2009 Fourth International Conference on Dependability of Computer Systems

Operational Availability of Railway Dispatch Communication System

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Abstract

In the article, issues on assessment of operational availability of transport telematic systems are presented. Digital railway dispatch communication system has been selected for analysis and assessment. Presented has been the model of the system's exploitation process, including its functional structure. Markov and semi-Markov processes have been used for modelling of the exploitation process. The conclusion contains the example of a computation of operational availability of the digital railway dispatch communication system.

1. Introduction

Centralisation of railway traffic steering and control imposes high requirements for tele-transmission infrastructure in the area of data transmission correctness, operational reliability, efficiency and availability for execution of data transmission service. Technical condition of elements and their exploitation process has a decisive impact on the railway dispatch communication system. Operational availability of the system and availability of the data transmission network can be assumed as measurements for assessment of exploitation effectiveness. Availability of the system and the dispatch communication network can be defined as ability of technological communication network to maintain itself in a condition allowing for execution of required functions in given conditions, at a given moment, or in a given time span, assuming that required external measures, assuring execution of those tasks, have been delivered.

The following terms can be adopted for the dispatch communication network:

- availability at a given moment – this is a probability that at the moment of an occurrence of a demand for performance of telecommunication service, the network will be serviceable for its performance,
- network operational availability – this is a probability of event that serviceable network is in stand-by position, and it is available.

2. Railway Dispatch Communication System

Digital system of selector dispatch communication is one of the key telematic systems in railway transportation. It is used for supporting management and organisation of conveyance process in railway transportation in the area of railway traffic safety and efficiency assurance for supervised railway lines. From the point of view of use of the systems for the tasks described above, availability is an important feature.

The digital dispatch (selector) communication system, operating on linear dispatchers posts at Traffic Control Units (EKR), allows for:

- communication between linear dispatcher and traffic control officers at calling posts of the supervised railway lines' sections, using the function of:
  - ✓ calling each individual traffic control officer,

978-0-7695-3674-3/09 $25.00 © 2009 IEEE
DOI 10.1109/DepCoS-RELCOMEX.2009.28

- ✓ group calling of a few traffic control officers at subsequent calling posts,
- ✓ simultaneous and collective calling of all users of the linear dispatcher's network.

- communication of the linear dispatcher with network and power feeding dispatchers,
- access to general exploitation network,
- access to emergency telephones of Police, Medical Rescue Service, and Fire Department units as well as others, essential in life-threatening situations or in view of possible damages to railway property.

Moreover, as a result of analysis of the linear dispatcher's work scope and a need for its improvement, also as regard electronic evidence of events. This solution should also provide a possibility of bilateral exchange of messages, describing traffic events.

The messages, feeding on-line the server of services provided by Carriage Management Centre (CKP), are first of all used for feeding the exploitation work evidence application. The digital dispatch communication system is based on existing copper cables, digital tele-transmission devices *x*DSL, data exchange in Ethernet protocol, and a simultaneous application of switching devices (*Soft Switch*). Wherever it was possible, that is, where there are fibre optics cables, the sections of xDSL (*Digital Subscriber Line)* links have been connected through the existing *Synchronous Digital Hierarchy (SDH*) to the main router of the Branch Unit of Polish Railway Lines JSC. Such solution improves quality and reliability of the entire system, because all stations of the digital dispatch communication system are serviced internally in its own safe *Virtual Private Network (*VPN), using the Railway Telecommunications resources.

3. Assessment of Operational Availability of Digital Dispatch Communication System

3.1. Definition of Operational Availability of Digital Dispatch Communication System

Taking into account the knowledge of the functional and reliability structure of network nodes (of commutative systems SK) and that of terminal of traffic control officer's post (ISDR) as well as understanding of the functional and reliability structure of bipolar network between the nodes, the availability of dispatch communication network for transmission of messages between posts of traffic control officers and a dispatcher can be written in a form of a general dependence:

$$A_{LD}(t) = A_{WP}(t)\ A_{WK}(t)\ A_{KT}(t)\ A_{TL}(t)\ A_{TD}(t) \tag{1}$$

When $t \to \infty$ then the value of the availability coefficient is obtained in a form of:

$$K_{gLD} = K_{gWP}\ K_{gWK}\ K_{gKT}\ K_{gTL}\ K_{gTD} \tag{2}$$

where:

