

Study on the Root Cause of Fuel Tanker Truck Accidents in Nigeria: Reliability of Accidents Caused by Human Factors (HF)

Chukwuemeka Peter Ukpaka^{1*}, Kenneth Chieloka Ekesiobi², Barinyima Nkoi³

Abstract

Accidents involving transportation of petroleum products by road are of high frequency in Nigeria, mainly because of overdependence on the tanker-truck system due to pipeline vandalism. We analyzed over 92 accidents involving tankers-trucks from 2014 to 2019. In this study, the analysis is done to examine the factors that caused the accident using accident records and petroleum distribution data from the Federal Road Safety Commission (FRSC). Petroleum tanker-truck accident reports from the FRSC office in Abuja were used to examine the root causes of the petroleum truck accident. The operation time (OT), mean time between accident MTBA, accident rate, reliability, and unreliability (distribution) of the petroleum tanker-truck could be determined using Monte Carlo's reliability analysis model. Thus, the data regarding the petroleum tanker-truck accident was collected from the safety and administrative department of FRSC for a six-year period and the PTD (Petroleum Tanker Drivers) arm of NUPENG (Nigeria Union of Petroleum and Natural Gas Workers) before they were further analyzed. Based on the explanatory results, the accident probability and relative accident consequence are identified. The elements that contributed to the accident were assessed for dependability and unreliability. The research showed that there is an increase in accident rate for the period of six years, and the reliability of some of the accident causal factors, such as human factor (HF), was at 4.286% in the first year and then decreased to 0.202% after the sixth year. This research work recommends safety personnels and regulatory bodies should properly monitor the accident rates of the petroleum tanker-trucks by adopting proper maintenance policies and proper sensitization of drivers. Since the majority of the accidents are cause by mostly humans, it surely improves the efficiency of the trucks and their working hours and will mitigate the rate of fuel tanker-truck accidents on Nigerian roads.

Keywords: Accident, factor, fuel, human, Nigeria, reliability, root, study, tanker, truck

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INTRODUCTION

Transportation is something that is very important if a nation is to move from an underdeveloped stage to a developed stage. Political and economic objectives can only be achieved through transportation. Transportation also serves to provide labor division [1, 2]. Transportation is a must do activity for all humans right from the moment of their birth to the day they die [3, 4, 5, 6]. Transportation is a major catalyst for the development of societies in terms of infrastructure and technology development. One way a business is said to serve people in the market is through the provision of some products [7–9]. Few manufacturers and retailers have broadened their conception of a product to include service. Edulijee

(2000) pointed out that a product consists of both goods (tangible) and services (intangible) [10]. A product is thus any good, service, or idea that can be offered to a market to suit a need, depending on the trans-situational goal of the individual [11], but the quality of such a product is often determined by its consumers. William Edwards Deming, well-known for his “plan, do, study, act” cycle, has made a substantial impact on management and Japan's subsequent reputation for producing high-quality, creative products and being a powerful economic force. Deming outlined fourteen principles in his model for business productivity and improvement, which focused on constant improvement efforts if an institution maintains its growth trajectory [12–15]. Deming initiated an approach to improving an organization through teamwork. The secret is to think of manufacturing as a system rather than as individual components and to implement continuous improvement. His 14-point plan is a complete philosophy of quality management [16–17].

There are so many essential infrastructures in the downstream sector of the Nigerian petroleum industry, especially in the areas of product blending and purity. It has been found and analyzed that over forty million liters of crude oil-related products are being shipped and supplied to consumers daily [18]. The major causal factor of the petroleum tanker-truck accident in Nigeria is the human factor. It means that the human factor is the main factor responsible for fuel tanker-truck accidents because if trucks are properly maintained, drivers are well sensitized on safety and accident preventive measures, heavy-duty vehicle routes are properly designated and aligned in congested areas, the accidents rate will drop drastically, and all these are responsibilities of the human [19]. The roads ought to be built to support huge vehicles weighing 60 tons or more. Nigerian highways are currently only built to support cars weighing up to 40 tons. As a result, the roads sustain damage and develop potholes that could lead to traffic accidents.

Generally, compared to other vehicles, fuel tankers are over involved in road accidents [20–22]. Restrictions on age and health condition of drivers, improvement on truck route alignment, and regular tanker maintenance will go a long way to mitigate tanker-truck accidents in the country. It was observed that human factors like driver's loss of concentration due to hours on the road or alcohol-induced route violations and speed violations cause a high percentage of truck accidents on the road [23–25].

