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Future generation of railway control systems for regional lines including new telematic solutions

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ABSTRACT

The paper deals with implementation problem of new generation of railway control and management systems dedicated for regional lines. The special infrastructure of such lines gives the possibility of application the new telematic technologies including the open radio transmission standards to control and monitoring the dissipated railway objects. In the paper the efficiency and safety analyses are presented based on stochastic process approach according to UE standards and recommendations.

KEYWORDS: regional lines, control systems, telematics, open radio transmission, efficiency and safety, Markov processes, time and probability analysis

1. Introduction

The loss of railway communication in sub regions may generate economic, social and demographic problems. For Poland the balanced development may respect the aspects of large regions beyond capitols and big agglomerations. Another problem is connected with ecological aspects and environment protection. Now only railway transport may assure above requirements and social needs.

It is a assumptions for so called railway regional lines, integrated with main or magisterial lines. Now this is a reason for modernization or revitalization of railway lines assigned to regional connections. of course both procedures must require the same, obligatory safety level. In the part he regional lines are defined and characterized.

The main problem of revitalization of regional lines is a modernization of communication – instead traditional telephone connections the new wireless radio communication is proposed. Such solution may be a skeleton for modern railway control and management system related to local control centre (LCC) and including station interlocking (SI) systems, block line/rail occupancy (RO) systems and level crossing system (LCS).

2. The structure of railway control system for regional line with radio transmission

The categories of railway lines are defined in regulation of Polish Ministry of Infrastructure (Dz.U. 2003 No 86 pos. 789, Instruction Id – 12 (D – 29) – Specification of Lines) [1]. Such specification does not strictly defined the regional line. The authors suggest following criteria for classification the railway line as a regional line:

- assigned to category first class or lower (not arterial) , it means that volume of trains is $T \geq 25$ (Tg/year), maximal speed is $v_{max} \leq 120$km/h (for freight trains $v_{max} \leq 80$km/h),
- with speed $v_{max} \leq 120$ km/h with UIC specification,
- mixed passenger and freight traffic,
- with volume of trains $l_{ppoc} \leq 20$ (in Poland typical 10-16, maximal 30),

and at least one above criterion must be satisfied.

The trends in modernization and revitalization must assure (according to UIC recommendations):

- maximal economical solutions of railway and management (i.e. closing of level crossing systems activated by driver),
- implementation of low cost radio transmission for train driver and between dispatcher, interlocking and line block systems (i.e. GSM-R).

Now in EU only a few railway administrations have research works on new information technologies for introduced regional lines. The some necessary reductions of management and railway procedures (with assurance of SIL4) may have an influence for following assumptions reducing the rules for dispatchers:

- work without extraordinary (manual) commands,
- setting of routes by train drivers in case of emergency control,
- reduction of full operation for two track lines.

The technical reduction rules are connected with:

- interlocking computer as "2002" configuration,
- interlocking desk in SIL 2,
- no local desks (only LCC),
- no train routes without stop in main additional tracks,
- no shunting routes (with maneuver mode only),
- no emergency signals in semaphores,
- no control of some types of points,
- application of axe counters for occupancy the rail sections and points.

The providing modernization works may destroy some recommendations assigned to given line, classified as regional, but satisfied another criteria.

The main emphasis is related to automation of control and management, corresponding to:

- automatic setting of route ways,
- automatic time scheduling implemented in dispatcher desks,
- automatic (computer) documentation in LCC, controlled area and neighbor stations,
- automatic co-operation with information system for passengers using radio communication via open public standards (WiFi, GSM).

These solutions reduce the dispatcher staff significantly. The typical structure of regional line equipped with radio-transmission links is presented on Fig. 1.

Now in Polish Railways the experimental system for regional line Radom – Tomaszów with radio transmission (ESTER) is implemented by KOMBUD S.A. We can distinguish following subsystems:

- Local Control Centre (LCC),
- Interlocking system for small station (IS),
- System Monitoring of Rail Section Occupation (RO),
- Level Crossing System (LCS).