$A_{LD}(t)$ – availability function of dispatch communication network,

$A_{WP}(t)$ – availability function of initial node (digital commutative system) of dispatch communication network,

$A_{WK}(t)$ – availability function of final node (digital commutative system) of dispatch communication network,

$A_{KT}(t)$ – availability function of transmission line of (fibre optics transmission cable together with linear transmission elements),

$A_{TL}(t)$ – availability function of traffic control officer's post,

$A_{TD}(t)$ – availability function of dispatcher's post,

K_{gLD} – availability coefficient of dispatch communication network,

K_{gWP} – availability coefficient of initial node (digital commutative system) of dispatch communication network,

K_{gWK} – availability coefficient of final node (digital commutative system) of dispatch communication network,
K_{gKT} – availability coefficient of transmission line of (fibre optics transmission cable together with linear transmission elements),
K_{gTL} – availability coefficient of traffic control officer's post,
K_{gTD} – availability coefficient of dispatcher's post.

3.2. Assessment of Commutative Nodes Availability

The following assumptions have been made referring to a description of time spans of stay of commutative nodes of the digital dispatch communication system in individual exploitation states.

Time of proper operation of the main processor is a random variable with distribution of:

$$F_p(t) = 1 - e^{-\lambda t}, \qquad t>0,\ \lambda>0 \tag{3}$$

Faulty processor is repaired within a time span of random described by variable γ with distribution of:

$$F_p(t)=1 - (1 + \mu t)\, e^{-\mu t}, \qquad t>0,\ \mu>0 \tag{4}$$

If at the moment of damage of the processor being in use, the switching system is unserviceable, the system becomes damaged. In this case, reuse starts after time $\gamma + \eta$, where η denotes time of repair of the switching system. Distribution of the random variable η is as follows:

$$F_k(t)=1 - (1 + \beta t)\, e^{-\beta t}, \qquad t>0,\ \beta>0 \tag{5}$$

The assumptions have been made basing on reliability requirements for telecommunication lines, described inter alia in [5], and reliability analysis of computer and microchip systems [6]. The assumption is made that the stochastic process $\{X(t) : t>0\}$, describing operation of the system, is the semi-Markov process. The following states can be differentiated:

s_0 - all elements are serviceable and the main processor has not started working yet (initial state of the process);
s_1 - both processors are serviceable and while using the serviceable processor, the repair of the faulty processor has been completed;
s_2 - one processor is serviceable, and the other is being repaired;
s_3 - both processors are unserviceable and one of them is being repaired;
s_4 - one processor is unserviceable and so is the switching system.

Matrix of probabilities of transitions between specified exploitation states can be written in the following form:

$$F(t) = \begin{bmatrix} 0 & F_{01}(t) & F_{02}(t) & 0 & 0 \\ 0 & 0 & F_{12}(t) & 0 & F_{14}(t) \\ 0 & F_{21}(t) & 0 & F_{23}(t) & 0 \\ 0 & 0 & F_{32}(t) & 0 & 0 \\ F_{40}(t) & 0 & 0 & 0 & 0 \end{bmatrix} \tag{6}$$

Additionally, it is assumed that *Æ* denotes the following event, namely: the switching system is serviceable at the moment of damage of the currently operating processor, and that the Æ event does not depend on the proper performance time of the operating processor. It is hereto assumed that probability of such event's occurrence is p_α:

$$P(Æ) = p_\alpha \tag{7}$$

Stationary value of the availability coefficient is expressed by formula:

$$K_g = \sum_{j=0,1,2} P_j = P_0 + P_1 + P_2 \tag{8}$$

where : $P_j = P\ \{X(t) = j\}$, j=0,1,2

$$P_j = \frac{\pi_j E(T_j)}{\sum_{j \in S} \pi_j E(T_j)} \tag{9}$$

Limit distribution πj of the inserted Markov chain $\{X(\tau_n):n=0,1,2,...\}$ is received by solving the system of equations [3]:

$$\begin{cases} \Pi = \Pi \cdot \mathbb{P} \\ \sum_{j \in S} \pi_j = 1 \end{cases} \tag{10}$$

where:

$$\mathbb{P} = \begin{bmatrix} 0 & p_{01} & p_{02} & 0 & 0 \\ 0 & 0 & p_{12} & 0 & p_{14} \\ 0 & p_{21} & 0 & p_{23} & 0 \\ 0 & 0 & 1 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 \end{bmatrix} \tag{11}$$

