TRANSBALTICA 2011

The 7th International Conference
May 5–6, 2011, Vilnius, Lithuania
Selected papers

ISSN 2029-2376 print / ISSN 2029-2384 online
ISBN 978-9955-28-840-4
http://transbaltica.vgtu.ltt

Vilnius Gediminas Technical University Transport Engineering Faculty, J. Basanavičiaus g. 28, LT-03224, Vilnius, Lithuania

RESEARCH RELIABILITY REALIZATION OF TRAIN SCHEDULE

Mareks Mezitis[1], Vladimirs Lubinskis[2], Julija Krepsha[3]

Riga Technical University (Riga, Latvia)
E-mails: [1]mareks.mezitis@rtu.lv, [2]vladimirs.lubinskis@apollo.lv, [3]julia_225@inbox.lv

Abstract. This article considers the realizing examples for automatic device with fault tolerance. The most important device structures with and no reservation are compared. The most common ways to increase fault tolerance are considered. The building for device structures witch duplication and optimal. The construction structures with redundancy and build in testing equipment BITE. We consider fault tolerance in systems of high risk of sudden failure. A comparison of economic composes in the recovery efficiency of devices. Proposed to build devices with high-availability operating conditions with the inevitable risk of harmful effects. We consider the probabilistic assessment of fault tolerance on each occasion.

Keywords: automatic device, duplication, redundancy, fault tolerance, sudden failure, risk of hazardous

1. Train-table and its reliability execution

Train-table is an organizing and technological foundation of the transportation process (Вентцель 1972). Schedule functionally integrates complex of technical means, depot work, rolling-stock, station in a single technological circuit. Reliable operation of this circuit provides trains movements on schedule.

But in real conditions in the technological circuit complex, that provides movements process, appears rejections, that lead to unforeseen schedule delays.

Failure rate of technical circuits i complex, defines:

$$\lambda_i = \frac{n_i(t + \Delta t) - n_i(t)}{\Delta t}, \quad i = 1, 2 \ldots K$$

where **K** – number of technological, technical and information complexes, its rejections affects trains movements and schedules implementation; $\mathbf{n_i(t)}$ – number of rejections, that causes disruption of schedule (number of delayed trains) with i complex in time t; $\mathbf{\Delta t}$ – the time of collection static dates.

Delays in the administration of trains may arise due to failures of locomotives, wagons, railroads, freight and passenger complexes, information complex (paperwork, management of transportation process).

Reliability of the timetable on the administration is determined by two parameters.

– Probability $\mathbf{P(\Delta t)}$ that all of trains during the period of time Δt (usually during a day) will be sent promptly on schedule.

– Availability coefficient ($\mathbf{K_Г}$) of all systems to perform work on the administration of trains in accordance with the schedule.

2. Definition of the P(Δt) index

This index can be determined using statistical dates on train movement according to the formula:

$$P(\Delta t) = 1 - \frac{\sum_{i=1}^{k} \lambda_i \cdot \Delta t}{N},$$

where N – number of trains that are departing during the day on the schedule;

$\sum_{i=1}^{k} \lambda_i \cdot \Delta t$ – number of detainees trains during the day.

However, performances reliability of schedule, that is calculated using aggregate statistics, not take into account the contribution of individual railway engineering and technical services to ensure uninterrupted movement of trains.

That's why appropriate evaluation of the reliability schedule taking into account the reliability and performance of the individual technological units that ensuring the movement of trains.

To determinate the rate **P(Δt),** taking into account performance of individual complexes, consider the system **S** which includes **K** complexes, providing the administration of trains in accordance with the schedule.

Process of functioning of this system can be described using mathematical model in the form of a Markov chain with discrete states and continuous time.

