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ANALYSIS OF SIMULATION MODEL APLICATION TO FORECAST THE RAILWAY WORKERS FAILURES

Milan MARKOVIĆ
Faculty of transport and traffic engineering
University of Belgrade, Belgrade, Serbia

Miloš IVIĆ
Faculty of transport and traffic engineering
University of Belgrade, Belgrade, Serbia

Norbert PAVLOVIĆ
Faculty of transport and traffic engineering
University of Belgrade, Belgrade, Serbia

Slađana JANKOVIĆ
Faculty of transport and traffic engineering
University of Belgrade, Belgrade, Serbia

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Abstract: In this paper the idea of treating the operational service workers as the elements of technique systems is suggested and the renewal theory is used to forecast the number of accidents caused by human factor. The analytical model is presented and limitations for its application are quoted.

Furthermore, the simulation model is developed and the conditions for its use are given. The model observes each worker separately and establishes the exact time of arisen failures, the number of failures at some moment t, time t_n, to the n^{th} failure, inconsistency of failure number and total number of failures of the observed population. The model is tested on the sample of 348 engine drivers in PE “Serbian Railways” who have made at leas one accident, in order to research the parameters necessary for using the renewal theory and simulation.

Keywords: Railway traffic, safety, renewal theory, human factor, accidents, simulation.

1. INTRODUCTION

The reasons of causing the traffic accidents in railway traffic are divided into several groups. The analyses of the reasons why the accidents are caused emphasize the importance of the human factor. This fact is best illustrated by the information that about 44% of the total number of accidents happened on the territory of the Republic of Serbia, human factor appeared to be the main reason for it. That is why the special attention is paid to the research of the human factor.

It is very often significant to forecast the total number of failures of the observed railway workers. One of the ways to establish this number is based on the use of the reliability theory. The basic idea of this work is to show the possibility of using the reliability of the renewal theory and simulation to forecast the number of railway workers' failures.

The work consists of 8 sections. The first section is the introduction. In the second section, the common problem setting in order to use the reliability theory to forecast the number of failures is given. Section 3 shows the analytical model to forecast the number of failures based on the renewal theory and the limits of its use are quoted. Section 4 shows the simulation model developed in this paper. Section 5 shows the analysis of the results obtained by the simulation and analytical model and proves the validity of the simulation model. The simulation model testing is done in section 6 in conditions when renewal process is not Poisson's. The result of researching the population of 855 engine drivers in railway traffic of Serbia, in the period of 8 years and relevant parameters are determined in section 7. Comparison of the results to real number of failures for each group of engine drivers in the observed population was done. The conclusion was given in section 8.

2. SETTING THE PROBLEM

Reliability of worker's activities can be observed as reliability of any technique element. It means that the reliability of the worker's performance can be described in the function of reliability $R(t)$, which represents probability of unfailured worker's performance to some moment t:

$$R(t) = P(T > t) \tag{1}$$

Parameter T is a random variable that describes the worker's working time before the failure, which leads to traffic accident respectively and the worker's labour time between two successive failures.

Suppose that T_1, T_2, T_3, ..., T_n are random variables which describe the worker's performance time from the observing starting point to the moment when the first failure appears, working time between the first and the second failure, between the second and the third, etc. These random variables can have the undefined probability distribution.

Which model is going to be used to forecast the number of failures depends on the sort of distributions and their parameters.

3. ANALYTICAL MODEL BASED ON THE RENEWAL THEORY

In most cases where the worker doesn’t have the break at work after having made a mistake (cases of traffic accidents) we can treat the working process and worker’s failures as the process with instant renewal.

If the random variables, which describe the time between two successive accidents T_i (i = 1, 2, ..., n) are independent and with the same distribution the renewal process as a "common process" in forcasting the number of traffic accidents can be used. Certainly the most common use is the application of analytical model in case of Poisson's process renewal.

If random variables T_i (i = 1, 2, ..., n) have exponentional distribution with parameter λ, then the renewal process is Poisson's.

The characteristics of location, the absence of consequences and ordinating which characterize Poisson's process can be noticed in worker's failure process (making the mistakes):

- it is impossible that worker fails two or more times in a short time interval (ordinarity),
- probability of the failure appearance in some time interval **τ** depends on the length of the observed time interval only, and it doesn’t depend on the time location of the interval,
- probability of the workers’ failures in some moment doesn’t depend on the working process in the previous moment (absence of failure).