The system's availability coefficient can be calculated from this dependence:

$$K_{gWP} = K_{gWK} = \frac{(1-p_\alpha)p_{21}E[T_0] + p_\alpha \cdot p_{21}E[T_1] + p_\alpha \cdot E[T_2]}{(1-p_\alpha)p_{21}\{E[T_0] + E[T_3] + E[T_4]\} + p_\alpha \cdot p_{21}E[T_1] + p_\alpha \cdot E[T_2]} \tag{12}$$

Adopting the assumptions of the model and computing the quantities forming the above formula, the availability coefficient of digital commutative nodes can be recorded in the form of:

$$K_{g_{WK}} = K_{g_{WP}} = \frac{\mu^2 + \lambda\, p_\alpha(\lambda+\mu)}{\mu^2 + \lambda\, p_\alpha(\lambda+\mu) + \lambda(1-p_\alpha)\mu^2(\frac{2}{\beta} + \frac{2}{\mu}) + \frac{\lambda^2 p_\alpha(\lambda+3\mu)}{\lambda+\mu}} \tag{13}$$

3.3. Availability Assessment of Traffic Control Officer's Post and Dispatcher's Post

Analysing the exploitation process of traffic control officer's post and dispatcher's post, the following exploitation states can be differentiated:

s_0 - state of proper realisation of the function in the dispatch communication system (both devices for realisation of the functions – a console and a telephone operate properly at the post),

s_2 - state of proper realisation of the function in the dispatch communication system by a single device,

s_1- state in which functions in the dispatch communication system are impossible to be realised (both devices for realisation of the functions are out of order).

Matrix of transitions between exploitation states takes in this case the following form:

$$P = \begin{bmatrix} 1-\lambda_{02} & 0 & \lambda_{02} \\ \mu_{10} & 1-\mu_{10} & 0 \\ \mu_{20} & \lambda_{21} & 0 \end{bmatrix} \tag{14}$$

where: i = 0,1,2;

j= 0,1,2;

The system of equations, determined for the matrix of the system transitions with entered excessive data and in conditions of the system's stationary character and for t → ∞, is replaceable with the following system of algebraic equations:

$$
\begin{gathered}
0 = -\lambda_{02}P_0 + \mu_{20}P_2 + \mu_{10}P_1 \\
0 = \lambda_{21}P_2 - \mu_{10}P_1 \\
0 = \lambda_{02}P_0 - (\lambda_{21} + \mu_{20})P_3
\end{gathered}
\tag{15}
$$

Upon specifying which of the states correspond to states of operability, and which ones to the states of inoperability, the availability coefficient of the system can be determined as a total of probabilities of the system's stay in states of proper realisation of data transmission function. In case of the hereto discussed system, dependence on availability coefficient of K_{gTD} will take a form expressed by equation:

$$K_{gTD} = P_0 + P_3 \tag{16}$$

Probabilities P_0 and P_3 have been obtained by solving the system of equations, however, in order to obtain unequivocal solution, one of the equations (in case of the hereto discussed system – the first one) has been replaced with equation:

$$\sum_{i=0}^{k} P_i = P_0 + P_1 + P_3 = 1 \tag{17}$$

where: k – the number of all exploitation states.