Therefore, it is advised that road users regulatory bodies like the FRSC and VIO arm of the state Ministry of Transportation that are bound by law to regulate traffic laws, safety, and road worthiness of vehicles should work with NUPENG to sensitize drivers on the ethics of safety while on the road considering the nature of their vehicle and the hazardous nature of its content and also carry out some necessary checks like ensuring that each truck has fire-fighting equipment: a valid fire extinguisher; a complete toolbox; exhaust muffler spark arrestors; and also that they are not using expired tires [19]. This must be done before the truck enters the gantry to load petroleum product. Also considering the hazardous nature of the product these trucks carry and the damage it can do if spilled, the NUPENG HSE task force check points should be sited at all accident hotspots along the federal and state roads to ensure the drivers are following traffic rules and not taking unnecessary risks.

MATERIALS AND METHOD

Based on this study, a reliability approach will be used. The research primarily explains how the study was conducted, the applied methods and techniques in data collection, the reasons for which they were used according to the research aims and objectives, and statistical tools used to analyze the study.

Materials

Data collection was a challenge for this research, as it is for many studies in developing countries. As there is no public data base in Nigeria, accident reports will be obtained from the Federal Road Safety Commission (FRSC). This organization is required by law to record, investigate, and address incidents involving petroleum and vehicles (Molinero, 2008). Thankfully, these reports will cover a maximum of 4 years, from 2014 to 2019. Each accident report that is obtained has sufficient facts

(causes, outcomes (fatality/casualties), and quantity of products spilled) to provide a contextual view of dangers, accident occurrence, and severity.

Data was also collected from the petroleum tanker drivers arm of the NUPENG (Nigerian Union of Petroleum and Natural Gas Workers). Data representing yearly distribution and sales of petroleum products (PMS, HHK, and AGO) across the states in Nigeria were obtained from NNPC reports, while petroleum product price regime details was obtained from the Petroleum Product Pricing Regulatory Agency (PPPRA).

Study Area

The research area is Nigeria is a West African nation. With a population of over 211 million, it is the most populous country in Africa. It is in the Atlantic Ocean, between the Sahel to the north and the Gulf of Guinea to the south. Its area is 923,769 kilometers (574,003 miles). Nigeria shares borders with Benin to the west, Cameroon to the east, Niger to the north, and Chad to the northeast. Nigeria is a federal republic made up of 36 states plus the Federal Capital Territory, which is home to the nation's capital, Abuja. Lagos, the second-biggest metropolis in Africa and one of the world's major metropolitan regions, is the largest city in Nigeria.

British colonialists constructed Nigeria's first roads for largely the same purposes as the railways, but with three additions: (i) they carry goods directly to and from the ports; (ii) they feed the railway system and so complement it; and (iii) they assist missionaries and administrative officers in administering and opening the interior. In Nigeria, road construction began after railways and came before the following three phases: (i) The Ibadan-Oyo Road, constructed in 1905, was Nigeria's first road. Initially constructed in 1975, the 109-kilometer Lagos-Ladan expressway was the first of its kind. It currently has a branch in Benin City that is dualized all the way to Asaba, Delta State. There was also the construction of dual carriage ways such as the Kaduna-Zaria-Kano expressway, the first in the north. However, the high rate of accidents on Nigerian roads became a factor militating against the development of road transportation. It was in response to this that the Federal Road Safety Commission, with a popular acronym, FRSC, was established by Decree 45 of 1988 as a child of necessity. The Decree 45 was amended in 1992 [19]. Since May 1999, numerous legislative efforts have been implemented to upgrade the nation's formerly poor road infrastructure and broaden its network, emphasizing the importance of roads to socio-political and economic development [5].

According to Onuoha (2007), the running of the nation's road network was vested in the federal and state ministries of works. At the federal level, the ministry of works was not only recognized to make it wholly road-focused, but also several new institutions and legal regimes were introduced to achieve the government's objectives in the sector. According to Onuoha (2007), Nigeria has a total of 194,394 km of roads, out of which 60,068 km (including 1,194 km of expressways) are paved and 134,326 km are unpaved [5].

Nigerian roads are notoriously unkempt, with many attributing their high accident rate to them. Onuoha (2007) notes that the Federal Roads Maintenance Agency (FERMA) started patching the 32,000-kilometer network of federal roads in 2004 and started a more extensive rehabilitation in 2005 [5]. Several badly maintained sections of federal trunk roads have been brought back to serviceability by the Ministry of Works through the FERMA operation 500 roads program.

