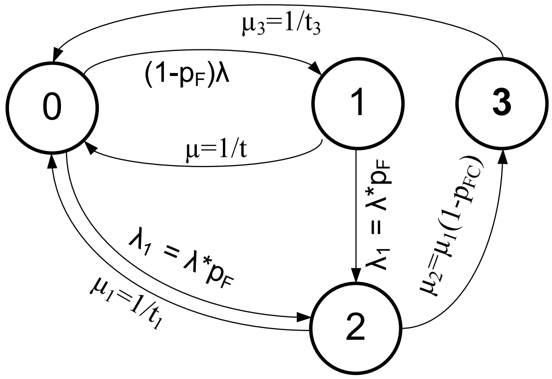

Fig. 7. Model with addition system [own study]

In the model from Fig. 7 we can distinguish:
- 0 - state of correct work
- 1 - waiting on data about other train,
- 2 - reception of critical data,
- 3 - state of dangerous situations.

In the model from Fig. 7 individual indicators mean:
- λ - the intensity of applications – sent messages on the track,
- λ_1 - the intensity of critical applications,
- p_F - the probability of critical situation,
- p_{Fc} - the probability of correct response
- μ - service time,
- μ_1 - service time of critical situation,
- μ_2 - the intensity of the move to the dangerous state,
- μ_3 - time to return to the full efficiency.

In this situation the undesirable state is state 3. For this model we can describe the general form of transmission matrix:

$$M = [p_{ik}] = \begin{bmatrix} p_{00} & p_{01} & p_{02} & p_{03} \\ p_{10} & p_{11} & p_{12} & p_{13} \\ p_{20} & p_{21} & p_{22} & p_{23} \\ p_{30} & p_{31} & p_{32} & p_{33} \end{bmatrix} \quad \textbf{(2)}$$

where $0 \le p_{jk} \le 1$, and $\sum_{k=1}^{j} p_{jk} = 1$ j,k = 1,2, …, n.

and differential equation:

$$\begin{cases} \frac{dP_0(t)}{dt} = -P_0(t)\cdot\lambda(1-p_F) + \mu\cdot P_1(t) - P_0(t)\cdot\lambda_1 + P_2(t)\cdot\mu_1 + P_3(t)\cdot\mu_3 \\ \frac{dP_1(t)}{dt} = P_0(t)\cdot\lambda(1-p_F) - \mu\cdot P_1(t) + P_1(t)\cdot\lambda_1 \\ \frac{dP_2(t)}{dt} = P_1(t)\cdot\lambda_1 + P_0(t)\cdot\lambda_1 - P_2(t)\cdot\mu_1 - P_2(t)\cdot\mu_2 \\ \frac{dP_3(t)}{dt} = P_2(t)\cdot\mu_2 - P_3(t)\cdot\mu_3 \end{cases} \quad \textbf{(3)}$$

Solving formula (3) and assuming the initial conditions the probability of P_3 equal:

$$P_3 = \frac{\lambda_1\mu_2}{(\mu_1+\mu_2)\cdot\mu_3 + \lambda_1\cdot(\mu_2+\mu_3)} \quad \textbf{(4)}$$

We can also write the formula of the availability:

$$A = 1 - \lim_{t \to \infty} P_{dangerous}(t) = 1 - P_3 = 1 - \frac{\lambda_1 \mu_2}{(\mu_1 + \mu_2) \cdot \mu_3 + \lambda_1 \cdot (\mu_2 + \mu_3)} \quad (5)$$

In order to make an analysis, in the Table 1 proposed the following assumptions related to typical dispatcher data.

Table 1.

L.p.	Parameter	Values
1.	λ	12/h
2.	λ_1	$\lambda_1 = \lambda * p_F$
3.	p_F	0.001%, 0.01%, 0.1%, 1%, 10%
4.	μ_1	30/h
5.	μ_2	$\mu_2 = \mu_1 \cdot (1 - p_{FC})$ where p_{FC} is the probability of correct reaction – 0.999
6.	μ_3	4h

In the Table 2 is presented the comparison of the calculation for models from Fig. 6 and 7.

Table 2.

L.p.	Probability of dangerous situation	The value of availability *A* without addition system	The value of availability *A* with addition system
1.	0.001%	0.999520	0.999999
2.	0.01%	0.995223	0.999999
3.	0.1%,	0.954198	0.999998
4.	1%	0.675676	0.999984
5.	10%	0.172414	0.999846

4. Conclusion

The results confirm the assumption that the use of the proposed solutions can help to increase the safety of trains movement. Solutions based at wireless networks along with GPS data allow to quick response in case of emergency. Implementation of a dedicated GSM-R and additional solutions based on WiFi networks, public radio or GSM, additionally can contribute to increase the level of safety, [1]. The proposed model based at Markov processes allowed to estimate the value of the availability and compare the estimated results of the proposed models, [9]. An important issue in the case of the use of open wireless networks is a problem of protection, but using the appropriate security mechanisms of transmission in open networks and using conventional transmission devices (eg. modems), it is possible to achieve safety transmission in level SIL-4, [4].

Presented conception is a part of research work which is realized by authors at the University of Technology and Humanities in Radom. Currently realized by the team similar telematic solution is dedicated to inland and road transport, [6]. On the basis of conception of additional system for rail drivers, next stage will be attempt of building and testing the system with use of public radio transmission standards (free frequency band).

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