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INVESTIGATION THE CORRELATION BETWEEN INTENSITY OF TRANSPORT PROCESS AND TRANSPORT SYSTEMS' FAILURES

The railway control systems' failures become real when they coincide with events from train traffic flow. The purpose of this paper is to propose a method for modelling the influence of railway traffic intensity on the safety of the railway transport movement. Correlation between the flow of railway control systems' failures and intensity of transport process is investigated and correlation coefficient is given.

BADANIE KORELACJI POMIĘDZY NATĘŻENIEM PROCESU TRANSPORTOWEGO A AWARIAMI SYSTEMÓW TRANSPORTU

Awarie systemów sterowania pociągami stają się realne, kiedy zachodzą jednocześnie z innymi zdarzeniami ruchu pociągów. Celem niniejszego referatu jest zaproponowanie metody modelowania wpływu natężenia ruchu kolejowego na bezpieczeństwo ruchu transportu kolejowego. Zbadana została korelacja pomiędzy przepływem awarii systemów sterowania kolejowego i natężeniem procesu transportowego oraz przedstawiono współczynnik korelacji.

1. INTRODUCTION

Railway control systems are integral part of modern society. They are becoming more complex and increasingly dependent on advanced technology. Today advanced railway industry has been actively replacing electromechanical relay-driven interlocking systems with complex microprocessor interlocking control devices. Rapid advances in technology in modern railway transport have resulted in increasing intensity of transport traffic flow and high-speed train movement. The need to effectively model railway transport systems and to predict their associated risk is a matter of extreme importance for reliability engineering.

In railway systems not every failure influences safety of the train movement. If general indicator for safety of transport process is: "The probability that for the time **ti** from the beginning of the transport process through route **i** till the moment of transfer to unsafe failure is not less than the time Ti for train traveling through the **i-th** route" [1] and if we assume that

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the "route" is train movement from signal to signal then criterion for safety of train movement will be absence of system failure during the time duration of the route.

Unsafe failures can be classified as: potential, real, realized, and catastrophic.

Fig.1. Types of system failures

Between each of these categories has probability distance. Catastrophic failures have less likelihood.

Railway systems are safety-critical systems. They "generate" their failures and the failures affect or not affect technological process of train movement. The flow of failures and repairs is Poisson. Obviously we have to consider not only safety of the systems but safety of the transportation process as well. The correlation between the two processes is complex and depends on the type of the railway station, the intensity of transport process through the station, the structure of the railway interlocking system and hierarchy of the failures.

Working system can be dangerous if:

- The system is technically imperfect from safety point of view.

The reasons for technically imperfect system may be:

  - If there is no technical solution
  - Because of limited resources, funds or time.

- In a technically perfect system there are mistakes made by manufacturer, installer, maintaining personnel, and so on.

Failed system is dangerous if:

- The system allows unsafe failures, which break totally, or partly system availability and cause the object of the safety to threat human life.
- When the system is in safe failure the human takes the control and enters wrong command.

Transportation process from the point of view of railway control system is flow of events consisting of trains' routes. The flow of transportation process has his parameters. The events in the transportation process are timetable determined and not determined routes. Determined routes are often violated by delays, so for the events of the flow of transportation process can be considered random time duration and random time of arrivals. The two flows have common crossing points and they are real dangerous failures of the system. Investigation and quantitative assessment of the relation between the two flows is complex and difficult matter

This research aims to assess the practical value of correlation between train traffic and system failures. The following objectives are pursued:

1. To describe and explain the method, including its assumptions (that is, to assess whether the approach is correct).
2. To assess whether the approach is mathematically sound.
3. To assess its practical value for safety criterion of transportation process.

Therefore, an additional research objective is:

4. To assess its practical value for predicting the probability of real dangerous failures at railway stations.

The results of this study will help us to develop an accurate model for analyzing and predicting catastrophic failures at railway stations.

