Journal of Civil Engineering and Architecture 12 (2018) 527-542
doi: 10.17265/2328-2142/2018.07.007

Modeling Highway Traffic Safety for Developing Countries Using Delphi Technique and Bayesian Network: Case Study for Nigeria

Anthony C. Mbakwe[1], Anthony A. Saka[2], Keechoo Choi[3] and Young-Jae Lee[2]

1. Dynatrend Construction Ltd., Bowie, MD 20720, Maryland, USA

2. Department of Transportation and Urban Infrastructure Studies, School of Engineering, Morgan State University, Baltimore, MD 21251, USA

3. Department of Transportation Engineering, Ajou University, Suwon 442-749, Korea

Abstract: Highway traffic safety is an issue confronting developing countries and those of industrialized nations. Nigeria, as a developing country, has been experiencing unusually high traffic related injury and fatality rates. In order to commence combating highway safety problems in Nigeria, the first task is to identify the major contributing factors; however, Nigeria has no reliable and comprehensive database of traffic accidents and casualties. Consequently, the Delphi technique was utilized in generating the required data such as number of registered automobiles, number of licensed drivers, and annual fatality count for modeling and forecasting accident rates in Nigeria. A Bayesian network model was developed and used, with the data obtained from Delphi process, to demonstrate possible traffic safety responses to different scenarios of changes in the Nigerian socio-political culture. Although the Delphi technique and the Bayesian network model only estimate the accident and safety data, those methods can be a realistic option when those data are not available, especially for the developing countries. As a result, the major accident contributors have been identified and the top three contributors—road condition, DUI (driving under the influence) and reckless driving—are policy related. The Nigerian traffic safety outlook would improve significantly if the existing laws and policies can be enforced, even at a very moderate level.

Key words: Highway safety, Delphi technique, Bayesian network, developing countries, Nigeria.

1. Introduction

Highway traffic safety is a world problem. Almost 1.2 million people die and tens of millions are injured annually worldwide in road crashes [1]. This problem is worse in developing countries where little attention is devoted to promoting public safety on highways. About 70% of those deaths occur in developing countries [1]. Many of the highway casualties are pedestrians and non-occupants of motorized vehicles in poor countries. More people would die if serious actions are not envisaged and put into action. Many researchers have shown that traffic crashes are the world's ninth most important problem affecting humanity [2].

Roads play very crucial roles on the socio-economic activities and conditions of developing countries such as Nigeria, because they are the most popular modal class of transportation. The majority of the population cannot afford traveling by air and those who can find their destinations are still hours from the airport leaving them to brave completing their trips through challenging road networks. Trips by railroads are virtually nonexistent. This explains why road travels are common and highways have assumed a place of prominence as a very important route to conduct social activities and businesses [3].

Presently in Nigeria, new highways and roadways

Corresponding author: Young-Jae Lee, Ph.D., associate professor,research fields: public transportation, ITS, and traffic safety.

are periodically built with no touch of routine maintenance. Most existing and ageing highways are rendered impassible as a result of lack of rehabilitation. The state in which the roads in Nigeria are left is a recipe for innovative driving and indeed, most professional drivers actually indulge in innovative driving practices in order to maneuver their vehicles to their destinations in the quickest possible time. The policymakers have basically turned the other way and in the process ignored and abandoned some of the most essential elements of highway safety and the traffic challenges that swathe the country.

Overall, there is a lack of attention to highways which are considered the lifeline of the country's economic and social activities. When it comes to highway transportation policies, whatever currently exists is rendered irrelevant due to inadequate enforcement or no enforcement at all. The policymakers, as well as the general population, have long tolerated and accepted the culture of inappropriate highway contract kickbacks with reckless impunity resulting in substandard levels workmanship. Law enforcement personnel and the highway patrol officers whose duty is to enforce highway traffic laws have failed because of their abject propensities to accept bribes (which they believe is a norm) from whoever breaks traffic laws, and in so doing leave the lawbreakers unaccountable for their actions.