Let's consider that all **K** complexes as a single system **S** that can be in one of the following states:

– S0 – all of **K** complexes are serviceable and each complex in full and in due time shall serve for the train schedule

– S1 – in the first (for example in locomotives) complex appeared rejection (rejection – locomotives issuance for trains with delay, locomotives repair on the technical station, delay of locomotive drivers and the other rejections). Intensity of occurrence of failures in the first complex will be **λ1.** Rejections take the system from state **S0** to **S1.** Intensity recovery readiness of the complex to the administration of trains will be **μ1.**

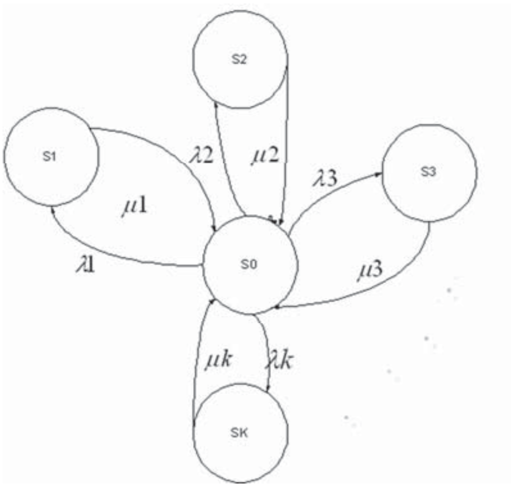
Similarly for the other complexes failure rate and recovery denote by

λ_i and μ_i, i – number of complex.

– S2 – rejection of the second complex

– Sk - rejection of the **k** complex.

Graph of system states:



The graph of system states can form the differential equations of Kolmogorov, which describe the random Markov process of changing states of the system.

Differential equations write using differentiation operator or stroke.

For example, train departures in accordance with the schedule provided by K = 4 complexes. Failures in the complexes appears in time intervals T – 2,4,6,8 hours, but complexes regenerates in time intervals T_B – 1, 1.25, 4, 7 hours respectively, it's equivalent to failure and regenerations intensities of complexes:

$$\lambda 1 = \frac{1}{2} \qquad \lambda 2 = \frac{1}{4} \qquad \lambda 3 = \frac{1}{6} \qquad \lambda 4 = \frac{1}{8}$$

$$\mu 1 = 1 \qquad \mu 2 = \frac{1}{1.25} \qquad \mu 3 = \frac{1}{4} \qquad \mu 4 = \frac{1}{7}$$

If at the beginning of the period to take the assumption that all complexes are operable, that corresponds to the states of complexes

$$p0(t=0) = 1,\ \ p1(t=0) = 0,\ \ p2(t=0) = 0,\ p3(t=0) = 0,\ p4(t=0) = 0,$$

solving the system of differential equations it's possible to define how this probabilities is changing in time.

System of differential equations of Kolmogorov, defines from systems graph state. Each probability is defined – all that flows in state with sign "–" and follows out with a sign "+":

$$\frac{d}{dt}p0(t) = -(\lambda 1 + \lambda 2 + \lambda 3 + \lambda 4)\cdot p0(t) + \mu 1 \cdot p1(t) +$$

$$+ \mu 2 \cdot p2(t) + \mu 3 \cdot p3(t) + \mu 4 \cdot p4(t)$$

$$\frac{d}{dt}p1(t) = \lambda 1 \cdot p0(t) - \mu 1 \cdot p1(t)$$

$$\frac{d}{dt}p2(t) = \lambda 2 \cdot p0(t) - \mu 2 \cdot p2(t)$$

$$\frac{d}{dt}p3(t) = \lambda 3 \cdot p0(t) - \mu 3 \cdot p3(t)$$

$$\frac{d}{dt}p4(t) = \lambda 4 \cdot p0(t) - \mu 4 \cdot p4(t)$$

Solution of differential equations system:

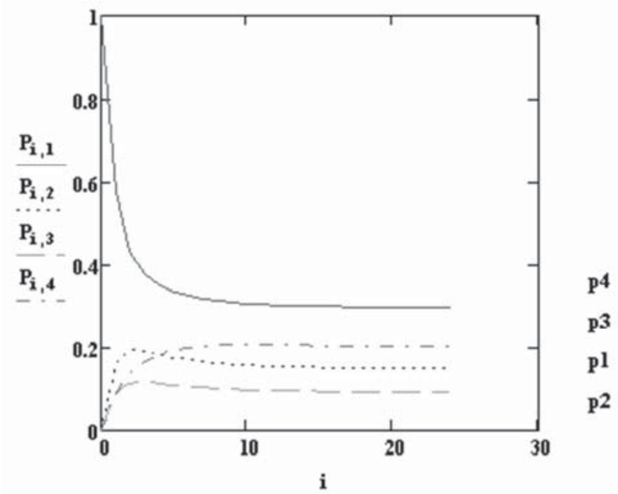
$$t := 0 \quad tk := 24 \quad h := 1 \quad n := \frac{tk - t}{h}$$