2. SUGGESTED APPROACH IN ASSESSING THE CORRELATION.

A method for solving the correlation between the flow of failures and restorations and the flow of transport process is proposed below:

- For each system device insuring given route reliability/safety parameters have to be defined.
- Configuration and structure of the station and routes have to be defined. The safety parameters of the subsystems controlling each of the routes in the station have to be found e. i. probability of potential dangerous failures and MTTDF for every route subsystem.
- Traffic flow through the station has his parameters, which have to be determined on the base of statistical data.
- For each device in the route's subsystems the probability of real dangerous failures have to be assessed.
- The railway system's real dangerous failures are determined according to intensity of the traffic flow for each route subsystem in the station.

3. THE TRANSPORT FLOW PARAMETERS

A route is specified for each train movement through the station area. For the purpose of our investigation we assume that events in the train traffic flow are the time intervals between train entering the route and train stop at the end of the route.

Many factors such as human action, traffic control system's failures and restorations, delay propagation and timetable-free train movement change flow process and contribute determine traffic as random. If train movement flow is composed of discrete units, then a discrete counting distribution can be used to describe the arrivals at positions on the flow path.

The interarrival times and dwells are expected to have typical stochastic properties. The interarrival times during operation will generally exhibit small fluctuations. On the other hand, rather large variations are expected in the actual occupation times of particular system elements (e.g. platform tracks). For correct analisys a sufficient number of independent samples (greater than 100) have to be collected from transportation process over a sufficiently long period of time.

In our work a histogram is used to determine the distribution of measurable data of the transportation process. Histograms show the center (i.e., the location) of the data; spread, dispersion, skewness of the data. These features provide strong indications of the proper distributional model for the data. The probability plot or a goodness-of-fit test can be used to verify the distributional model. On the base of the statistical data we assume Poisson distribution for the events of the traffic flow e.i. time duration of the routes in the station.

There are two important general points in the statement of the Poisson distribution:

- the equation describes the probabilities of random occurrences.
- the equation is applicable to "intervals" on the space or time axes.

The Poisson distribution describes a wide range of phenomena in the sciences. The Poisson distribution is a mathematical rule that assigns probabilities to the number occurences. The only thing we have to know to specify the Poisson distribution is the mean number of occurences.

4. DYNAMIC MODELLING OF CORRELATION BETWEEN SYSTEM'S FAILURES AND TRAFFIC FLOW

Defining subsystem of one route: a set of system devices consisting of system elements controlling a route. If an arbitrary infra element from this set is occupied by one train, then all other infra elements inside the set are also blocked. Consequently, any other train cannot use the entire set of elements insuring a route, during the same time slot.

Quantitative analysis can be performed using conventional analysis techniques on the flat Markov chain, which is often preferable for small state spaces up to 50,000 states.

Continuous-time Markov chains can represent various system conditions such as the number of functioning resources of each type, the number of tasks of each type, the number of concurrently executing tasks, the states of recovery for each failed resource, and transition between states, which represent the change of the system state due to the occurrence of a simple or compound event such as the failure of one or more resources, the completion of executing tasks, or the arrival of trains.

Railway control systems are complex systems consisting of central control units and track-site devices. We assume that the system is operational as long as the control system is operational and route's subsystems are operational. Each route subsystem is using control units and track-site devices to ensure his route. We assume that the time to failure and restoration for each component is exponentially distributed, with the parameters λ and μ respectively. We also assume that the traffic flow is Poisson and his parameters through each route are the same. The parameters of the traffic flow through one route are correspondingly: β and time duration of a route γ.

The flows of system failures and restorations and the traffic flow are assumed to be independent. The system allows two simultaneous train routes. The behaviour of the system can be represented by the finite-state continuous-time Markov chain (CTMC) shown in Figure 2.

In the figure below the dynamic behaviour of railway system states is represented through Markov chains:

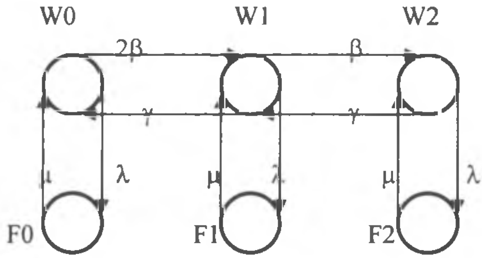

Fig.2. Markov model of railway system states

β - parameter of traffic flow.
γ = time to route parameter.
λ = time to failure parameter.
μ = time to repair parameter.