It is known that in Poisson’s renewal process the random variable, which describes the working time till the n^{th} failure has Erlang’s distribution of n^{th} order, with the probability density function:

$$f_n(t) = \frac{\lambda(\lambda t)^{n-1}}{(n-1)!} e^{-\lambda t} \quad (4)$$

The number of failures in time t in this case is described by random variable, which has Poison’s distribution with probability distribution.

$$P_n(t) = \frac{(\lambda t)^n}{n!} e^{-\lambda t} \quad (5)$$

where is:

t – time period which the forcast is being done for.

$$\lambda = \frac{1}{\bar{t}}$$

$\bar{t}$ - the average time, between two failures.

Mathematical expectation of the numbers of failures for one worker in some period of time t are equal:

$$H_{(t)} = \lambda \cdot t \quad (6)$$

If we observe undefined working unit with N workers from which K workers made failures ($K \leq N$), mathematical expectation of the number of failures where N workers in one working unit will make in an observed period t is:

$$H_{(t)} = K \cdot \lambda \cdot t \tag{7}$$

If the renewal process is a common process, but random variables T_i (i = 1, 2, ..., n) do not have exponential distribution with parameter λ, but Erlang's a^{th} order, random variables that describe the working time to n^{th} failure has Erlang's distribution of anth order, with probability density function:

$$f_n(t) = \frac{\lambda(\lambda t)^{an-1}}{(an-1)!} e^{-\lambda t} \tag{8}$$

The number of failures in time t, in this case is described by random variable where probability distribution is:

$$P_n(t) = \frac{(\lambda t)^n}{(an)!} e^{-\lambda t} \tag{9}$$

In common renewal process which are not Poison's, mathematical expectation of the number of failures in some time t is calculated in quite a complicated way. It is more convenient to use some of the marks which have their limitations which are not applicable, or to use the simulation model. When it is the question of the renewal process where the variables T_i (i = 1, 2, ..., n) do not have the same distribution, then it is necessary to make simulation model to forecast the number of failures in some time t.

We must emphasize that Poison's renewal process is real when dealing with workers' failures in the railway traffic. Analyzing the statistical sample consisting of 348 engine drivers who had failures (accidents) and worked in the period from 1994 to 2001 as engine drivers on the teritory of four sections of Serbian railways, it can be concluded that random variables T_i (i = 1, 2, ..., n) have exponential distribution and parametres of exponential distribution are the same in the group of engine drivers who made equal number of failures, je $\lambda_1 = \lambda_2 = \lambda_3 = ... = \lambda_n = \lambda$ = const.

4. SIMULATION MODEL

Simulaton model is basically used when analytical model can not be used or at least, not rationally used. In this case, as we previously said, if the renewal process of distribution is not Poisson's we should use simulation model. Analytical model can be used in the case of common or simple renewal process, but in these cases its use can be quite complicated and so we recommend the use of the simulation model. In conditions when random variables, which describe the time between two failures do not have the distribution of the same kind, but instead, have distribution of the same kind but with different parameters, it is necessary to use the simulation model respectively.

Simulation of the realization of the random variable T which describes the time between two failures (accidents) is done by random numbers. Random variable T can be shown by the distribution function or probability distribution. This model enables the parameters of the assumed probability distribution of the random variable T to be simulated.

The model observes each worker separately and establishes the accurate time of the failure made, the number of failures before a certain moment t, time T_n to n^{th} failure, the falure number variance and the total number of failures for the observed population. Model takes into consideration the fact that some workers (among observed population) have more or less capability of making mistakes. If j is the number of groups of workers with the same capability of making mistakes, the random variables T_{ij} (i = 1, 2, ..., n) can have different distributions.

The simulation model is developed in programming language Visual Basic 6.0.

5. PARALLEL TESTING OF ANALYTICAL AND SIMULATION MODEL IN CONDITIONS WHEN THE PROCESS IS POISSON'S

This section will show the results of parallel testing of analytical and developed simulation model to forecast the number of accidents in order to show its validity and possibility of its use in conditions when analytical model can not be used.

The table 1 shows the forecast number of failures depending on the number of workers for the observed period of 8 years where the process of distribution is Poisson's with the constant parameter value λ = 1/1460 random variables T_i, established by the analytical and simulation model. The same data are shown in graphic in the figure 1.