$$p := \begin{pmatrix} 1 \\ 0 \\ 0 \\ 0 \\ 0 \end{pmatrix} \qquad n = 24 \qquad i := 0, 1 .. n$$

$$f(t,p) := \begin{bmatrix} -(\lambda 1 + \lambda 2 + \lambda 3 + \lambda 4)\cdot p_0 + \mu 1 \cdot p_1 + \mu 2 \cdot p_2 + \mu 3 \cdot p_3 + \mu 4 \cdot p_4 \\ \lambda 1 \cdot p_0 - \mu 1 \cdot p_1 \\ \lambda 2 \cdot p_0 - \mu 2 \cdot p_2 \\ \lambda 3 \cdot p_0 - \mu 3 \cdot p_3 \\ \lambda 4 \cdot p_0 - \mu 4 \cdot p_4 \end{bmatrix}$$

$$P := \mathrm{rkfixed}(p, t, tk, n, f)$$

Graph of the probability S1, S2, S3, S4 of the complexes on time



Probabilities depend on the ratio of the intervals of complexes regeneration time and time between rejections. Probability that complex will be defective increases with increasing ratio $\frac{\mathbf{Tb}}{\mathbf{T}}$.

The chart shows that the least reliable is fourth complex with ratio 0.875, but the most reliable is second complex with ratio 0.313.

The required probability **P(Δt) –** probability that all of trains during the considered period **Δt** (during the day) will be sent without delay, right on schedule. This probability is the probability that all technological systems that provides movements of trains during the day.

As seen in the chart, state probability of each complex varies during the day from the initial state when all the complexes were operable to a steady state with certain probabilities that appropriate complexes will be operable.

Obviously, **P(Δt)** value equal to the probability that all technological complexes during the considered period will be operable – $\mathbf{P}(\Delta\mathbf{t}) = \mathbf{1} - (\mathbf{p1} + \mathbf{p2} + \mathbf{p3} + \mathbf{p4})$.

In the stationary conditions of complex working, probability **P(Δt)** is availability of the system of complexes **S,** this coefficient value can be determined from the solution of differential equations if t value is large.

$$\mathbf{P_{24,1}: = 1 - (P_{24,2} + P_{24,3} + P_{24,4} + P_{24,5})}$$
$$\mathbf{P_{24,1} = 0.299}$$

3. Systems stationary readiness coefficient definition for train administration in schedule

In stationary mode of system its state probabilities can be defined using system of algebraic equations which are compiled by the rule of a flux balance (that in the corresponding state flows equal to that of this state follows (Грунтов 1986)).

According to this rule from graph of states write the system of algebraic equations.

$$-(\lambda1 + \lambda2 + \lambda3 + \lambda4)\cdot p_0 + \mu1 \cdot p_1 +$$
$$+ \mu2 \cdot p_2 + \mu3 \cdot p_3 + \mu4 \cdot p_4 = 0$$
$$\lambda1 \cdot p_0 - \mu1 \cdot p_1 = 0$$
$$\lambda2 \cdot p_0 - \mu2 \cdot p_2 = 0$$
$$\lambda3 \cdot p_0 - \mu3 \cdot p_3 = 0$$
$$\lambda4 \cdot p_0 - \mu4 \cdot p_4 = 0$$

This system consists of five equations, but linearly depended only four equations because the first equation is a sum of a next four equations.