Research Methods

Because quantitative research approaches include surveys, simulation, mathematical modeling, laboratory experiments, statistical analysis, econometric modeling, and structured modeling, these were the methodologies employed in this study [26–27]. This study used the Monte Carlo approach and methodologies for reliability analysis.

Data Exploration

The accident reports that were acquired were sorted and categorized by the year, month, day, and time of the incident. The data will be divided into groups according to the states in which they occur. A contextual accident outcome data set will be created by tabulating the specifics of each event, including the number of fatalities, injuries, cars involved, and the kind and quantity of products involved. States were assigned identification numbers ranging from 1 to 37 and placed in alphabetical order.

An estimate of the number of truck tankers delivering products in each state annually can be obtained by adding up the total distributed volume of PMS, HHK, and AGO in each state and dividing the result by 33,000, which is the typical truck load in liters. Transportation of petroleum products to retail stations in Nigeria is entirely dependent on the truck tanker system because there is no retail station directly connected to the pipeline network and because the spatial connectivity of the pipeline network in Nigeria has been completely lost because of vandalism [28]. This estimate is predicated on the idea that truck tankers were utilized to carry the product at a specific point in the lifetime of the entire volume of used petroleum product produced annually. Later, the normalized relative accident probability computation was performed using this data. However, only four years' worth of data were utilized for the probability computation because state-by-state records of the total product distribution can only be found through 2009.

Analyzing the accident's financial impact, categories that can be estimated within the data set will be first selected. The categories included fatality, injury, product loss, and environmental damage. The inadequate information in the available reports led to the exclusion of several categories, including clean-up, property damage, victim evacuation, and traffic incident delay expenses. We incorporate part of the study discussion with key interest and stakeholder classification within the Nigerian transportation and distribution of petroleum products, as the risk assessment framework is intended to improve regulatory actions.

Framework for Data Analysis

Inspired by the collected data, the two main components of the risk assessment framework for this study are as follows: One component of risk assessment is the identification of accident causal factors through formulas; other components include equations for computing relative risk values and identifying accident hotspots by comparing the relative risk value across two or more geographical locations; and formulas for computing accident frequencies and accident casualty consequences. b) The cost impact aspect includes a method for calculating the annual cost impact of accidents and losses, as well as methods for estimating the direct and indirect costs of accidents.

Causal Factor Identification and Classification

We categorized the causes of accidents into three categories: non-human, unknown, and human, based on the cause of the accident as reported to regulators. Factors that influence the frequency of accidents in a particular year are known as accident causative factors.

Human causal factor is classified as: Human factor (Hf)

In this study, the human factors as shown in Equation (1)

$$(Hf) = DGD + TPI + AVA \quad (1)$$

Whereas speeding, reversing, driving while intoxicated, reckless overtaking, and other traffic infractions are the factors contributing to DGD. TPI refers to collisions brought on by outside influences on the road, or human factors unrelated to the driver, and AVA refers to violent and armed attacks such as armed robberies.

Accident Probability

Given that a state (or geographic area) j had n number of accidents reported in year y and that the total amount of petroleum product distributed and sold in that state was recorded (as "liters"), one can

estimate the total number of tanker trips k_j to the state by dividing $^{i''}$ by 33,000 liters, which is the typical tanker load. By applying the relative probability calculation, the likelihood of an accident occurring on each trip within a year for every state was determined to be:

$$\text{Accident probability per trip } (p) = \frac{nf}{kf} \quad (2)$$

In this case, j represents the number of accidents in a state, and k_j represents the number of trips made there. However, the chance value is predicated on the idea that the truck engaged in the accident in that state was meant to carry goods to the state and was not merely traveling through.

Relative Accident Consequence

The data displayed different accident locations i through m throughout state j (i.e., $i = 1, 2, \dots, m$ accident locations inside state j), and each accident location i in state j had a casualty consequence q recorded at it. Through the definition of $q_{i,j}$ per accident in terms of the total number of injuries ($q_{I,i,j}$) and deaths ($q_{F,i,j}$), the accident casualty effect may be assessed.

$$q_{(i,j)} = q_{F,i,j} + q_{I,i,j} \quad (3)$$

And total casualty consequence Q_j per year across state j is:

$$(Q_j) = q_{1j} + q_{2j} + q_{3j} + \dots + q_{mj} \sum_{i=1}^m q_{i,j} \quad (4)$$

To identify high-risk states, the relative accident casualties consequences in each state were calculated and compared using equation (4).