2. Literature Review

Highway traffic safety is a growing problem, not only in Nigeria, but also in other developing countries. The obvious causes of highway accidents may be human related, road related, policy related or automobile related. Whether the causes are considered individually or collectively, the major fact remains that they create serious problems on the highways. The casualty counts vary by countries and are influenced by one or a combination of the aforementioned causes.

Highway accidents are major concerns of Nigerians everywhere because there is hardly anyone whose life has not been touched, directly or indirectly, by the aftermath of highway crashes. Past researches have credited a large proportion of the blame to human factors. In order to find ways to curtail heavy loss of lives on Nigeria's roadways, Asogwa's [4] study to determine the effect of kola nut on vehicle operators who are prone to accidents revealed that out of 555 automobile operators that got into traffic accidents, 7.74% voluntarily admitted to have used alcohol, and 12.25% said they had consumed kola nuts. As a social snack, kola nut contains 2.5 percent caffeine, a stimulant that affects the central nervous system. When eaten, kola nuts stimulate an individual to the point that hunger and/or sleep are suppressed for several hours.

Bad roads are contributory to the number of accidents and their resulting aftermath. Adefolalu's [5] paper, towards a realization of better transport services in Nigeria, hinted that for a government to be able to fully control its establishment and simultaneously maintain political control over wide territories require the presence of well-maintained transport infrastructure all over the country. He pointed out that ensuring that law and order are respected and preserved entails the use of the full capability of the government to continuously stay in touch with all its branches. This occurs if the transportation systems are readily available and well-organized throughout the country. Improvement of the roadway network could be in the form of road expansion, rehabilitation, and improvement of current roads and bridges to ensure the safety of the users and the extension of the life span of the infrastructure. On policy related causes, Ottong [6] discussed the role played by public teaching regarding highway accidents. He emphasized that the government, the police, and the public can serve as the mode for the transfer of traffic knowledge in Nigeria. He stated that the business of building roads and educating the citizens on highway safety are the full responsibilities of every country, which transfers the task to the federal, state, or local governments.

Sleet and Branche [7] and other researchers contended that most of the accidents and the associated casualties are preventable. They also argued that with effective road traffic injury prevention policies in place, majority of the lives frequently lost and injuries sustained would be drastically curtailed. With the current traffic conditions, the prognosis for better global road safety is gloomy because the roadways are getting more crowded with more motorized and non-motorized traffic which becomes a part of the daily traffic pool. This situation is expected to worsen due to an increase in the global population resulting in the addition of even more automobiles into the daily highway traffic fleet.

2.1 Traffic Accident Data and Cost of Road Crashes

Wang's [3] study to evaluate some of the elements of injuries from highway accidents revealed that a person had about a 14% chance of sustaining an automobile related injury at some point in life, and the chance of an average automobile getting into a collision was about 20% in a period of five years. Ironically, industrialized nations with 80% of the world's automobiles have 15% death rate from crashes, while developing countries with 20% of world's automobiles have 85% crash-related fatality rate.

Ghee et al. [8] on the analysis of existing data on socio-economic impacts of road traffic accidents in developing countries considered the extent of the impact of road traffic injuries and deaths from socioeconomic standpoint. The objective of the research was to widen the understanding of the consequence of road accidents on the economy and measure the repercussion in socioeconomic terms. The study revealed that the World Bank and the WHO separately estimated half a million fatalities and 15 million hurt each year from highway related incidents.

2.2 The Delphi Technique

Delphi technique is a prediction approach formulated by the Rand Corporation in the 1960's [9]. This prediction approach was later improved by the United States government to serve as a management device by a group of individuals. It is important when a group of individuals is striving to take a stance on an important issue in a setting, or when the issue under consideration hinges on strong groups with differing ideas, convictions, or inclinations. The technique can be applied in varying size groups in an official or relaxed setting when the basic intent is to harness the knowledge of experts to generate data.