From this four equations,

$$\lambda1 \cdot \mathbf{p_0} - \mu1 \cdot \mathbf{p_1} = \mathbf{0}$$
$$\lambda2 \cdot \mathbf{p_0} - \mu2 \cdot \mathbf{p_2} = \mathbf{0}$$
$$\lambda3 \cdot \mathbf{p_0} - \mu3 \cdot \mathbf{p_3} = \mathbf{0}$$
$$\lambda4 \cdot \mathbf{p_0} - \mu4 \cdot \mathbf{p_4} = \mathbf{0}$$

obtain the expression for P_0 probabilities definition, that all technological complexes system in a stationary mode will be serviceable and provide train administration with the schedule.

Summing this equations and carrying out simple transformations, we have:

$$\mathbf{p0}\left(\frac{\lambda1}{\mu1} + \frac{\lambda2}{\mu2} + \frac{\lambda3}{\mu3} + \frac{\lambda4}{\mu4}\right) = \mathbf{p1} + \mathbf{p2} + \mathbf{p3} + \mathbf{p4}.$$

Using the normalizing condition

$$P0 + p1 + p2 + p3 + p4 = 1,$$

obtain:

$$\mathbf{p0} = \mathbf{Kg} = \frac{1}{1 + \left(\frac{\lambda1}{\mu1} + \frac{\lambda2}{\mu2} + \frac{\lambda3}{\mu3} + \frac{\lambda4}{\mu4}\right)}$$

$$\mathbf{p0}\left(\frac{\lambda1}{\mu1} + \frac{\lambda2}{\mu2} + \frac{\lambda3}{\mu3} + \frac{\lambda4}{\mu4}\right) = \mathbf{1} - \mathbf{p0}$$

General form for system with K complexes:

$$\mathbf{p0} = \mathbf{Kg} = \frac{1}{1 + \sum_{i=1}^{k} \frac{\lambda_i}{\mu_i}} \qquad (1)$$

The resulting formula defines systems K complexes generic availability that ensuring the movement of trains on schedule. It's necessary to express the quantity K_g through private rates of readiness of individual complexes to assess the contribution of individual complexes in the reliability on the timetable. Availability of the complex i defined with known formula:

$$\mathbf{kgi} = \frac{\lambda\mathbf{i}}{\lambda\mathbf{i} + \mu\mathbf{i}}. \tag{1A}$$

Hence the intensity of recovery in i complex:

$$\mu\mathbf{i} = \mathbf{kgi} \cdot \frac{\lambda\mathbf{i}}{1 - \mathbf{kgi}}$$

Substitute μi in the formula (1):

$$\mathbf{Kg} = \frac{1}{1 + \sum_{i=1}^{k} \frac{\lambda i}{kgi \cdot \frac{\lambda i}{1 - kgi}}} = \frac{1}{1 + \sum_{i=1}^{k} \left(\frac{1}{kgi} - 1\right)} \tag{2}$$

Number of sent and detained trains in the schedule in the time Δt is a integral parts of the values N(t)*Kg, N(t)*(1-Kg) respectively.

Using formula (2) it's possible to define what part of trains delayed by the fault of specific complex.

Conclusion

The article considers the based questions that are related in problem for ensuring the train schedule.

When calculating the reliability of the timetable are taking in account locomotives, wagons and other parameters probabilities of failures that most significantly effect the organization of the transportation process.

In this article propose to consider probability of failure of individual elements as a unified systems **S** failure of one of the **K** complexes which can be in one of the most stable states:

- the system is fully operable
- System partially operable in case of failure of one or more complexes
- the system is completely inoperable.

The system of Kolmogorov differential equations was composed based on the theory of Markov chains.

Calculation of the reliability parameters of the timetable on this system showed that the least reliable is fourth complex with ratio $T_b/T = 0.875$, but the most reliable is second complex with ratio $T_b/T = 0.313$.

To assess the readiness factor authors of the article suggest using the system of algebraic equations which are compiled by the rule of a flux balance.

Based on the above calculations and theoretical hypotheses it can be argued that ensuring the reliability of the timetable depends of the intensity of failures and recoveries in any given complex of whole system.

References

Вентцель Е. С. 1972. Исследование операций. М.: “Сов. Радио”.

Грунтов П. С. 1986. Эксплуатационная надёжность станций. М.: Транспорт.