To determine the number of deaths in a certain accident and its relative probability, accident fatality data were utilized. As a result, we used the following equation to compute the cumulative frequencies after classifying all accidents according to the number of fatalities.

$$(Pa) = \frac{\sum_{c=1}^x aNc}{\sum_{c=1}^x Nc} \quad (5)$$

where x is the total number of categories or rankings, Nc is the number of accidents in a particular category c , Pa is the frequency of an accident with more than N deaths, and N is the number of deaths. Yang et al. (2010) also employed this technique.

The Parameters of Road Reliability

The testing reliability models of the road and road sections, which take into consideration the interval between the occurrences of two consecutive accidents on the observed road, require temporal and spatial data on the road accident occurrence as input parameters. Then, using the forms of the technical systems reliability theory, the characteristics of road reliability are computed from a temporal perspective (Pham, 2003). We noted the time of $t = 365 \text{ days} = 8,760 \text{ hours}$ when examining the likelihood and frequency of accidents on the sections and on the route overall.

The time and location of each traffic accident (year, month, hour) as well as the distance traveled (kilometer, meter) have been used to assign each accident, giving us the temporal-spatial distribution of traffic accidents by sector. The χ^2 test was used to determine if the empirical time distributions between subsequent accidents on the sections match the theoretical distributions. According to formulas explained by (Laxhvj & Kauffeld, 2003), the calculated main parameters of sections ($I = 1, 2, 3, \dots, 20$) and road are as follows [29]:

$$\text{Accident rate function } (\lambda) = \frac{1}{T_0} \quad (6)$$

$$\text{Distribution function (F)} \quad F(t) = \int_0^{\partial} f(t)dt = \int_0^{\alpha} \lambda e^{-\lambda t} dt = 1 - e^{-\lambda t} \tag{7}$$

$$\text{Reliability function (R)} \quad R(t) = 1 - F(t) = e^{-\lambda t} \tag{8}$$

$$\text{Meantime between two accidents (T}_0\text{)}. \quad T_0 = \int_0^{\partial} R(t)dt = 1 / \lambda \tag{9}$$

The probability is that there will not be an accident (P_0).

$$P_0 = e^{-\lambda t} \tag{10}$$

The probability of n recoveries (P_n).

$$P_n = \frac{(\lambda t)^n}{n} e^{-\lambda t} \tag{11}$$

where λi^* is the failure rate reallocated to the i th element of the system, and λ^* is the maximum allowable failure rate.

RESULTS AND DISCUSSION

In this research, the results of the analysis on the factors that cause fuel tanker-truck accidents were carefully observed before a conclusion was made.

The following table and numbers, respectively, show the findings from the six-year inquiry into the fuel tanker-truck accident:

Analysis on Accident Probability According to the Causation Factor

The results for the analysis on accident probability conducted in this current research are presented in Table 1.

Table 1. Analysis on accident probability.

Accident Factor	Years of Sampling					
	2014	2015	2016	2017	2018	2019
HF	0.1667	0.2580	0.3103	0.2282	0.3378	0.3750

From Table 1, it is observed that accident probability increased from 0.1667 to 0.3750 of the accident caused by human factor (HF). From the analysis in Table 1, it was seen that the accident probability of the accident caused by human factors was high.

Relative Accident Consequences

Table 2 is arranged according to losses like product, lives, vehicles, and infrastructure according to Appendix D. It is observed that there is an increase of relative accident consequence from 126 to 213 on the human factor (HF). The analysis in Table 2 shows that the relative accident consequence of the accidents caused by human factors was high.

Table 2. The results for analysis on relative accident consequences.

Accident Factor	2014	2015	2016	2017	2018	2019
	HF	126	115	117	191	130

Results on Reliability of Accident Caused by Human Factor (HF)

According to Table A in Appendix A, it shows the data evaluated from the human factors (HF) of the petroleum tanker-truck accidents for a six year period using the reliability analysis. The uptime, or operating time, was found to decrease from 2734 hours to 2016 hours. The meantime between accidents (MTBA) decreased annually as well, going from 273.4 hours to 74.7 hours. Additionally, the accident rate increased from 0.00114 to 0.00308. This shows that accidents due to human factors increased over the years.

