MODELING AND ANALYSING OF RAILWAY SECTION FUNCTIONING WITH RESPECT TO TRAFFIC RELIABILITY AND SAFETY

Nikolay Georgiev *

1.Introduction

Any transportation operation has the inherent need to provide safe, effective and efficient services to passenger, the shippers and consignees of manufactured goods and raw materials. Railways are not different-the railway transport is a special kind of society serving systems which in addition to fulfil inherent transportation activities must also involve safety-related functions. In other words, safety is considered to be a basic property immanent to such kind of systems.

Railways, like most transportation systems, are comprised of sub-systems and those sub-systems are made-up of components essential to their functioning. The degree of safety, effectiveness and efficiency of the railway depends on the availability and proper functioning of all of its sub-systems and components. Because there are many sub-systems and components and because they are often interdependent the analysis of railway reliability and safety requires a complex and systematic approach.

More specifically, this exposition shows how the analysis of railway reliability and safety can be best accomplished through the use of a mathematical model based on the relationships and interdependencies of:

-the functioning of a railway section relative to the performance of its sub-systems (e.g. stations and interstations);

-the functioning of the sub-systems relative to the performance of each sub-system's components (physical devices and equipment, human operators and maintainers and so on);

-the resultant reliability and safety at any particular point in time.

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2.A model of a railway section for traffic reliability and safety analysis

The railway section is a special kind of functioning system that is to be considered a set of sub-systems. From the point of view of railway reliability and safety the separate sub-systems are in series-as shown in Fig.1. It can be seen that a failure of any sub-system leads to a failure of the system and the time required to repair the failed sub-system is the time that the system remains inoperable, as the sub-system are in series. With the intent to develop a model

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Ing. Nikolay Georgiev, Department of Technology, organization and management of the transport, Higher School for Transport Engineering "Todor Kableshkov", Sofia, Bulgaria, phone: +359 2 717104, e-mail: safetyniky@mail.com

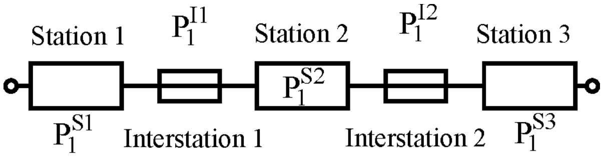

Fig.1

of railway section functioning let assume that the flow of events (failure, restorations) is a common flow (stationary Poisson flow). Through this flow the system (railway section) will go from one state to another. According to the theory [2] if the events flow due to which any system goes from one state to another is common flow then the accidental quantity "time for system staying in i state" has exponential distribution. In this case, the process of transition from any state to another is named Markov process. Namely by Markov analysis the work of some railway sub-system can be described. If the states of repair (restoration) are excluded, for the separate railway sub-systems are characteristic the following states.

<u>Railway station:</u>

1.A state of availability. In this case technical failures and mistakes of the operating personnel (assuring railway traffic) are missing. The probability of the sub-system being in this state is- P_1^S;

2. The railway station works with lowering of its effectiveness because of partial failures of railway road equipment. The probability of the sub-system being in this state is- P_2^S;

3.The sub-system does not work because of complete failure of the railway road equipment- P_3^S;

4.The railway station works with lowering of its effectiveness because of partial failure of the electricity supply means (overhead electricity line, other electricity devices and so on)- P_4^S;

5.The station does not work in consequence of complete failure of electricity supply means- P_5^S;

6.The station works with lowering of its effectiveness because of failure of the safety appliance (track and signal control, interlocking system and so on). In this case there is whatever technical failure in consequence of which the safety appliances can not execute their aims with respect to assurance of the traffic safety. The probability of the sub-system being in this state is- P_6^S;

7.A state characterized by the presence of personnel mistakes in consequence of which the safety appliances go to the so named protective failure- P_7^S;

8.A state characterized by the presence of personnel mistakes after technical failure of the safety appliances. This is very dangerous state with probability- P_8^S.

Here a state of the railway station when the man-operator is completely not available is not considered.

<u>Interstation:</u>

1.A state of availability. There are not any technical failures. The state is characterized by probability- P_1^I;

2.A state of complete unavailability in consequence of complete road failure- P_2^I;

3.The interstation works with lowering of its effectiveness in consequence of partial road damage- P_3^I;

4.The interstation is not available because of the presence of any complete failure of electricity supply means - P_4^I;

5.The interstation works with lowering of its effectiveness because of any partial failure of electricity supply means - P_5^I.