Table 1: Forecast number of failures

	Number of failures λ = 1/1460 t = 8 years					
Number of workers	50	100	150	200	250	300
Analytical model	100	200	300	400	500	600
Simulation model	96	198	292	395	498	592

In the figure 2 there is shown different graphic display of the analytically obtained and simulated numbers of accidents for the group of 50, 100, 150, 200, 250 and 300 engine drivers. Their correlation coefficient in reference to line $y = x$ is r = 0,99 and it shows very tight connection between analytically obtained and simulated number of accidents, so we don't have the reason to reject the hypothesis that simulation model is valid.

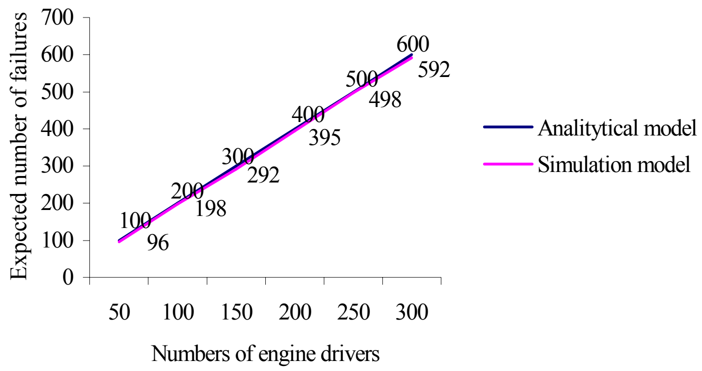

Figure 1: Graphic display of the forecast number of failures for analytical and simulation model

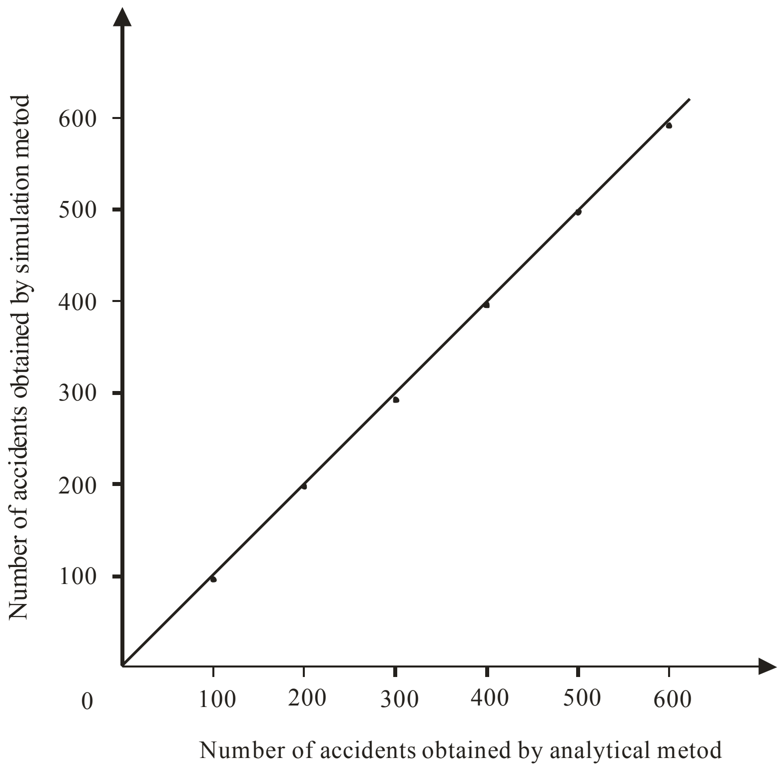

Figure 2: Graphic display of analytically obtained and simulated number of accidents for the given number of engine drivers

6. TESTING OF SIMULATION MODEL IN CONDITIONS WHEN THE RENEWAL PROCESS IS NOT POISSON'S

In the previous section we showed the results of testing the simulation model in conditions when the renewal process is Poisson's. As we emphasized before, it is rational to use analytical model in such cases. Analytical model can be used in conditions when dealing with common or simple renewal process, but its application in these cases is mostly complex. Simulation is necessary in conditions when random variables T_i, which describe the working time of the engine drivers between $i-1$ and i failure don't have the same types of distribution, but have the same types of distribution with different parameters.

This section shows the results of model testing in conditions when random variables T_i have exponential distribution with different parameters λ_i, so the analytical model can not be used.

In table 2 the given values of parameters are shown λ_i for $i = 1$ to 6. In the cases when simulated number of failures is larger than 6, it is taken that $\lambda_i = \lambda_6$.

