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Analysis of Traffic Accident Frequency and Reliability Using Appropriate System Reliability Model - A Simulation Approach

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Research Article

Abstract: This paper studies the application of system reliability theory with certain modifications to a four lane highway. It can be modeled the four lane highway as a series parallel system. To analyze traffic accident frequency and reliability of each Lane, we generated number of accidents in each section by using simulation technique. Assuming that the time between two accidents will follow an exponential distribution, we determined reliability and accident frequency of each Lane along with its sections. Based on the results obtained, conclusions were drawn.

Key words: Reliability, unreliability, Accident frequency rate, Mean time between two accidents, Poisson process Exponential failure law.

1. Introduction

Now a day, road traffic is increasing enormously and posing many traffic problems like traffic jams, accidents which in turn lead to risky and prolonged journey. This also makes public nuisance, air and sound pollution and public inconvenience. Because of these problems many researchers are concentrated on the analysis of traffic accidents for improving safe and comfortable journey. Many methods were introduced to study the safety measures in highways. In order to understand the behavior of **traffic accidents rate**, there is a need for collecting and analyzing the traffic accident data. Thus the main objective of this paper is to analyze the traffic accidents in highways. The purpose of analysis is (i) to identify accident prone zones based on the past accidents data,(ii)to identify hazardous roots in a region and (iii) to estimate accidents rate, and reliability of different roots. Roots can be broadly classified into (i) **road ways** and (ii) **highways**. Some roots are risky because of hairpin curves (deep curve), ghat roads, and steep ups and downs. Based on this nature of road, **accident rate**, risky factors and **reliabilities** are varying. A Location can be identified as **hazardous** by the occurrence of abnormal number of accidents or the high rate of accident over a given period of time. In this direction many different methodological approaches were developed by Lord, Haucer[6] for modeling of occurrence of traffic accidents. From the aspect of temporal analysis of traffic accident occurrence, two approaches were developed namely (1) **collective approach** and (2) **individual approach.** The **collective approach** , which determines the frequency of traffic accidents over a long period of time was developed by several authors namely Haucer[5],persaud[11],Miaou and Lum[9], Milton and Mannering[10], Golob and Recker[3,4], while **individual approach** determines the probability of traffic accidents in a real time was developed by Hughes and Council [7], Lee et al [8], Golob and Recker[3,4]. In the analysis of traffic accident frequency no attempt has been made to consider the process of occurrence of traffic accidents from the aspect of system reliability by considering a highway as system and its sections as units. Ushakov and Harrison [13] ,Dhillon[1] made an attempt to study the occurrence of traffic accidents in the reliability aspect. The term **reliability** of the traffic safety system can be viewed as the **ability of the system** to fulfill the given functions within certain time interval. In engineering, general mathematical models are adopted to the real problems to estimate reliability. In this approach Dragan. Jovanovich, Jodor Backalic Svetlana Basic[2] applied the system reliability models for the analysis of traffic accident frequency under the assumption that the time between two accidents follows an exponential distribution and determined the probability of occurrence of accidents in various sections within each road and mean time between two accidents on single road. But in order to determine a location which is **hazardous** we have to wait for a long period of time and experiences of accidents involve much risk such as number of deaths, loss of limbs , machinery of the vehicle and so on. Therefore to determine safety measures of traffic accidents, one should know and observe the number of accidents over a longer period of time. Practically this is a difficult task. Thus we motivated to develop a model for obtaining safety measures of traffic accidents by using **simulation technique** and applying the theory of system reliability in highways. In the analysis of traffic accident frequency the term **reliability** may be considered to determine a **hazardous section** on the highway. In engineering terminology a failure causes an interruption in the function of the system and requires a repair or replacement or recovery of the system, followed by putting the system back into operation. In the process of road traffic flow, the occurrence of traffic accident causes a delay or significant slowdown of traffic but following the investigation and other services like ambulance service, assistance of traffic police and so on ,the traffic flow can be normalized and to resume the normality in traffic. Failure in engineering terminology means shifting of the system instantaneously from operational state (**up state**) to failure state (**down state**) .Up state is denoted by **1** and down state is denoted by **0** for a system. On similar lines an accident turns the normal traffic to **standstill**. Here normal flow of traffic is equivalent to up state of the system, while down state represents the standstill traffic. Thus 1 represents the normal flow of traffic and 0 represents the state of the stand still. Here shifting from state 1 to 0 is instantaneous. But from state 0 to 1 requires some slack time which is repair time in engineering terminology. A type of accident has the character of sudden failure or in other words it instantly switches the system from an operational state to a state of failure. With this understanding we developed a system reliability model to the traffic flow and its safety.