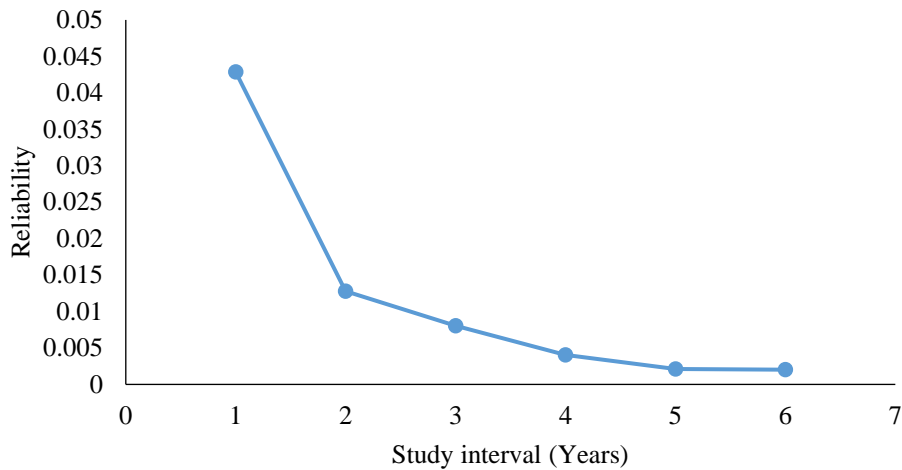


Figure 1. Reliability analysis for accident cause by human factor (HF).

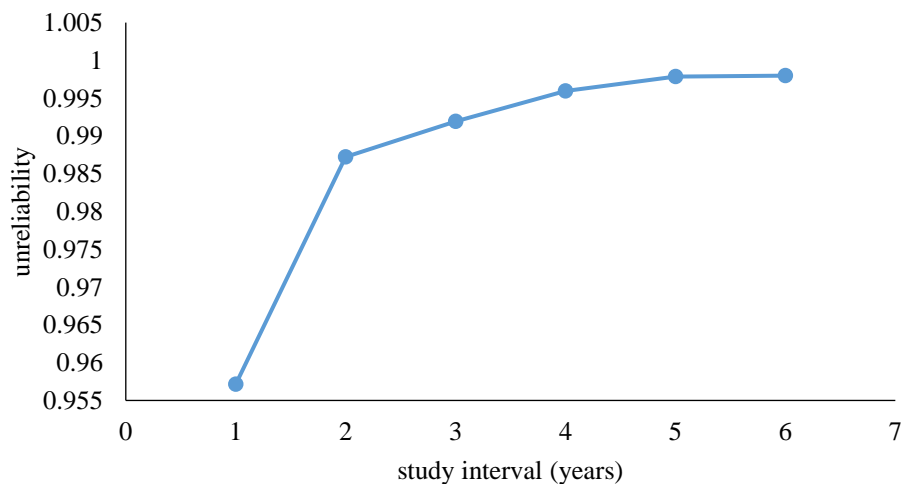


Figure 2. Unreliability analysis for accident cause by human factor (HF).

Figures 1 and 2 show the reliability of the study interval against reliability; there is a sharp decrease in reliability from the first year 0.04286 (4.286%) to the sixth year 0.00202 (0.202%). In Figure 2 (unreliability), from the first year 0.95714 to the 6th year 0.99798. The reliability was decreasing as the accident rate was increasing, while the unreliability was increasing. This shows that human factors (HF) were becoming less reliable yearly due to regular accidents. Also, from Figure 1, it was observed that the reliability of the truck accidents due to human factors for the entire six years is less than 10%, which is an indication that human factors such as driver's loss of concentration mostly due to longer hours on steering, dangerous driving (over-speeding), wrong overtaking, speed violations, route violations, drink driving, and other traffic violations are the main causes of fuel tanker-truck accidents [30].

CONCLUSION

This research was carried out mainly on petroleum tanker-truck accidents on roads based on human factors of accident causes for a six-year period. This investigation shows that this accident of the petroleum truck occurs during delivery after operating for several hours over a period running into years. If causes of accidents are not properly managed, the tendency of influencing the transportation of petroleum products negatively can occur. These accident causal factors include the human factor (HF) (dangerous driving, drivers' loss of concentration, usually alcohol-induced, wrongful overtaking, speed violation, route violation, drink driving, and other traffic violations; attacks such as armed robbery; and illegal parking on roadsides).