Table 2: Given values of parameter **λ**

$1/\lambda_1$	$1/\lambda_2$	$1/\lambda_3$	$1/\lambda_4$	$1/\lambda_5$	$1/\lambda_6$
474	674	874	1074	1274	1474

There was accomplished the simulation for the period of 16 years, for given values of parameter λ, but chosen by random order. Forecast number of failures for different number of workers is shown in table 3.

In figure 3, it is shown the forecast number of failures.

Table 3: Forecast number of failure

Number of workers		50	100	150	200	250	300
Total number of accidents	For shown values λ	297	599	901	1177	1485	1794
	For shown values λ chosen by random order	297	586	878	1140	1452	1803

7. ADDITIONAL TESTING OF THE SIMULATION MODEL

For the purpose of additional testing of the model and confirming some of given presumptions connected by the nature of renewal process, another analysis has been done. Observed statistical sample consists of 855 engine drivers from 4 sections of Serbian Railways (Belgrade, Lapovo, Užice and Zaječar). Their work was observed in the period of 8 years (1994 – 2001). Among these 855 engine drivers, 348 engine drivers made at least one accident, and the rest of 507 engine drivers didn't have any accident during that period.

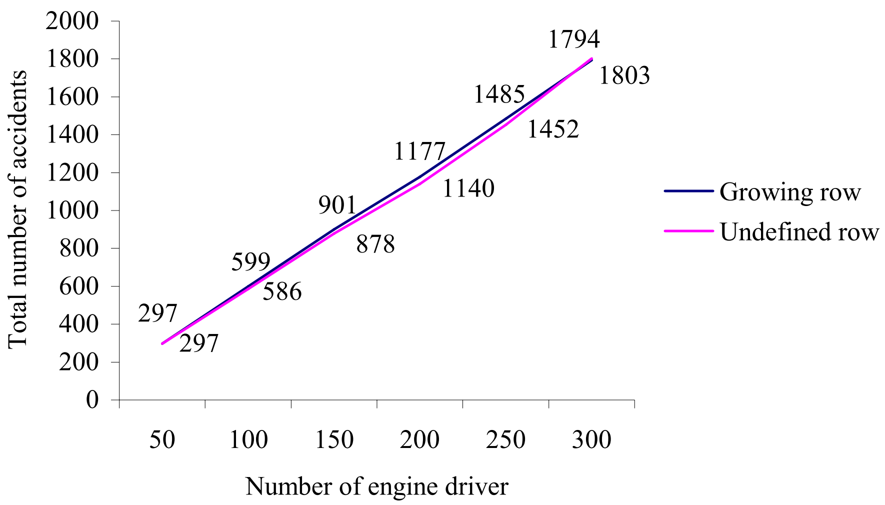

Figure 3: Forecast number of failures shown in graphic

Analyzing the observed statistical sample it was concluded that 348 engine drivers had made 780 accidents for the period of 8 years. The number of accidents, which these engine drivers made separately, is 1 – 6.

Table 4: The frequency of the number of failures (accidents)

Number of accidents	1	2	3	4	5	6	Σ
Number of engine drivers	152	86	41	28	25	16	348

In this section there will be separately observed groups of engine drivers who made exactly *i* (1, 2, ...,6) accidents. It is interesting to test simulation model in conditions when each group of engine drivers is observed separately, when we separately observe engine drivers who made exactly *i* accident.

Table 5 shows the values of parameter λ, for the observed groups of engine drivers that were obtained by analyzing the statistical sample.

Table 5: The values of parameter of exponential distribution of the random variables T_i for particular groups of engine drivers

Number of accidents	1	2	3	4	5	6
Parameter $1/\lambda$	2920	1460	974	730	584	487

In the table 6 the number of accidents is given for particular group of engine drivers obtained by using the simulation model and also the number of accidents obtained from the sample.

Table 6: The real and simulated number of accidents for particular group of engine drivers

Number of group	1	2	3	4	5	6
Number of accident which every engine driver makes	1	2	3	4	5	6
The number of engine drivers in the group	152	86	41	28	25	16
The total number of accidents in the group	152	172	123	112	125	96
Simulated number of accident	146,7	174,0	123,9	113,0	126,7	96,2

In figure 4 is given graphic display of the data.