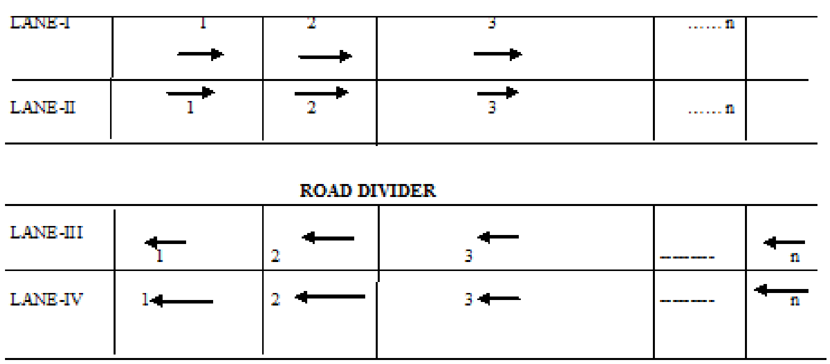
2. Model

In determining the reliability of a highway, a preliminary analysis is necessary that would determine its structure and level of complexity or defining the system units.

For the analysis, we consider the following assumptions:

1. Assume that a four lane highway-road as a **system.**
2. Assume that each road (lane) as a **sub-system.**
3. Assume that each road is divided into n-sub sections with different length based on the distance between two stages and considered these sub sections as units within each subsystem. Thus each road as a complex system consists of n- units that refer sub sections. The section represents road between two stages along with road distance.
4. Assume that a traffic flow interruption in any unit causes the traffic flow interruption in the whole road.
5. Let $R_j^{(i)}(t)$ be the i^{th} unit(section) reliability in j^{th} subsystem(lane), for i=1,2,…..….n and j=1,2,3,4.
6. Let the Process {N (t), t=1, 2…} be the number of accidents occurs per unit time t and which follows the poison process with its rate parameter λ.
7. Let the time between two accidents follows an exponential distribution with failure rate λ.
8. Let the distribution function of an exponential accident (failure) law is $F_i(t) = 1 - \exp(-\lambda_i t)$, $i = 1,2,......n.$ (2.1)
9. The diagrammatic representation of the four lane road is as follows:

Fig1: Representation of the four lane road as parallel series system.



3. Determining Road reliability

In order to obtain an adequate mathematical model with the real system reliability theory, different statistical distributions are approximated with the help of real process. For example the distribution of time between two events is approximated to an exponential failure law. Traffic flow begins at the time t=0 and the time period without traffic accident is interval [0, t_1], Where t_1 is the moment of occurrence of the first traffic accident. The next period without accident is the interval [t_1, t_2], where t_2 is the moment of occurrence of second traffic accident. In most of the analysis, the Poisson's distribution of events in stochastic process is used as a starting distribution. The basic form of Poisson distribution is continuous time counting process which possesses the following properties: independent increments, stationary increments, no counted simultaneously occurrences. A homogeneous poisson processes characterized by its rate parameter λ which is the expected number of events that occurs per unit time and per Km (Km-Kilometere). If the system of events has poisson distribution, then the time between two occurrences of events (accidents) will follows an exponential distribution with parameter λ. Therefore it has been adopted that all the empirical distributions of the duration of the time period without accidents can be replaced by the corresponding exponential distribution. The road safety indices like reliability, accident frequency rate and Mean Time Between two Accidents(MTBA) can be determined based on the assumption that the inter arrival time (time between two accident occurrence) in the i[th] section is distributed according to an exponential failure(accident) law with the distribution function

$$F_i(t) = 1 - \exp(-\lambda_i t) \ , i = 1,2,......n. \quad (3.1)$$

Then the probability density function is given by

$$f_i(t) = \lambda_i e^{-\lambda_i t} \ \text{, where } \lambda_i > 0 \quad (3.2)$$

The distribution function $F_i(t)$ of the random variable T is equal to the probability that an accident will occur before the time t. This function is also called the function of unreliability. The reliability function $R_i(t)=1- F_i(t)$.

