RELIABILITY AND MAINTENANCE ANALYSIS OF CCTV SYSTEMS USED IN RAIL TRANSPORT

ANALIZA NIEZAWODNOŚCIOWO-EKSPLOATACYJNA SYSTEMÓW MONITORINGU WIZYJNEGO STOSOWANYCH W OBIEKTACH KOLEJOWYCH

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Abstract: CCTV systems are widely used across plethora of industrial areas including transport, where their function is to support transport telematics systems. Among others, they are used to ensure travel safety. This paper presented a reliability and maintenance analysis of CCTV. It led to building a relationships graph and then Chapman–Kolmogorov system of equations was derived to describe it. Drawing on those equations, relationships for calculating probability of system staying in state of full ability S_{PZ} , state of the impendency over safety S_{ZB1} as well as state of unreliability of safety S_B were derived.

Keywords: Closed Circuit Television, reliability, operation and maintenance

Streszczenie: Systemy monitoringu wizyjnego są wykorzystywane w wielu obszarach przemysłu, w tym także w transporcie. Wspomagają wówczas realizację funkcji, które są świadczone przez systemy telematiki transportu. W artykule zaprezentowano analizę niezawodnościowo-eksploatacyjną systemów monitoringu wizyjnego. Umożliwiło to zaproponowanie grafu relacji, zaś następnie na utworzenie układu równań Kołmogorowa-Chapmana opisujących go. Na tej podstawie możliwe było wyznaczenie zależności pozwalających na obliczenie wartości prawdopodobieństw przebywania systemu w stanach: pełnej zdolności S_{PZ} , zagrożenia bezpieczeństwa S_{ZB1} oraz zawodności bezpieczeństwa S_B .

Słowa kluczowe: systemy monitoringu wizyjnego, niezawodność, eksploatacja

1. Introduction

CCTV systems are widely used across plethora of industrial areas including transport [16], where their function is to support transport telematics systems [9, 21, 22]. Among others, they are used to ensure travel safety. Then, the CCTV systems can be classified as electronic safety systems. They are used in both stationary facilities (e.g. railway stations, level crossings) and mobile objects (e.g. electric multiple units, passenger carriages, electric locomotives). Thanks to this, the level of safety of both travellers and transported cargo increases.

The CCTV systems installed in rail transport work in various maintenance conditions [4, 8]. Because they are elements responsible for safety, they should keep their usability. Therefore, the reliability and maintenance analysis of these systems is important. So far, the authors have analysed these systems' structures in terms of reliability. Some developments also concerned the reliability and maintenance analysis [17, 19] taking into account the relationships in the system with particular reference to issues related to power supply [15]. The paper showed general deliberations concerning the reliability and maintenance analysis of the CCTV systems with particular reference to restoration to the state of usability.

2. Characteristics of the CCTV systems

The Closed Circuit Television (CCTV) is used as one of the subsystems of transport telematics systems. It is a set of technical and programme measures designed for observing, detecting, recording, and signalling conditions indicating the existence of danger. They may include (depending on configuration) the following basic devices [6, 13, 14]:

- cameras with lenses,
- transmission media with interfaces,
- recorders,
- monitors,
- power systems,
- lighting systems,
- other systems (e.g. protection systems, processing devices, filter systems, and elements screening electromagnetic disturbances).

Fig. 1 illustrates the most common CCTV system, which consists of cameras (usually up to 16), a digital video recorder, and two monitors. The first monitor shows the overview of all connected cameras. The overview can be divided (usually into 4, 9, and 16 fields). On the second monitor, a picture from the camera that currently detected motion through a motion detection system is shown. Events are recorded digitally via a digital video recorder on HDD hard drives. The digital video recorder may have a lot of functions, such as: a sequential switcher, a video splitter, an event recording system integrated with motion detection. It is most often equipped with an Ethernet card as well, thanks to which remote handling via the Internet (the Intranet) using the TCP/IP protocol is possible [7]. Such solutions are used in, among others, railway stations.