A solution of this system of equations is stationary probabilities of the system's residence in states allowing for realisation of services to transmit data from those posts:

$$P_0 = \frac{(\lambda_{21} + \mu_{20})\mu_{10}}{\mu_{10}(\lambda_{21} + \mu_{20} + \lambda_{02}) + \lambda_{21}\lambda_{02}}$$

$$P_3 = \frac{\lambda_{02}\mu_{10}}{\mu_{10}(\lambda_{21} + \mu_{20} + \lambda_{02}) + \lambda_{21}\lambda_{02}}$$

Thus, the availability coefficient of traffic control officer's post and dispatcher's post will take the form of:

$$K_{g_{TD}} = P_0 + P_3 = \frac{(\lambda_{21} + \lambda_{02} + \mu_{20})\mu_{10}}{\mu_{10}(\lambda_{21} + \mu_{20} + \lambda_{02}) + \lambda_{21}\lambda_{02}} \tag{18}$$

3.4. Assessment of Fibre Optics Link Availability

When modelling single optic telecommunication links, using series structure, the availability of such component elements as: amplifiers, cables, regenerators should be taken into consideration. Analysing the optic link exploitation process, the following effectiveness states can be determined:

- S_0 – state of proper realisation of transmission functions in the dispatch communication system,
- S_1 – state in which transmission realisation functions in the dispatch communication system are impossible to be realised.

The matrix of probabilities of transitions between the determined states takes the form of:

$$\mathbf{P} = \begin{bmatrix} 1-\lambda_k & \lambda_k \\ \mu_k & 1-\mu_k \end{bmatrix} \tag{19}$$

Using the previously presented way, the stationary value of the availability coefficient of optic amplifier, regenerator, and transponder can be determined in the form of:

$$K_{g\ trans} = K_{g\ reg} = K_{g\ wzm} = P_0 = \frac{\mu_k}{\mu_k + \lambda_k} \tag{20}$$

where index k denotes parameters of a distribution of proper operation time and repair time, respectively for: optic amplifier, regenerator, and transponder.

The operational availability of the entire optic link is also influenced by such component elements as cables the availability of which is computed using the Cable Cut (*CC*) parameter that expresses an average length of cable that disconnects once during the whole year (8760 [h]). The *CC* coefficient is expressed in kilometres, while the value of $MTBF_K$ *(Mean Time Between Failure)* parameter for the cable, the length of which is L, is determined in hours and constitutes [2]:

$$MTBF_K(L) = \frac{CC \times 8760}{L} \tag{21}$$

Thus, the value of the availability coefficient for fibre optics cable can be written in a form of:

$$K_{gK} = P_0 = \frac{MTBF_K}{MTBF_K + MTTR_K} \tag{22}$$

where: $MTTR_{K}$ – is the repair time of the fibre optics cable

The above considerations can be illustrated in the form of dependence that can be used to determine the value of the operational availability coefficient of dispatch communication network for transmission of messages between posts of traffic control officers and the dispatcher, assuming that data transmission realisations commences by using the functional series structure of the system. The fibre optics transmission line has been assumed neither to have amplifiers nor regenerators, which is acceptable at typical and quite short distances (a few kilometres) for dispatch communication sections. Upon considering the formulas that illustrate operational availability coefficients for determined subsystems of the digital dispatch communication network, the dependence can be presented for a general exploitation effectiveness coefficient that is expressed by stationary operational availability. The formula ca be written in the following form:

$$K_{gLD} = \left[\frac{\mu^2 + \lambda p_\alpha(\lambda + \mu)}{\mu^2 + \lambda p_\alpha(\lambda+\mu) + \lambda(1-p_\alpha)\mu^2(\frac{2}{\beta} + \frac{2}{\mu}) + \frac{\lambda^2 p_\alpha(\lambda + 3\mu)}{\lambda + \mu}} \right]^2 \cdot \\ \cdot \left[\frac{(\lambda_{21} + \lambda_{02} + \mu_{20})\mu_{10}}{\mu_{10}(\lambda_{21} + \mu_{20} + \lambda_{02}) + \lambda_{21}\lambda_{02}} \right]^2 \cdot \left[\frac{\mu_k}{\mu_k + \lambda_k} \right]^2 \cdot \left[\frac{MTBF_K}{MTBF_K + MTTR_K} \right] \tag{23}$$

Determination of the availability coefficient of dispatch communication network requires knowledge about intensity of transitions between specified exploitation states. Numerical values of those parameters can be estimated based on reliability forecasting methods, which in case of systems being introduced for exploitation (in particular, this refers to the hereto considered digital dispatch communication system in Polish railway transport) is justified. Either exploitation research studies or data originating from exploitation tests of similar elements of the system can be another way to acquire data on numerical values occurring in the above dependence (23). This refers to estimation of fibre optics telecommunication lines parameters.