The mean time between two consecutive accidents (MTBA) is obtained as

$$MTBA = T_{oi} = \int_0^\infty R_i(t)dt = \int_0^\infty e^{-\lambda_i t} dt = \frac{1}{\lambda_i} \quad (3.3)$$

The accident frequency $a_i(t)$ also represents an important and widely used reliability characteristic and represents the measure of current speed of the accidents occurrence. $a_i(t)$ can be expressed in various time units and depends on the time units which is used for calculation of MTBA.

For Poisson distribution, the accident frequency as the current speed of the accidents occurrence is constant at the moment in the i[th] observed time period.

The accident frequency function on the i[th] section is

$$a_i(t) = \lambda_i \quad (3.4)$$

The expected number of accidents in a certain period is:

$$A_i(t) = \lambda_i t \quad (3.5)$$

Here we consider the time units as t-168 (hours). The road reliability is determined by the reliability of the sections of that road. The observed road represents the simple series system because all the sections are in series. Therefore the j[th] road reliability is

$$R_j(t) = \prod_{i=1}^{n} R_j^{(i)}(t) = e^{-\sum_{i=1}^{n} \lambda_i t} \ , j = 1,2,3,4. \quad (3.6)$$

Since all the four lanes (roads) are in parallel, the entire four lanes road reliability is the function of reliability of all the four lane roads. Thus the entire four lane road (system) reliability is

$$R_s(t) = 1 - \prod_{j=1}^{4}\left[1 - \prod_{i=1}^{n}\left(R_j^{(i)}(t)\right)\right] = 1 - \prod_{j=1}^{4}\left[1 - R_j(t)\right] \quad (3.7)$$

4. Results and conclusions

Obtaining the number of accidents in a particular section or on the road over a longer period of time is practically difficult task as it involves loss of lives, loss of machinery, cost etc. Thus the number of accidents based on the Poisson process can be generated by using simulation technique. In this section, based on the simulated results we determine the reliability of each section -using equation (3.2), each lane (road)-using equation (3.6) and the entire system reliability-using equation (3.7).

Table 1: Representation of observed number of accidents in Lane-I and some appropriate results for analysis

Lane I Sections (km)	**Length**	**Observed number of Accidents**	**$\lambda_i(h^{-1})$**	**T_{0i}(h)**	**$A_i(t)$**	**$R_i(t)$**
1	40	14	0.002083	480	0.35	0.70468809
2	36	09	0.001488	672	0.25	0.77880078
3	50	15	0.001786	560	0.30	0.74081822
4	20	04	0.001190	840	0.21	0.81873075
5	14	03	0.001276	784	0.22	0.80711774
	160	45	0.0078238*	127.83*	1.32*	0.26866615*

**represents the respected characteristics of the Lane-I*

Table 2: Representation of observed number of accidents in Lane-II and some appropriate results for analysis

Lane II Section (km)	**Length**	**Observed number of Accidents**	**$\lambda_i(h^{-1})$**	**T_{0i}(h)**	**$A_i(t)$**	**$R_i(t)$**
1	40	16	0.002381	420	0.40	0.67032004
2	36	13	0.002149	465.231	0.36	0.69690156
3	50	8	0.000952	1050	0.16	0.85214379
4	20	11	0.003274	305.455	0.55	0.57649810
5	14	05	0.002126	470.4	0.36	0.69967254
	160	53	0.010882*	91.891*	1.83*	0.16069390*

**represents the respected characteristics of the Lane-II*

Table 3: Representation of observed number of accidents in Lane-III and some appropriate results for analysis

Lane III Section (km)	Length	Observed number of Accidents	$\lambda_i(h^{-1})$	$T_{0i}(h)$	$A_i(t)$	$R_i(t)$
1	40	14	0.002083	480	0.35	0.70468809
2	36	16	0.002646	378	0.44	0.64118039
3	50	10	0.001190	840	0.20	0.81873075
4	20	04	0.001190	840	0.20	0.81873075
5	14	07	0.002976	336	0.50	0.60653066
	160	51	0.010086*	99.148*	1.69*	0.18370126*

**represents the respected characteristics of the Lane-III*

Table 4: Representation of observed number of accidents in Lane-IV and some appropriate results for analysis