The Delphi process involves the selection of a panel of experts that has excellent understanding of the proposed assignment. The panelists chosen are experts in highway traffic safety, transportation officials, medical professionals, policymakers and law enforcement personnel. A total of 35 participants were used of which 71% were traffic safety experts, 11% were policymakers and law enforcement personnel, and 18% were medical doctors, nurses, and paramedics. Their ages ranged from 41 years to 74 years with a mean age of 54 years. However their specific experience with highway traffic critical events was not known. Each panelist works independently and/or anonymously on the project over a set period of time without collaborating with other panelists. The Delphi process works extremely well because of the anonymity involved. The results of their work are transferred to a facilitator that collects all the data. The facilitator has the option to exchange feedbacks with the panelists as many times as may be necessary for possible reevaluation of the results they transmit and to make revisions until consensus and convergence are achieved.

2.3 The Bayesian Network

Shuttleworth [10] defined Bayesian probability model as the process of using probability to try to forecast the likelihood of a future event. This probability is usually evaluated as a percentage. It evaluates an individual's degree of certainty in a scheme. Researchers use the Bayesian probability model to evaluate their level of self-reliance on a given outcome. As stated by Bruyninckx [11], the Bayesian model is one of the major models that are useful in reasoning and taking a quick action when there is doubt. The result obtained from the Bayesian network models is always consistent regardless of how the information is processed when Bayesian probability tools are used.

Heckerman and Breese [12] said that one of the primary elements of a Bayesian model is that it allows the model creator to use commonsense and real-world knowledge to eliminate needless complexity in the model. In Bayesian model, meaningless relationships are removed explicitly by declaring the meaningful ones. After establishing all the variables in a model, the variables that cause changes in the system are deliberately associated to those that they influence. Only those influences are considered. Mbakwe et al. [13] extensively utilized the Bayesian network in a separate research on highway traffic safety which gave results consistent with those of other researchers in highway traffic safety.

3. Methodology

Three independent tasks are pursued namely (a) identification of the major highway safety problems contributors in Nigeria; (b) assessment of the actions of the policymakers and the public on highways in Nigeria; and (c) utilization of the Bayesian Network Model to predict accident rate in Nigeria in the absence of an existing useable accident database. These three independent tasks are tackled by exploiting the Delphi processes to generate required data. Later, Bayesian Network Model is employed in modeling and forecasting the accident rates the results of which are factored into methods to combat highway safety problems in the country.

3.1 Methodology Validation

In order to test the quality of the methodology, a technique was devised to authenticate the quality of the data obtained from the Nigerian Delphi Panel. To achieve this, in the previous research [13], Korea, a country that underwent similar highway safety challenges and had very good highway safety database, was chosen. Three target years (1988, 1998, and 2008) were used. The data harnessed through the Delphi Technique, in combination with the Bayesian Network Model, were utilized in modeling and forecasting traffic accident rates as shown in Table 1. Forty participants were chosen from Korea and the result obtained from the Korean Panel was found to be statistically similar to the actual data in Korean national database and is displayed as Table 2, thereby confirming the Delphi technique.

3.2 Data Collection

Due to very poor highway safety records, the highway accident data are obtained by leveraging the knowledge of Nigeria's transportation experts and utilizing them in data collection. This is done through the process known as the Delphi technique. Data collection is carried out in two phases: (a) the highway traffic accident records phase and (b) the highway/roadway transportation projects phase. Throughout the data collection, the Delphi panelists work independently and make no references to available records in order to preserve the overall data quality. A minimum of three iterations are carried out per data collection area.