The root cause reliability analysis was used for the successful evaluation of the accident factors. The method was successfully used to evaluate the reliability of the petroleum truck accident factors during the distribution of petroleum products. The mean time between accidents (MTBA), accident rate, and reliability for each accident-causing factor were assessed using the Monte Carlo reliability analysis model, as indicated in Appendix A. From the research work, it was also observed that the accidents of these trucks are mostly caused by human factors over the past 6 years.

In all these, we can conclude that the study of petroleum tanker-truck accidents using the root cause reliability approach was carried out, and after analysis, we can agree that the human factor is the least reliable, which means that the human factor is the root cause of fuel tanker-truck accidents in Nigeria, which also agrees with Adetikan, 2017 reviewed in the article published.

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APPENDICES

Appendix A: Results on Reliability of Accidents Caused by Human Factor (HF)

Table A. Result of accidents caused by human factors.

Parameters	Period (Years)					
	2014	2015	2016	2017	2018	2019
Uptime (UT) (Hrs/yr)	2764	2400	2352	2304	2160	2016
Study interval (SI)(Hrs)	8760	8760	8760	8760	8760	8760
Meantime between accident (MTBA) (hrs)	276.4	150	130.6	109.8	84.4	74.7
Accident (AR)	0.04286	0.00182	0.00205	0.00239	0.00285	0.00308
Reliability	0.95714	0.01277	0.00806	0.00406	0.00212	0.00202

Unreliability (UR)	7.07hrs	0.98723	0.99194	0.99594	0.99787	0.99798
TMTBA	7.07hrs					

Appendix B. Summary of year parameters extracted truck accident report (human factors) (HF).

Year	No. of Accidents	Operational Time (h)	Fatality	No of Injuries	No of Vehicle Involve	No of Trip	Quantity of PMS Loss (10 ³ L)	Quantity of AGO Loss (10 ³ l)	Quantity of HHK Loss (10 ³ l)
2014	10	58	52	74	34	60	4095.4	500	400
2015	16	50	43	112	51	62	6712.4	900	530
2016	18	49	43	134	66	58	9600	690	600
2017	21	48	51	140	68	92	7943.4	400	876
2018	25	45	37	93	62	74	7456.5	820	345
2019	27	42	61	152	99	72	8328.26	720	654

Appendix C: Calculation Sheet for Truck Accident Analysis on Accidents Probability Human Factor (HF)

$$\text{Accident Probability (2014)} = \frac{\text{Number of accident}}{\text{Number of trip of tanker}} = \frac{n}{k} = \frac{10}{60} = 0.1667$$

$$\text{Accident Probability (2015)} = \frac{\text{Number of accident}}{\text{Number of trip of tanker}} = \frac{n}{k} = \frac{16}{62} = 0.2580$$

$$\text{Accident Probability (2016)} = \frac{\text{Number of accident}}{\text{Number of trip of tanker}} = \frac{n}{k} = \frac{18}{58} = 0.3103$$

$$\text{Accident Probability (2017)} = \frac{\text{Number of accident}}{\text{Number of trip of tanker}} = \frac{n}{k} = \frac{21}{92} = 0.2282$$

$$\text{Accident Probability (2018)} = \frac{\text{Number of accident}}{\text{Number of trip of tanker}} = \frac{n}{k} = \frac{25}{74} = 0.3378$$

$$\text{Accident Probability (2019)} = \frac{\text{Number of accident}}{\text{Number of trip of tanker}} = \frac{n}{k} = \frac{27}{72} = 0.3750$$

Relative Accident Consequence (HF)

Accident casualty consequence = Number of fatalities + Injuries

$$q_{i,j} = q_f + q_i$$

$$q_{i,j} (2014) = q_f + q_i = 52 + 74 = 126$$

$$q_{i,j} (2015) = q_f + q_i = 43 + 112 = 155$$

$$q_{i,j} (2016) = q_f + q_i = 43 + 134 = 177$$

$$q_{i,j} (2017) = q_f + q_i = 51 + 140 = 191$$

$$q_{i,j} (2018) = q_f + q_i = 37 + 93 = 130$$

$$q_{i,j} (2019) = q_f + q_i = 61 + 152 = 213$$

Appendix D: Reliability Analysis of Petrol Truck Accidents

Analysis of Accident cause by Human Factor (HF)