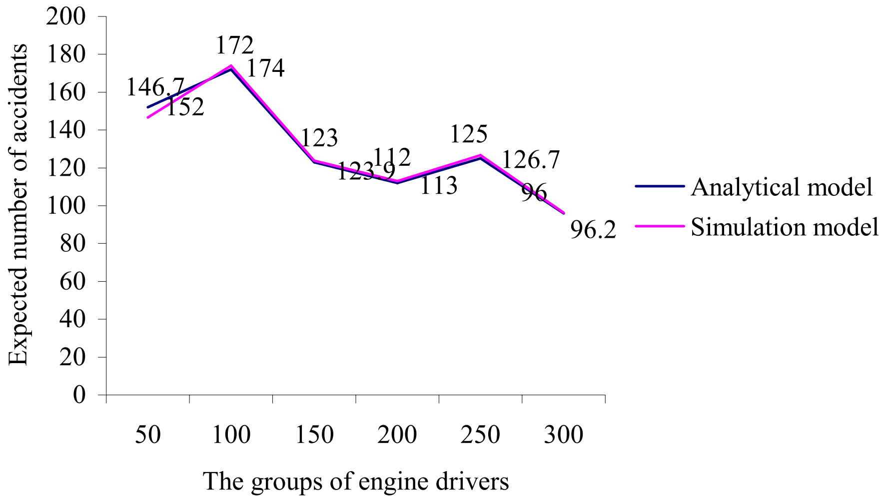

Figure 4: Graphic display of the real and simulated number of accidents for particular groups of engine drivers

In figure 5 there is shown a bit different graphic display of the real and simulated number of accidents for each observed group. Their correlation coefficient related to line $y = x$ is $r = 0{,}97$ shows the tight link between the real and simulated number of accidents, and confirms the validity of the simulation model.

8. CONCLUSION

The models given in this paper can be useful in forecasting the number of accidents caused by human factor. The analytical model was shown and limitations for its use were quoted.

The simulation model is developed and conditions for its use were given. Model examines each worker separately and establishes the accurate time of arising failure, the number of failures to some moment t, time t_n to n^{th} failure, variance of failures number and the total number of failures for the observed population. Validity of developed simulation model was done by its comparison to analytical model and characteristics obtained from the sample.

There were shown some results of research that had been done in the sample of 855 engine drivers of Serbia Railways, observed in the period of 8 years. Obtained data emphasize that random variables, which describes the time between two successive failures have exponential distribution, and they are in the group of workers with similar linking in making mistakes $\lambda_1 = \lambda_2 = \lambda_3 = ... = \lambda_n = \lambda$, and due to it we can use the analytical model for that population. It doesn't mean that using the simulation model won't be necessary in the other population.

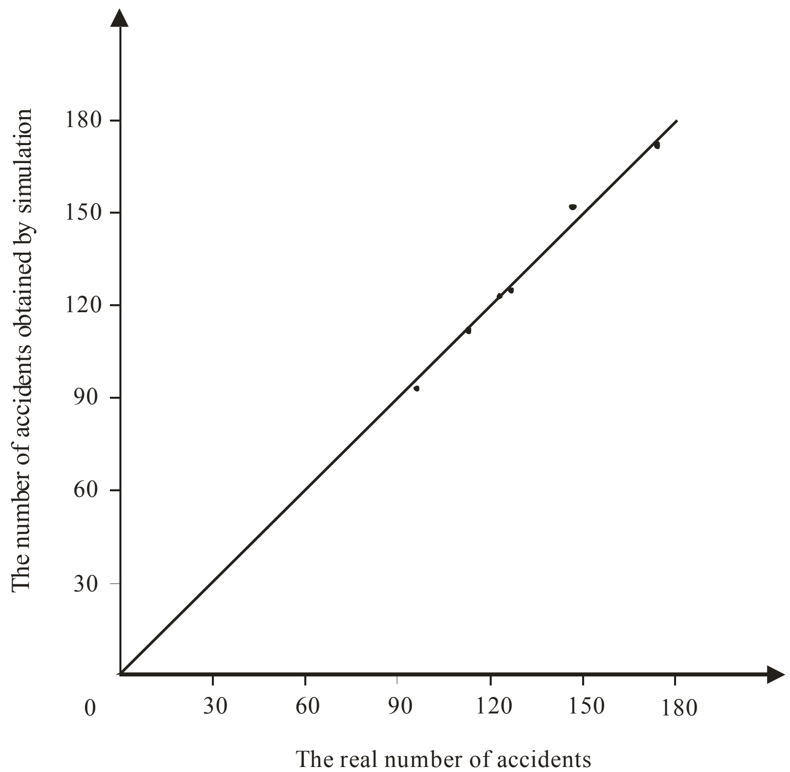

Figure 5: Graphic display of analytically obtained and simulated number of accidents for each observed group

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