The radio transmission is realized using open standard in 433.725 MHz channel with 25MHz band. The speed of transmitted data is 19 200 bit/s. the telegrams in the system is protected by 128 bit AES key according to EN 50 159 standard and CRC 32 integrity code [6]. The applied transmission devices Satellar produced by Satel are characterized high reliability (MTBF about 52600 h) and authorized controlled access.

The authors suggest the more flexible solutions, devices APRISA produced by 4RF Communication based on WiFi standards including typical industrial (existing cable) standards such RS232c, RS485 and Ethernet. (The functional and reliability parameters are similar, but additional requirements such 128 bit AES and 32 bit CRC may be implemented according to EN 50 159 standard).

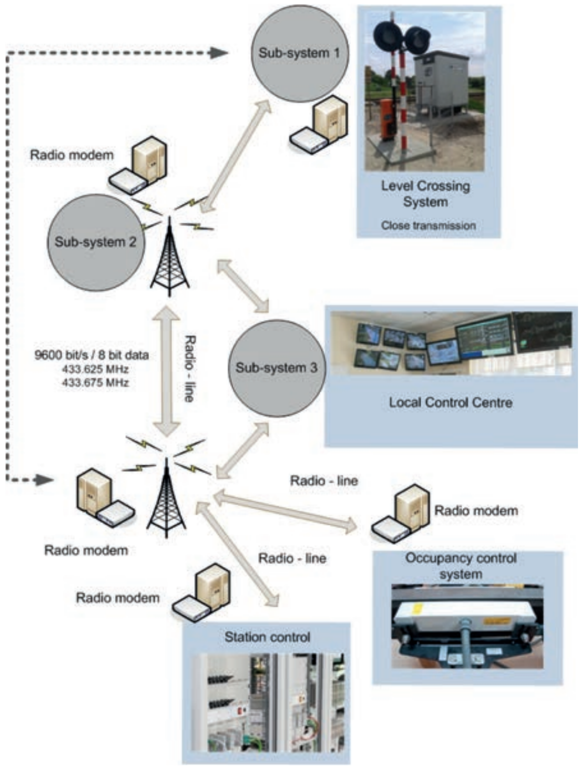

Fig. 1 The structure of regional line equipped with radio transmission links [own study]

3. The modeling of radio transmission

The main change in system safety is radio transmission applied on different levels responsible for dispatcher management and control [2]. For analysis the basic parameters influencing for safety and functionality the humongous stationary and ergodic Markov process theory is applied. It is a combination of stochastic processes theory and mass service theory, because the probabilistic and time measures (delays and queues) may be estimated [3],[5].

For introduced radio transmission links we propose as a measure the availability – the sum of probabilities of occurrence in the state of possible work.

$$A = \lim_{t\to\infty} \sum_i P_i(t) \qquad (1)$$

where i is connected with states of possible operation.

The second important parameters are delays, the time of delay may be evaluated using Markov process approach.

3.1 The subsystem

In the elementary subsystem level devices IS, RO, CLP systems and remote devices such train detectors or axe counters, the two channel radio transmission is proposed (Fig. 2). The figure below shows the Markov model of two channel transmission of single devices [4].

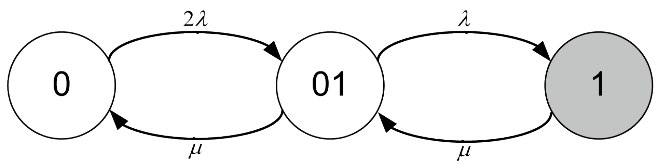

Fig. 2. The Markov model of two channel transmission of single device [own study]

For model from Fig.2 the following states are introduced:
0 – state corresponding to operation with both radio transmission channels,
01 – state with operation only one transmission channel,
1 – state of system failure connected with both faulty radio transmission channels.