To Evaluate the Operating Time Per Year

Operational time per year = Operating time per week x 4 weeks x 12 months

For 1st year (2014) = 58 x 4 x 12 = 2764 hrs/yr

For 2nd year (2015) = 50 x 4 x 12 = 2400 hrs/yr

For 3rd year (2016) = 49 x 4 x 12 = 2352 hrs/yr

For 4th year (2017) = 48 x 4 x 12 = 2304 hrs/yr

For 5th year (2018) = 45 x 4 x 12 = 2160 hrs/yr

For 6th year (2019) = 42 x 4 x 12 = 2016 hrs/yr

Total operating time = 2764 + 2400 + 2352 + 2304 + 2160 + 2016 = 13996 hrs

Mean Time Between Accident (MTBA) for the Human Factor

$$MTBA = T_o = \frac{\text{Operating time}}{\text{Number of Accident}}$$

$$\text{For 1st year (2014)} = MTBA = \frac{\text{Operating time}}{\text{Number of Accident}} = \frac{2764}{10} = 276.4 \text{ hrs}$$

$$\text{For 2nd year (2015)} = MTBA = \frac{\text{Operating time}}{\text{Number of Accident}} = \frac{2400}{16} = 150 \text{ hrs}$$

$$\text{For 3rd year (2016)} = MTBA = \frac{\text{Operating time}}{\text{Number of Accident}} = \frac{2352}{18} = 130.6 \text{ hrs}$$

$$\text{For 4th year (2017)} = MTBA = \frac{\text{Operating time}}{\text{Number of Accident}} = \frac{2304}{21} = 109.8 \text{ hrs}$$

$$\text{For 5th year (2018)} = MTBA = \frac{\text{Operating time}}{\text{Number of Accident}} = \frac{2160}{25} = 86.4 \text{ hrs}$$

$$\text{For 6th year (2019)} = MTBA = \frac{\text{Operating time}}{\text{Number of Accident}} = \frac{2016}{27} = 74.7 \text{ hrs}$$

Total Mean Time Between Accident (TMTBA) for the Human Factor (HF)

$$TMTBA = \frac{\text{Annual hours per year}}{\text{Total Accidents per year}} = \frac{y_1 + y_2 + y_3 + y_4 + y_5 + y_6}{10 + 16 + 18 + 21 + 25 + 27}$$

$$TMTBA = \frac{276.4 + 150 + 130.6 + 109.8 + 86.4 + 74.7}{10 + 16 + 18 + 21 + 25 + 27} = \frac{827.9}{117} = 7.07 \text{ hrs/failure}$$

Accident Rate (λ) for Human Factor (HF)

$$\text{Accident rate}(\lambda) = \frac{\text{Number of Accidents per year}}{\text{Study interval (hours)}}$$

$$\text{Study interval} = 1 \text{ year} \times 24 \text{ hrs} = 365 \times 24 = 8760 \text{ hours/year}$$

$$\text{For 1st year (2014)} = \text{Accident rate}(\lambda) = \frac{\text{Number of Accident per year}}{\text{Study interval (hours)}} = \frac{10}{8760} = 0.00114$$

$$\text{For 2nd year (2015)} = \text{Accident rate}(\lambda) = \frac{\text{Number of Accident per year}}{\text{Study interval (hours)}} = \frac{16}{8760} = 0.00182$$

$$\text{For 3rd year (2016)} = \text{Accident rate}(\lambda) = \frac{\text{Number of Accident per year}}{\text{Study interval (hours)}} = \frac{18}{8760} = 0.00205$$

$$\text{For 4th year (2017)} = \text{Accident rate}(\lambda) = \frac{\text{Number of Accident per year}}{\text{Study interval (hours)}} = \frac{21}{8760} = 0.00239$$

$$\text{For 5th year (2018)} = \text{Accident rate}(\lambda) = \frac{\text{Number of Accident per year}}{\text{Study interval (hours)}} = \frac{25}{8760} = 0.00285$$

$$\text{For 6th year (2019)} = \text{Accident rate}(\lambda) = \frac{\text{Number of Accident per year}}{\text{Study interval (hours)}} = \frac{27}{8760} = 0.00308$$

$$\text{Total Accident rate for 6 years} = \sum \text{failure rate/year}$$

$$\begin{aligned} \text{Total accident rate} &= 0.00114 + 0.00182 + 0.00205 + 0.00239 + 0.00285 + 0.00308 \\ &= 0.001333 \text{ /year} \end{aligned}$$

Reliability Analysis (R) for Human Factor (HF)

$$\text{Reliability, } R = e^{-\lambda t}$$

where λ is Accident rate/year, t = operating time/year.