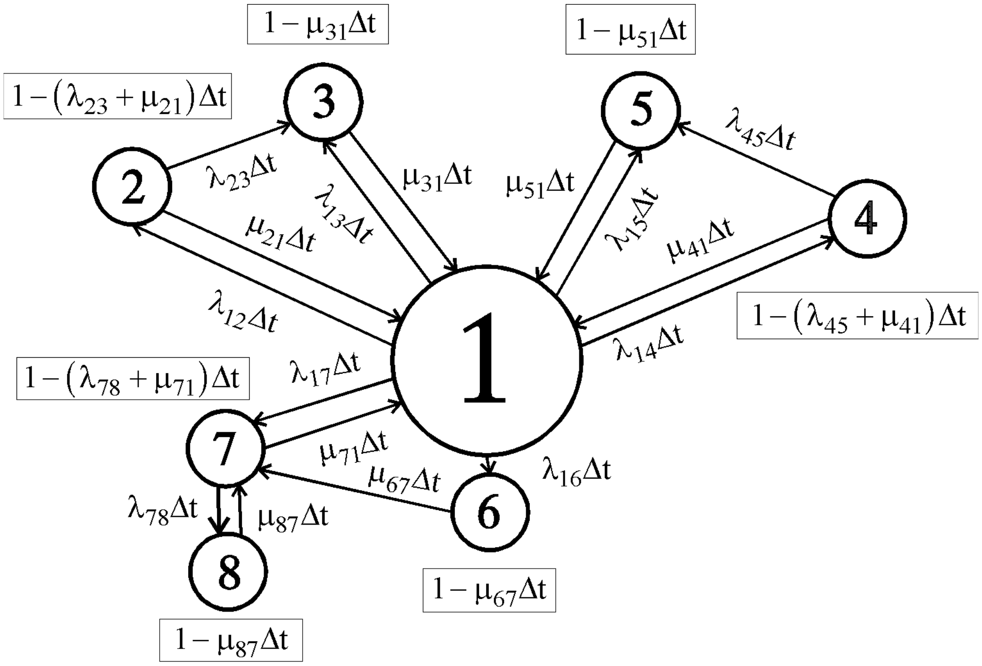

Fig.2

The transition from one state to another (for whatever sub-system) is determined by the flow of failures and repairs. This is with respect to all its components. This process is characterized by ***mean time between failure***- T_{F_i} (and ***failure rate***- λ_{ij}), ***mean time to repair***- T_{R_i} (and ***repair rate***- μ_{ij}): $\lambda_{ij}=\frac{1}{T_{F_i}}, \mu_{ij}=\frac{1}{T_{R_i}}$.

These arguments allow building of a graph which describes the separate states i of he sub-systems (railway station-Fig.2 and interstation-Fig.3) by the probabilities P_i. The Determining of P_i (probability of the state i, so called transition probability) is possible by Kolmogorov linear differential equations. Using the rules for building and resolving of these equations and the dependence $\sum_i P_i = 0$ it is possible to determine the probabilities any sub-system being on state i. The transitions from one state to another are expressed by the respective rates- λ_{ij} and μ_{ij}. With respect to the railway station the expressions take the forms:

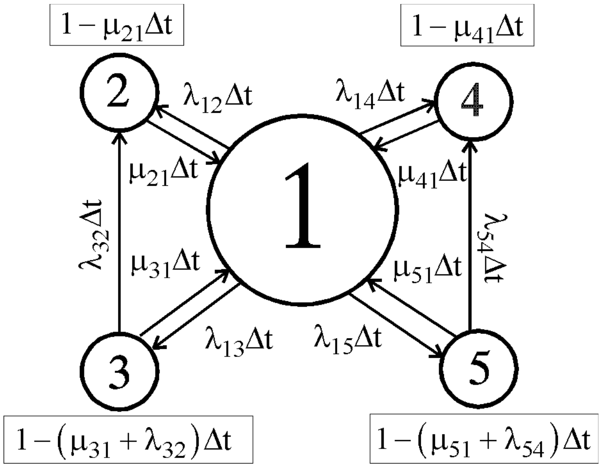

Fig.3

$$P_1^S = 1\Big/\Big[1+\frac{\lambda_{12}}{(\lambda_{23}+\mu_{21})}+\frac{(\lambda_{13}+\frac{\lambda_{12}.\lambda_{23}}{\lambda_{23}+\mu_{21}})}{\mu_{31}}+\frac{\lambda_{14}}{\lambda_{45}+\mu_{41}}+\frac{(\lambda_{15}+\frac{\lambda_{14}.\lambda_{45}}{\lambda_{45}+\mu_{41}})}{\mu_{51}}+\frac{\lambda_{16}}{\mu_{67}}+$$
$$+\frac{\lambda_{17}+\lambda_{16}}{\mu_{71}}+\frac{\lambda_{78}(\lambda_{17}+\lambda_{16})}{\mu_{71}\mu_{87}}\Big];\ P_2^S=\frac{P_1^S.\lambda_{12}}{\lambda_{23}+\mu_{21}};\ P_3^S=\frac{P_1^S}{\mu_{31}}(\lambda_{13}+\frac{\lambda_{12}.\lambda_{23}}{\lambda_{23}+\mu_{21}});\ P_4^S=\frac{P_1^S.\lambda_{14}}{\lambda_{45}+\mu_{41}}$$
$$P_5^S=\frac{P_1^S}{\mu_{51}}(\lambda_{15}+\frac{\lambda_{14}.\lambda_{45}}{\lambda_{45}+\mu_{41}});\ P_6^S=\frac{P_1^S.\lambda_{16}}{\mu_{67}};\ P_7^S=\frac{P_1^S(\lambda_{17}+\lambda_{16})}{\mu_{71}};\ P_8^S=\frac{P_1^S(\lambda_{17}+\lambda_{16})}{\mu_{71}}.\frac{\lambda_{78}}{\mu_{87}}.$$