Fig. 1 An example of the CCTV system

In rail transport, there are different kinds of electromagnetic disturbances. Therefore, it is important to use solutions that are resistant to these disturbances, or minimise their effect [3, 12]. One of the used solutions is the use of a transmission medium – an optical fibre [18]. The advantages of this solution are, among others, low attenuation, resistance to external magnetic and electric fields, and the lack of outwards emission of energy. It is used between facilities situated within a vast rail area. It requires the use of converters that convert electrical signals into optical ones and vice versa. Vibrations are an important issue that should be taken into account during the design of the CCTV systems (especially in mobile transport objects) [2].

3. Selected issues of reliability and maintenance analysis of CCTV systems used in rail transport

Analysing the CCTV system used in rail transport, it can be said that it has a mixed structure [1, 5, 20]. For the purpose of further analysis, a management and archiving centre, as well as cameras were distinguished. Damage of the management and archiving centre causes the transition of the system from the state of complete usability $R_O(t)$ to the state of unreliability of safety $Q_B(t)$. Damage of one of the cameras causes the transition of the system from the state of complete usability $R_O(t)$ to the state of the impendancy over safety $Q_{ZB1}(t)$. Transitions restoring the state of complete usability are also possible (renewal process [10, 11]):

- from the state of the impendancy over safety ($Q_{ZB1}(t)$) to the state of complete usability $R_O(t)$ with the intensity of μ_{ZB2} ,
- from the state of the unreliability of safety ($Q_B(t)$) to the state of complete usability $R_O(t)$ with the intensity of μ_{ZB1} .

Fig. 2 illustrates the relationships in the considered system in terms of the reliability and maintenance aspect.

Fig. 2 Reliability and maintenance relationships in the CCTV system

Markings in fig.:

- $R_0(t)$ – the probability function of the system staying in the state of complete usability S_{PZ} ,
- $Q_{ZB}(t)$ – the probability function of the system staying in the state of the independency over safety S_{ZB} ,
- $Q_B(t)$ – the probability function of the system staying in the state of unreliability of safety S_B ,
- λ_{B1} – intensity of transitions of the management and archiving centre,
- $\lambda_{ZB2}, \lambda_{ZB3}$ – intensity of transitions of cameras,
- μ_{B1} – intensity of restoration of the state of usability of the management and archiving centre,
- μ_{ZB2} – intensity of restoration of the state of usability of the cameras.

The system shown in Fig. 2 can be described by the following Chapman–Kolmogorov equations:

$$\begin{aligned}
 R'_0(t) &= -\lambda_{B1} \cdot R_0(t) - \lambda_{ZB2} \cdot R_0(t) + \mu_{ZB2} \cdot Q_{ZB1}(t) + \mu_{B1} \cdot Q_B(t) \\
 Q'_{ZB1}(t) &= \lambda_{ZB2} \cdot R_0(t) - \lambda_{ZB3} \cdot Q_{ZB1}(t) - \mu_{ZB2} \cdot Q_{ZB1}(t) \\
 Q'_B(t) &= \lambda_{B1} \cdot R_0(t) + \lambda_{ZB3} \cdot Q_{ZB1}(t) - \mu_{B1} \cdot Q_B(t)
 \end{aligned} \tag{1}$$

Assuming the baseline condition:

$$\begin{aligned} R_0(0) &= 1 \\ Q_{ZB1}(0) &= Q_B(0) = 0 \end{aligned} \quad (2)$$

and applying the Laplace transform, we obtain the following system of linear equations:

$$\begin{aligned} s \cdot R_0^*(s) - 1 &= -\lambda_{B1} \cdot R_0^*(s) - \lambda_{ZB2} \cdot R_0^*(s) + \mu_{ZB2} \cdot Q_{ZB1}^*(s) + \mu_{B1} \cdot Q_B^*(s) \\ s \cdot Q_{ZB1}^*(s) &= \lambda_{ZB2} \cdot R_0^*(s) - \lambda_{ZB3} \cdot Q_{ZB1}^*(s) - \mu_{ZB2} \cdot Q_{ZB1}^*(s) \\ s \cdot Q_B^*(s) &= \lambda_{B1} \cdot R_0^*(s) + \lambda_{ZB3} \cdot Q_{ZB1}^*(s) - \mu_{B1} \cdot Q_B^*(s) \end{aligned} \quad (3)$$