In accident records phase, the initial task is to obtain the major contributors to highway accidents in Nigeria. The predetermined guidelines for accomplishing this goal, along with a table containing seven suspected major contributors, are transmitted to all panelists for their evaluation. They are asked to assess each of the major contributors (with the option to add or remove from the list) and assign the percentage of accidents each contributes using their best expert judgments. Other factors whose combined net effects have been considered minimal are left out. The aggregate points awarded to these factors together equal 100%. The tabulation of the aggregate average percentage points at convergence is displayed in Table 3.

Table 1 Summary of traffic accident probabilities for all scenarios tested.

Traffic accident scenario	% Δ from state	Probability	Poor state
PE	Poor	0.066%	-
	Moderate	0.060%	9.1%
	Good	0.050%	24.24%
PE* & TSE**	Poor/Poor	0.066%	-
	Poor/Moderate	0.066%	-
	Poor/Good	0.065%	1.52%
PE & TSE	Moderate/Poor	0.061%	5.58%
	Moderate/Moderate	0.059%	10.61%
	Moderate/Good	0.058%	12.12%
PE & TSE	Good/Poor	0.051%	22.73%
	Good/Moderate	0.049%	25.76%
	Good/Good	0.047%	28.79%

* PE denotes policy enforcement;

** TSE denotes traffic safety education.

Table 2 Korean Delphi survey data vs. Korean national data.

	No. of registered automobiles		No. of road traffic accidents		Fatality/10,000 vehicles		No. of licensed drivers	
Year	Korean Survey	Korean Actual	Korean Survey	Korean Actual	Korean Survey	Korean Actual	Korean Survey	Korean Actual
1988	4,984,615	2,035,448	226,744	225,062	26	57	7,612,308	6,191,821
1998	10,313,359	10,469,599	242,077	239,721	10	9	18,973,077	19,549,002
2008	16,736,744	16,778,884	216,359	215,822	6	4	25,066,923	25,268,379

3.3 Licensed Drivers, Automobile Registration, Annual Accidents, and Fatality Rate

In a similar method as in major accident contributing factors, the Delphi panel provided the number of licensed drivers; automobiles registered annually, number of accidents, and highway accident deaths per 10,000 vehicles for years 2000 through 2009. The mean of the data provided is displayed in Table 4.

3.4 Conditional Probability Table

The conditional probability table is populated by the Delphi panel using the variables of each of the major accident causes. Convergence is achieved within three iterations. Samples of the full conditional probability table with and without accidents are displayed as Tables 5 and 6, respectively. Policy enforcement and traffic safety education and their relationships with the other major accident causes are fully utilized in the conditional probability scenarios.

3.5 Highway/Roadway Transportation Projects

In highway/roadway transportation projects phase, the major highway construction contracts awarded between 2000 and 2009 are utilized. The highway construction contracts considered are only those that are completed or are supposed to have been completed based on the agreed upon contract duration. Because accurate records of previously awarded highway contracts are unavailable, the Delphi panelists again use their professional knowledge and judgments to estimate the percentage of contracts that meet the stipulated criteria. The data collection comprised of:

(1) Construction project awards for new roadway construction;

(2) Construction contract awards for highway/roadway extension and/or expansion;

(3) Awards for highway/roadway preventive maintenance work.

Based on the above criteria, the Delphi panelists additionally estimate the percentage of awarded contracts that are fully executed and those that are abandoned. The probable reasons for their abandonment are also obtained. Delphi panel data on contract awards are presented in Tables 7 and 8.

Table 3 Traffic accident contributing factors.

Contributing factors	Average	Median	Variance	Standard deviation
Road condition	22	20	8.75	2.96
Road obstruction	5.89	6	1.11	1.05
Traffic control devices	3.44	2	1.53	1.24
Driving under the influence	22.11	13	13.61	3.69
Reckless driving	26.67	25	25.25	5.02
Mechanical failure	9	10	6.5	2.55
Driver fatigue	10.89	10	2.36	1.54

Table 4 Licensed drivers, vehicle registration, annual accidents, and fatality rate.