For the sub-system interstation and by the same conditions we have:

$$P_1^I = 1\Big/\Big[1+(\frac{\lambda_{12}+\frac{\lambda_{13}.\lambda_{32}}{\lambda_{32}+\mu_{31}}}{\mu_{21}})+\frac{\lambda_{13}}{\lambda_{32}+\mu_{31}}+(\frac{\lambda_{14}+\frac{\lambda_{15}.\lambda_{54}}{\mu_{51}+\lambda_{54}}}{\mu_{41}})+\frac{\lambda_{15}}{\mu_{51}+\lambda_{54}}\Big];$$
$$P_2^I=\frac{P_1^I}{\mu_{21}}.(\lambda_{12}+\frac{\lambda_{13}.\lambda_{32}}{\lambda_{32}+\mu_{31}});\ P_3^I=\frac{P_1^I.\lambda_{13}}{\lambda_{32}+\mu_{31}};\ P_4^I=\frac{P_1^I}{\mu_{41}}.(\lambda_{14}+\frac{\lambda_{15}.\lambda_{54}}{(\mu_{51}+\lambda_{54})});\ P_5^I=\frac{P_1^I.\lambda_{15}}{\lambda_{54}+\mu_{51}}$$

Determining of P_i and having in mind the fact that the separate sub-systems are connected in series with respect to railway traffic reliability and safety we can obtain the probability that the system (railway section) being operable as a whole:

$$P_{section} = \prod_{i=1}^{n} P_1^{S(I)_i}\ , \tag{1}$$

where:

n -total number of railway stations and interstations;

$P_1^{S(I)_i}$ -probability that any sub-system is operable;

As regards to safety work of any station (or interstation), it should be noticed that this work should be determined by all failures (technical or man-operator mistakes). These failures would threaten the traffic safety in the presence of any opportune conditions. Consequently, with respect to railway accident probability, in whatever subsystem-i, it is possible to write the expression:

$$Q^{S(I)_i} = \sum_{j=1}^{m} P_j.Q_j^{accd}\ , \tag{2}$$

where:

m -total number of causes for railway accident;

P_j -probability the sub-system station (or interstation) being in state predisposed to dangerous work because of j kind of technical failure or personnel mistake;

Q_j^{accd} -probability of a railway accident after the origin of j kind of failure (damages or man mistakes).

The safety work of any sub-system will be determined by the flow of dangerous failures. These failures determine its existence on variety of states. With respect to the railway station these states are:

-states characterized by road damages- P_2^S, P_3^S;

-states characterized by electricity equipment damages- P_4^S, P_5^S;

-states characterized by safety appliances failures as well as personnel mistakes- P_6^S, P_8^S.

With respect to railway interstation are included all states connected with technical failures. In consequence of these failures a railway accident would be realized. The probabilities are $P_2^I, P_3^I, P_4^I, P_5^I$. The safety work of any station (interstation) is expressed by the probability of railway accident non-admission:

$$P_{safety}^{S(I)_i} = 1 - Q^{S(I)_i} . \tag{3}$$

Then for the safety work of railway section as a whole we can write:

$$P_{section}^{safety} = \prod_{i=1}^{n} P_{safety}^{S(I)_i} . \tag{4}$$

3.Conclusion

This method provides a possibility for an assessment of the technical failures (and the personnel mistakes) influence over the reliable and safe functioning of railway station, interstation and section as a whole. Taking into consideration the influence of the time between the technical failure and realized subjective mistakes as well as the time to restoration of the traffic it is possible to take due precautions. Of course, these mitigation measures should be economical expedient and leading to an increase of the traffic reliability and safety level. The proposed method is universal and can be used for an assessment of the technical maintenance quality as well as the repair of the railway equipment. Using the presented material it is possible to find the most dangerous components and sub-systems with respect to railway traffic safety. The practical application of the method requires the processing of respective statistical material in a considerable degree. This procedure requires the necessity of a systematization of the operational data in the separate railway units.

References

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Summary

The assurance of railway traffic reliability and safety is a complex and very important problem. From its right decision depends in great scale qualitative work of the railway transport at all. The decision of such a problem requires system approach. The paper presents a mathematical model of railway section concerning the traffic reliability and safety.