Probabilities of the system staying in the distinguished maintenance states from the symbolic (Laplace's) perspective are in the following form:

$$\begin{aligned} R_0^*(s) &= \frac{s^2 + s \cdot \mu_{B1} + s \cdot \lambda_{ZB3} + s \cdot \mu_{ZB2} + \mu_{B1} \cdot \lambda_{ZB3} + \mu_{B1} \cdot \mu_{ZB2}}{s^3 + s^2 \cdot (\lambda_{B1} + \mu_{B1} + \lambda_{ZB2} + \lambda_{ZB3} + \mu_{ZB2}) +} \\ &\quad + s \cdot \left(\lambda_{B1} \cdot \lambda_{ZB3} + \lambda_{B1} \cdot \mu_{ZB2} + \mu_{B1} \cdot \lambda_{ZB2} + \mu_{B1} \cdot \lambda_{ZB3} + \right. \\ &\quad \left. + \mu_{B1} \cdot \mu_{ZB2} + \lambda_{ZB2} \cdot \lambda_{ZB3} \right) \\ Q_{ZB1}^*(s) &= \frac{s \cdot \lambda_{ZB2} + \mu_{B1} \cdot \lambda_{ZB2}}{s^3 + s^2 \cdot (\lambda_{B1} + \mu_{B1} + \lambda_{ZB2} + \lambda_{ZB3} + \mu_{ZB2}) +} \\ &\quad + s \cdot \left(\lambda_{B1} \cdot \lambda_{ZB3} + \lambda_{B1} \cdot \mu_{ZB2} + \mu_{B1} \cdot \lambda_{ZB2} + \mu_{B1} \cdot \lambda_{ZB3} + \right. \\ &\quad \left. + \mu_{B1} \cdot \mu_{ZB2} + \lambda_{ZB2} \cdot \lambda_{ZB3} \right) \\ Q_B^*(s) &= \frac{s \cdot \lambda_{B1} + \lambda_{B1} \cdot \lambda_{ZB3} + \lambda_{B1} \cdot \mu_{ZB2} + \lambda_{ZB2} \cdot \lambda_{ZB3}}{s^3 + s^2 \cdot (\lambda_{B1} + \mu_{B1} + \lambda_{ZB2} + \lambda_{ZB3} + \mu_{ZB2}) +} \\ &\quad + s \cdot \left(\lambda_{B1} \cdot \lambda_{ZB3} + \lambda_{B1} \cdot \mu_{ZB2} + \mu_{B1} \cdot \lambda_{ZB2} + \mu_{B1} \cdot \lambda_{ZB3} + \right. \\ &\quad \left. + \mu_{B1} \cdot \mu_{ZB2} + \lambda_{ZB2} \cdot \lambda_{ZB3} \right) \end{aligned} \quad (4)$$

The solution of the above mentioned set of equations in the field of time is the next step of the analysis and is not discussed there.

Received relationships (4) enable the determination of the probabilities of the CCTV system staying in the state of complete usability R_0 , the impendency over safety Q_{ZB1} , and unreliability of safety Q_B .

4. Reliability and maintenance modelling of CCTV systems used in rail transport

Simulation and computer methods and studies give an opportunity to determine influence of the reliability and maintenance parameters of particular elements on reliability of the entire system relatively fast. Of course, the reliability structure of the system and the reliability characteristics of the particular elements and systems must be known in advance.

Thanks to the computer assistance, calculations enabling determination of the probability of the system staying in the state of complete usability can be made. Such procedure is shown in the following example.

Example

Assuming the following values describing the analysed system:

- duration of research – 1 year (the value of this time is given in the units as hours [h]):

$$t = 8760 \text{ [h]}$$

- reliability R_{B1} :

$$R_{B1}(t) = 0,99$$

- reliability R_{ZB2} :

$$R_{ZB2}(t) = 0,95$$

- reliability R_{ZB3} :

$$R_{ZB3}(t) = 0,97$$

Knowing the value of reliability R_{B1} , you can estimate the intensity of transitions from the state of complete usability to the state of unreliability of safety. Assuming the simplest, exponential model of distribution of usability time, we can use the following relationship:

$$R_{B1}(t) = e^{-\lambda_{B1}t} \text{ for } t \geq 0$$

so

$$\lambda_{B1} = -\frac{\ln R_{B1}(t)}{t}$$

For $t = 8760 \text{ [h]}$ and $R_{B1}(t) = 0,99$ we obtain:

$$\lambda_{B1} = -\frac{\ln R_{B1}(t)}{t} = -\frac{\ln 0,99}{8760} = 1,147298 \cdot 10^{-6} \left[\frac{1}{h} \right]$$

Knowing the value of reliability R_{ZB2} , the intensity of transitions from the state of complete usability to the state of impendency over safety can be estimated.