The transition between states are described corresponding to:
λ – failure rate of single radio transmission channel
μ – recovery, repair rate (reciprocal to time of return from failure)

The Markov model from Fig. 2 can be described by equations:

$$\begin{cases} \frac{dP0}{dt} = -2 \cdot P0 \cdot \lambda + \mu \cdot P01 \\ \frac{dP01}{dt} = 2 \cdot \lambda \cdot P0 - \cdot P01 \cdot \lambda - \mu \cdot P01 + \mu \cdot P1 \\ \frac{dP1}{dt} = \lambda \cdot P01 - \mu \cdot P1 \end{cases} \tag{2}$$

To the solving of equation the Mathematica software was used (Fig. 3). The probabilities to be in the states P0, P01 and P1 for $t \to \infty$, amount:

$$P0 = \frac{\mu^2}{2\lambda^2 + 2\lambda\mu + \mu^2}$$
$$P01 = \frac{2\lambda\mu}{2\lambda^2 + 2\lambda\mu + \mu^2} \tag{3}$$
$$P1 = \frac{2\lambda^2}{2\lambda^2 + 2\lambda\mu + \mu^2}$$

Availability for model form Fig. 2 shows the formula:

$$A = \lim_{t\to\infty} \sum_{i=0,01} P_i(t) = P0 + P01 = \frac{\mu^2 + 2\lambda\mu}{2\lambda^2 + 2\lambda\mu + \mu^2} \tag{4}$$

Assuming the value of λ as at least $10^{-5}h^{-1}$ (recommended for SIL2 devices) and
$\mu = 10^2/h$, we may estimate the availability as:

$$A = \lim_{t\to\infty} \sum_{i=0,01} P_i(t) = 0{,}99999999999998 \tag{5}$$

Of course the time of delay τ_{d1} is equal to μ^{-1}. (typical value is assumed as 10^{-1}h).

The Fig. 3. presents the window of analysis in Mathematica software for model from Fig. 2.

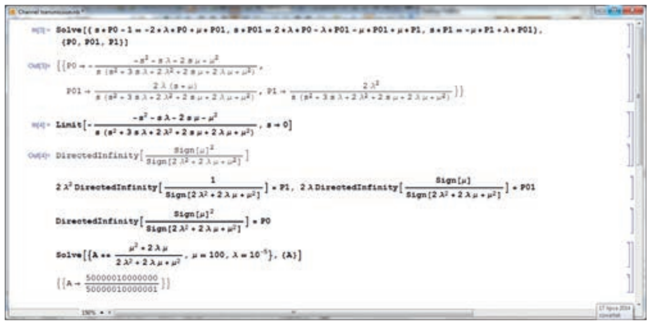

Fig. 3. The window of analysis the Markov model from Fig. 2 [own study]

3.2 The concentrator

The Markov model of concentrator (Fig. 4) is based on mass service theory introduced by Tannenbaum for telecommunication and computer network application [7]. On the Fig.2 the following states are introduced:
0 – state corresponding to operation (service) of message,
1_i – state with waiting for service where *i* is a number messages for processing.

The transition between states are described corresponding to:
λ' – intensity of received messages,
μ' – service rate (reciprocal to time of single message service).

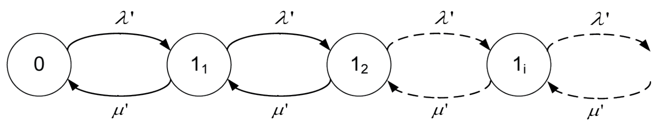

Fig. 4 The Markov model of concentrator [own study]