S1: W0: working system without train on a route.
S2: F0: system failure without train on the route.
S3: W1: working system with two trains on a route.
S4: F1: system failure with two trains on two routes.
S5: W2: working system with one train on a route.
S6: F2: system failure with one train on a route.
Mean times of system being in states Si are:
$m1=1/(\lambda+2\beta)$; $m2=1/\mu$; $m3=1/(\beta+\gamma+\lambda)$; $m4=1/\mu$; $m5=1/(\gamma+\lambda)$; $m6=1/\mu$;

The P matrix of the probabilities of transfers from state Si to Sj are given by:

$$P = \left\| \begin{array}{llllll} 0 & \lambda/(\lambda+2\beta) & 2\beta/(\lambda+2\beta) & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 & 0 \\ \gamma/(\beta+\gamma) & 0 & 0 & \lambda/(\beta+\gamma+\lambda) & \beta/(\beta+\gamma+\lambda) & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & \gamma(\gamma+\lambda)/ & 0 & 0 & \lambda/(\gamma+\lambda) \\ 0 & 0 & 0 & 0 & 1 & 0 \end{array} \right\|$$

The probability of system transfers from state i to state j is correspondingly:

$P_{12} = \lambda/(\lambda+2\beta)*[1-\exp(-t(\lambda+2\beta))]$
$P_{13} = 2\beta/(\lambda+2\beta)*[1-\exp(-t(\lambda+2\beta))]$
$P_{34} = \lambda/(\beta+\gamma+\lambda)*[1-\exp(-t(\beta+\gamma+\lambda))]$
$P_{35} = \beta/(\beta+\gamma+\lambda)*[1-\exp(-t(\beta+\gamma+\lambda))]$
$P_{56} = \lambda/(\gamma+\lambda)*[1-\exp(-t(\gamma+\lambda))]$

Given a Poisson distribution with rate β, the distribution of waiting times between states Si are:

$F_1(t) = 1\text{-}\exp(-t(\lambda+2\beta))$
$F_2(t) = 1\text{-}\exp(-t\mu)$
$F_3(t) = 1\text{-}\exp(-t(\beta+\gamma+\lambda))$
$F_4(t) = 1\text{-}\exp(-t\mu)$
$F_5(t) = 1\text{-}\exp(-t(\gamma+\lambda))$
$F_6(t) = 1\text{-}\exp(-t\mu)$

For a station with parameters $\lambda = 0.000005$, $\mu = 0.1$, $\beta = 1.9$, $\gamma = 12.98$ the homogeneous continuous –time Markov chains (CTMCs) is shown in Figure 3:

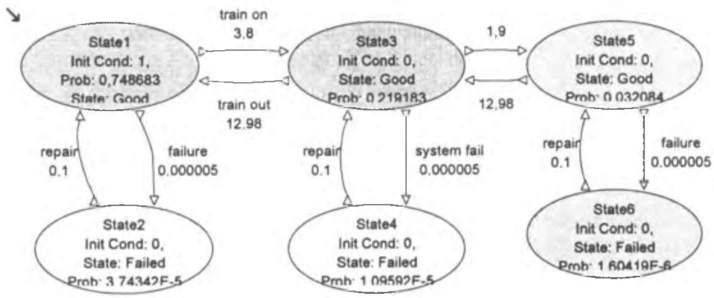

Fig.3. Dynamic modelling of the system states through homogeneous CTMCs

For the correlations P4/P2 and P6/P2 we obtain: 0.292 and 0.042 correspondingly. The intensity of the traffic flow is important factor for assessing the probability of real dangerous failures in railway stations. The results have shown that increasing intensity lead to increasing probability of catastrophic failures but don't consider the variations in time duration of the train's routes.

5. CONCLUSION

The investigation of the correlation between potential and real dangerous failures in railway systems will contribute more precisely assessment of safety of transport process. The influence of the intensity of transport process in railway stations is important as far as rapid advances in technology have resulted in increasing speed in railway transport.

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