Assuming the simplest, exponential model of distribution of usability time, the following relationship can be used:

$$R_{ZB2}(t) = e^{-\lambda_{ZB2}t} \text{ for } t \geq 0$$

so

$$\lambda_{ZB2} = -\frac{\ln R_{ZB2}(t)}{t}$$

For $t = 8760 [h]$ and $R_{ZB2}(t) = 0,95$ we obtain:

$$\lambda_{ZB2} = -\frac{\ln R_{ZB2}(t)}{t} = -\frac{\ln 0,95}{8760} = 5,855398 \cdot 10^{-6} \left[\frac{1}{h} \right]$$

Knowing the value of reliability R_{ZB3} , the intensity of transitions from the state of complete usability to the state of impendency over safety can be estimated. Assuming the simplest, exponential model of distribution of usability time, the following relationship can be used:

$$R_{ZB3}(t) = e^{-\lambda_{ZB3}t} \text{ for } t \geq 0$$

so

$$\lambda_{ZB3} = -\frac{\ln R_{ZB3}(t)}{t}$$

For $t = 8760 [h]$ and $R_{ZB3}(t) = 0,97$ we obtain:

$$\lambda_{ZB3} = -\frac{\ln R_{ZB3}(t)}{t} = -\frac{\ln 0,97}{8760} = 3,477078 \cdot 10^{-6} \left[\frac{1}{h} \right]$$

We obtain:

$$R_0^*(s) = \frac{5,43 \cdot 10^{42} \cdot s + 5,43 \cdot 10^{42} \cdot \mu_{B1} + 1,56 \cdot 10^{48} \cdot s^2 + 1,56 \cdot 10^{48} \cdot s \cdot \mu_{B1} + 1,56 \cdot 10^{48} \cdot s \cdot \mu_{ZB2} + 1,56 \cdot 10^{48} \cdot \mu_{B1} \cdot \mu_{ZB2}}{3,8 \cdot 10^{37} \cdot s + 1,56 \cdot 10^{48} \cdot s^2 \cdot \mu_{B1} + 1,56 \cdot 10^{48} \cdot s^2 \cdot \mu_{ZB2} + 1,63 \cdot 10^{43} \cdot s^2 + 1,56 \cdot 10^{48} \cdot s^3 + 1,45 \cdot 10^{43} \cdot s \cdot \mu_{B1} + 1,79 \cdot 10^{42} \cdot s \cdot \mu_{ZB2} + 1,56 \cdot 10^{48} \cdot s \cdot \mu_{B1} \cdot \mu_{ZB2}}$$

Adopting $\mu_{ZB2} = 0,2$, $\mu_{B1} = 0,1$ and applying the Laplace transform, we obtain:

$$R_0 = 0,99995925$$

The practical application of the presented deliberations allows to determinate the influence of the values of transitions intensity μ_{ZB2} and μ_{B1} on the probability of the system staying in the state of complete usability R_0 . Intensities μ_{ZB2} and μ_{B1} must be understood as reciprocals of times t_{ZB2} and the t_{B1} intensities, which determine the time of restoration of the state of complete usability.

Generalising the presented deliberations, it can be concluded that, analysing the operation of the CCTV systems, their reliability and maintenance properties, as well as the influence of duration of renewal that will restore the state of complete usability should be taken into account.

5. Conclusion

The issue presented in the paper concerned the CCTV systems used in rail transport as the transport telematics system. This paper presented the reliability and maintenance analysis of these systems. It led to building a relationships graph and then Chapman–Kolmogorov system of equations was derived to describe it. Drawing on those equations, relationships for calculating probability of system staying in state of complete usability S_{PZ} , state of the impendency over safety S_{ZB1} as well as state of unreliability of safety S_B were derived. A particular emphasis was put on the issues of restoring the state of complete usability. In further research, it is planned to conduct analyses allowing to determine the influence of times of restoration of the state of complete usability on the probability of the system staying in the distinguished states.

6. Literature

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