Lane IV Section (km)	Length	Observed number of Accidents	$\lambda_i(h^{-1})$	$T_{0i}(h)$	$A_i(t)$	$R_i(t)$
1	40	05	0.000744	1344	0.13	0.88249691
2	36	13	0.002149	465.231	0.36	0.69690156
3	50	17	0.002024	494.118	0.34	0.71177032
4	20	12	0.003571	280	0.60	0.54881164
5	14	02	0.000850	1176	0.14	0.54881164
	160	49	0.009339*	107.0767*1.57*	0.20825994*	

**represents the respected characteristics of the Lane-IV*

From equation (3.7) we determine the entire four lane highway reliability as

$$R_s(t) = 1 - \prod_{j=1}^{4}\left[1 - \prod_{i=1}^{n}\left(R_j^{(i)}(t)\right)\right] = 0.603295$$

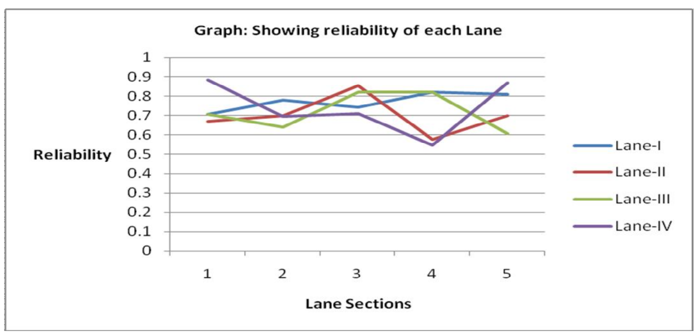


Fig3.1: *Graph representing reliabilitiesin different lanes and their sections.*

Conclusions

From table 1 & 3 It is observed that the reliability of section-4 is **0.81873075**, while section-1 has the least reliability and higher accident frequency can be observed in section-1. Thus section-1 is not reliable for the safety journey. Thus it is suggested to take some preventive actions in those sections with less reliability by putting signal lights or zebra lines or speed breakers and so on. Further it is observed from table 1 to 4 that lane I and lane IV have more reliability than lane II and lane III.This tallies with reality that extreme lanes(lane I and IV) are more safer than interior lanes(lane II and III).

From table 2, It is observed that the reliability of section-3 is **0.8521430**, while section-4 has the least reliability and higher accident frequency can be observed in section-IV. Thus section-4 in lane II is not reliable for the safety journey.

From table 4, It is observed that the reliability of third and fourth sections are having the highest reliability **0.54881164** , while section 5 has the least reliability and higher accident frequency can be observed in section-5. Thus section-5 is not reliable for the traffic control and safety journey. It can be considered accident porn zone in the highway considered. Similar type of conclusions can be obtained from fig1.. From equation (8), it is observed that the four lane highway reliability is **0.603295.**

5. Further Scope of the work

The model proposed in this paper for highways can be applied to different roads in region or different roots under a depot. This can also be applied for railways, airways and see ways. Further we can also consider factors like (i) various transports (public and private) (ii) types of vehicles (cars, two wheelers, busses -Ordinary, express, Luxury, Semi Luxury). We can also consider the experience of the driver which plays a vital role in averting accidents.

Appendix:

The method of generation of accidents in different lanes using random numbers is given below for a ready reference:

X	P(X)	F(X)	Random Interval
0	0.12	0.12	00-11
1	0.35	0.47	12-46
2	0.15	0.62	47-61
3	0.38	1.00	62-100

Using the random interval we generated random number of accidents as follows:

Random Number	25	35	09	05	04	13	01	04	02
Generated random Number of accidents (Per week)	1	1	0	0	0	1	2	0	0
Random Number	03	13	01	06	08	59	41	04	22
Generated random Number of accidents (Per week)	0	1	0	0	0	1	1	0	1
Random Number	11	38	07	10	04	18	67	09	03
Generated random Number of accidents (Per week)	0	1	0	0	0	1	3	0	0

Procedure for simulating number of accidents (per week or for the time period t=168 hours):

Step1. Determine the random interval to which the generated random number belongs to.

Step2. Then the corresponding number represents the generated accidents.

For example: consider the random number 25. This belongs to the interval 12-46.Therefore generated random number of accident is1.(see in the above table).

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