The system availability is connected with state 0, as follows:

$$A = \lim_{t\to\infty} \sum_{i=0} P_i(t) = P0 \tag{6}$$

where P0 is equal to:

$$P0 = 1 - \tfrac{\lambda'}{\mu'} \tag{7}$$

and Pi may be expressed as:

$$Pi = (1 - \tfrac{\lambda'}{\mu'})(\tfrac{\lambda'}{\mu'})^i \tag{8}$$

The time of delay is related to time of waiting for service (plus time of service):

$$\tau_{d2} = N \frac{1}{\lambda'} \tag{9}$$

where N is a mean length of messages waiting for service equal to:

$$N = \frac{\frac{\lambda'}{\mu'}}{1 - \frac{\lambda'}{\mu'}} \tag{10}$$

Typical values of λ' and μ' may be assumed as $1,2*10^2h^{-1}$ (it is related to mean time of request 30s) and $1,8*10^3h^{-1}$ (it correspond to 2s time of service) thus we can estimated N ≈ 0.07 and $\tau_{d2} \approx 2,1$s. For such assumption A = 0,93 (such value may be better if mean time of request will be bigger).

3.3 The local control centre

The LCC is a typical duplex system with transmission overlay (only one transmission channel is processed, second is treated as hot standby), Fig. 5:

0 – state of typical work with both transmission channels,
01 – state with waiting for service,
1 – state after correct switch to single transmission channel,
2 – state of uncontrolled transmission failure (no connection with concentrators),
3 – state of controlled transmission failure (emergency procedure is realized.

The parameters of transition are:

λ – failure rate of single transmission failure
μ – recovery, repair rate (reciprocal to time of return from failure)
λ" – intensity of received messages,
μ" – service rate (reciprocal to time of single message service)
p_{FS} – probability of correct switch to second transmission

Fig. 5 The Markov model of dispatcher/control centre [own source]

$$A = \lim_{t\to\infty} \sum_i P_i(t) = P0' + P1 \quad (11)$$

where:

$$P0' = P0\left(1 - \frac{\lambda''}{\mu''}\right) \quad (12)$$

According to (7) and (8) we must normalize probabilities:

$$P0' + P01' + P02' + \ldots = P0 \quad (13)$$

Probabilities P0 and P1 are equal to:

$$P0 = \frac{\mu^2}{\mu^2 + \mu\lambda + p_{FS}\lambda^2}$$

$$P1 = \frac{\lambda\mu p_{FS}}{\mu^2 + \mu\lambda + p_{FS}\lambda^2} \quad (14)$$

Assuming value of rates like for model from Fig. 2 and Fig. 3. the availability is equal to: A = 0,933551592 (P1 = 0,062178681, P0 = 0,933613822, P0'= 0,87137291).

The delay is the same, because the values of λ" μ" are assumed as in point 3.2.

4. Conclusion

The results from analysis of availability and delays in radio transmission links between many control subsystems for railway regional line detects the conditions for implementation such open standards.

The availability is very high (0,99999999999998 - for sub-system from Fig 2., 0,93 for model from Fig. 4 and 0,933551592 for model from Fig. 5). The availability for sub-systems and LCC have comparable values with typical cable communication devices, the safety is assured by the same CRC32 coding (integrity) and additional cryptographic codes (AES128). The availability for concentrators depend on time of processing and may be better for radio devices produced by specialized manufactures (the availability is related with queue of waiting messages).

The total delay is less than 2s and may be reduced using better procedures of queuing and processing. The low volume of trains in the regional line shows that λ' and λ" are not critical for service of received messages.

The transmission is treated as a overlay on the existing fail safe railway control devices responsible for station interlocking, level crossing and rail occupancy monitoring. The safety of such SIL4 subsystem (dedicated to regional lines) reflects the recommendations obligatory for other lines.

The main aim of this work is connected with modeling the functionality of open radio transmission systems. Based on Markov theory the tree models are evaluated, it is a tool for analysis the more sophisticated systems. Of course these models may be verified using at first simulation software and some laboratory tests for real confirmation the all introduced parameters.

The presented transmission system is arbitrary and may be modified with respect to real needs (for example, the second radio link for any sub-system may be not connected with concentrator but for neighbor sub-system).

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