4. Example of Digital Dispatch Communication System Operational Availability Assessment

Assessment of operational availability, using the assessment method suggested above, has been made for digital dispatch communication system and data transmission (Fig. 1). The data – required for computations of coefficients of operational availability, which is one of the measurements of telematic systems operational availability– originate from Railway Telecommunications Plants - ZTK (Warsaw Plant, Poznan Plant, and Gdansk Plant) and refer mostly to information on faults of specified elements and devices and repair times of those faulty devices. If there is no data on behaviour of such devices in the exploitation process, then data has been adopted included in technical – exploitation requirements for this type of systems and data and voice transmission networks in railway communications [9], [10]. The parameters prediction methods, presented in [1], [6], and [7], have also been used for assessing intensity of damages of the devices and intensity of repairs. Using dependencies (19), (24), (26), (27), (28), and (29), the following results have been obtained.

Assumed are the following values of damages parameters function and renewal of the digital commutative system:

$\lambda = 1.25\ 10^{-5}$ 1/h, $\mu = 0.65$[1/h], p_{α}=0.99998, β=0.405

Compliant to dependence (19), the availability coefficient of commutative systems, being the nodes of the assessed system, has the value of:

$$Kg_{WK} = Kg_{WP} = 0{,}99985$$

Assumptions on parameters of intensity of damages and intensity of repairs:

$\lambda = 3.45\ 10^{-5}$ 1/h, μ =0.41 [1/h]

Using the dependence (18), the value of the availability coefficient is computable for posts of traffic control officer and section dispatcher:

$$K_{g_{TD}} == 0{,}99999$$

For fibre optics line peripherals, the following values have been adopted referring to parameters of damages intensity and repair intensity of transponder, regenerator, and amplifier, respectively:

$\lambda_k = 8.4\ 10^{-6}$ 1/h, $\mu_k = 1.5$ 1/h

Basing on dependence (26), the value of the availability coefficient has been computed:

$$Kg_{trans} = Kg_{reg} = Kg_{wzm} = 0{,}99998$$

For fibre optics cable, the following values of dependencies (21) and (22) components are assumed:

CC = 95, L = 6890 km, $MTTR_K$ = 5.3 h

$$MTBF_K(L) = \frac{CC \times 8760}{L} = 120{,}8[h],\ K_{gK} = \frac{MTBF_K}{MTBF_K + MTTR_K} = 0{,}9579$$

Considering the dependence (23), the value of the availability coefficient of the digital dispatch communication system, being used in Polish railways for communication between the traffic control officer and the dispatcher is:

$$K_{gLD} = 0{,}95762$$

5. Summary

Analysing the results, the proposed hereto in the paper usefulness of the way to assess the level of occupancy of telematic system in railway transport for execution of tasks, related to maintenance of train traffic, can be found. Moreover, it can be stated here that reliability parameters of individual devices of digital dispatch communication system are quite good (high values of availability coefficients). The availability coefficient value of such system for communication between the traffic control officer and the dispatcher is not as satisfactory. Comparing the value with recommendations, included in inter alia [3], this is a difference of ca. 0.043. The lower value of the availability coefficient of the entire system results from a size of the availability coefficient of commutative systems (although it does not essentially differ from recommendations related to availability of digital commutative systems), and first of all from the value of the availability coefficient of fibre optics transmission line. The availability of the fibre optics line is influenced by quite high value of the cable cut (CC) coefficient, which in railway conditions has often been the case over the past few years due to modernisation works of railway lines, alongside which fibre optics cables are placed. The availability of the hereto assessed system can be improved through better protection of fibre optics lines against incidental or intended (thefts) damages and organisation of services responsible for maintenance of those lines (reduction of damage removal time).

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