$$\text{For 1st year (2014)} = R = e^{-\lambda t} = e^{-0.00114 \times 2764} = 0.04286$$

$$\text{For 2nd year (2015)} = R = e^{-\lambda t} = e^{-0.00182 \times 2400} = 0.01277$$

$$\text{For 3rd year (2016)} = R = e^{-\lambda t} = e^{-0.00205 \times 2352} = 0.00806$$

$$\text{For 4th year (2017)} = R = e^{-\lambda t} = e^{-0.00239 \times 2304} = 0.00406$$

$$\text{For 5th year (2018)} = R = e^{-\lambda t} = e^{-0.00285 \times 2160} = 0.00213$$

$$\text{For 6th year (2019)} = R = e^{-\lambda t} = e^{-0.00308 \times 2016} = 0.00202$$

Unreliability (UR) (Distribution Function (F)) (HF)

$$UR = F = 1 - e^{-\lambda t} = 1 - R$$

$$\text{For 1st year (2014)} = UR = F = 1 - e^{-\lambda t} = 1 - R = 1 - 0.04286 = 0.95714$$

$$\text{For 2nd year (2015)} = UR = F = 1 - e^{-\lambda t} = 1 - R = 1 - 0.01277 = 0.98723$$

$$\text{For 3rd year (2016)} = UR = F = 1 - e^{-\lambda t} = 1 - R = 1 - 0.00806 = 0.99194$$

$$\text{For 4th year (2017)} = UR = F = 1 - e^{-\lambda t} = 1 - R = 1 - 0.00406 = 0.99594$$

$$\text{For 5th year (2018)} = UR = F = 1 - e^{-\lambda t} = 1 - R = 1 - 0.00213 = 0.99787$$

$$\text{For 6th year (2019)} = UR = F = 1 - e^{-\lambda t} = 1 - R = 1 - 0.00202 = 0.99798$$

Analysis of Accidents Caused by Human Factor (HF) **To Evaluate the Operating Time Per Year**

Operational time per year = Operating time per week x 4 weeks x 12 months

$$\text{For 1st year (2014)} = 58 \times 4 \times 12 = 2764 \text{ hrs/yr}$$

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$$\text{For 5th year (2018)} = 45 \times 4 \times 12 = 2160 \text{ hrs/yr}$$

$$\text{For 6th year (2019)} = 42 \times 4 \times 12 = 2016 \text{ hrs/yr}$$

$$\text{Total operating time} = 2764 + 2400 + 2352 + 2304 + 2160 + 2016 = 13996 \text{ hrs}$$

Mean Time Between Accident (MTBA) for the Human Factor

$$MTBA = T_o = \frac{\text{Operating time}}{\text{Number of Accident}}$$

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$$\text{For 6th year (2019)} = MTBA = \frac{\text{Operating time}}{\text{Number of Accident}} = \frac{2016}{27} = 74.7 \text{ hrs}$$

Total Mean Time Between Accident (TMTBA) for the Human Factor (HF)

$$TMTBA = \frac{\text{Annual hours per year}}{\text{Total Accident per year}} = \frac{y_1 + y_2 + y_3 + y_4 + y_5 + y_6}{10 + 16 + 18 + 21 + 25 + 27}$$

$$TMTBA = \frac{276.4 + 150 + 130.6 + 109.8 + 86.4 + 74.7}{10 + 16 + 18 + 21 + 25 + 27} = \frac{827.9}{117} = 7.07 \text{ hrs/failure}$$

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$$\text{For 5th year (2018) = Accident rate } (\lambda) = \frac{\text{Number of Accident per year}}{\text{Study interval (hours)}} = \frac{25}{8760} = 0.00285$$

$$\text{For 6th year (2019) = Accident rate } (\lambda) = \frac{\text{Number of Accident per year}}{\text{Study interval (hours)}} = \frac{27}{8760} = 0.00308$$

Total Accident rate for 6 years = \sum failure rate/year

$$\begin{aligned} \text{Total accident rate} &= 0.00114 + 0.00182 + 0.00205 + 0.00239 + 0.00285 + 0.00308 \\ &= 0.01333 \text{ /year} \end{aligned}$$

Reliability Analysis (R) for Human Factor (HF)

$$\text{Reliability, } R = e^{-\lambda t}$$

where λ represents Accident rate/year, t = operating time/year.

$$\text{For 1st year (2014) = } R = e^{-\lambda t} = e^{-0.00114 \times 2764} = 0.04286$$

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