Year	Licensed drivers (1,000)	Registered vehicles (1,000)	Annual accidents	Fatality per 10,000 vehicles
2000	12,157	5,419	18,983	22.43
2001	12,983	5,824	19,850	22.86
2002	13,383	6,038	20,197	21.14
2003	13,833	5,796	21,817	19.29
2004	14,383	6,371	22,367	18.57
2005	14,883	6,726	22,233	15.57
2006	15,367	7,586	23,750	14.14
2007	15,800	8,603	23,950	13.71
2008	16,217	8,523	24,467	12.57
2009	16,700	9,071	25,083	12.86

3.6 Data Analysis

Data collected are analyzed for application in Bayesian network model. In the analysis of the data, the mean of the aggregate data for all the accident contributing factors is calculated (Table 3). The top three accident contributors are also noted. The contributions of unexecuted highway transportation projects and impact of inadequate maintenance work coupled with lack of rehabilitation are factored into the analyses of the data. The percentage of fully funded, but unconstructed/abandoned projects as well as the percentage of the fully executed contracts is obtained. The percentage of fully funded contracts is compared to actual percentage constructed. The obtained difference is a direct reflection of the impact of the deviant behaviors of those directly involved in the contract execution.

3.7 Modeling and Forecasting

The Bayesian network model developed and utilized in this paper is displayed as Fig. 1. The probability distribution of nodes in the model generated from the above Bayesian network is displayed as Fig. 2. The approach consists of the establishment of a node for each of the identified highway accident contributing factors. Each of these variables is appropriately linked and assigned contributing probabilities as shown in Fig. 2 and Eqs. (1)-(9). The panelists utilize the assigned conditional probabilities to populate the probability table. The policy enforcement and traffic safety education scenarios with the accident causes are used in the network. The kind of policy enforcement applied in the network is based on three systems of reactions by the law enforcement community to compel and/or punish those who break the traffic laws in order to force them to obey the existing traffic laws. In this case, the researchers utilized three states of enforcement—poor, moderate, and good—which were individually inserted into the network to evaluate their responses. The data are employed in forecasting the highway accident rate in Nigeria for different policy and driving scenarios.

Table 5 Conditional probability mean values (partial) table with accident present.

																Page 1
						PM1	PM2	PM3	PM4	PM5	PM6					
Road condition	Road obstruction	Traffic control devices	Reckless driving	Mechanical failure	Driver fatigue	Yes	Yes	Yes	Yes	Yes	Yes		Average	Median	Variance	Std deviation
Poor	No	Inadequate	No	No	No	0.08	0.03	0.05	0.05	0.03	0.04		0.049	0.049	0.00027	0.016
Poor	No	Inadequate	No	No	Yes	0.08	0.03	0.07	0.05	0.03	0.04		0.051	0.049	0.00032	0.018
Poor	No	Inadequate	No	Yes	No	0.07	0.04	0.07	0.05	0.04	0.05		0.057	0.053	0.00021	0.015
Poor	No	Inadequate	No	Yes	Yes	0.07	0.05	0.09	0.06	0.05	0.05		0.064	0.059	0.00018	0.014
Poor	No	Inadequate	Yes	No	No	0.08	0.05	0.1	0.06	0.05	0.06		0.069	0.064	0.0003	0.017
Poor	No	Inadequate	Yes	No	Yes	0.08	0.05	0.08	0.06	0.06	0.06		0.069	0.064	0.00017	0.013
Poor	No	Inadequate	Yes	Yes	No	0.09	0.05	0.1	0.07	0.05	0.08		0.073	0.071	0.00032	0.018
Poor	No	Inadequate	Yes	Yes	Yes	0.08	0.06	0.11	0.07	0.05	0.07		0.076	0.074	0.00033	0.018
Poor	No	Adequate	No	No	No	0.06	0.02	0.04	0.04	0.02	0.03		0.037	0.039	0.00018	0.013
Poor	No	Adequate	No	No	Yes	0.07	0.02	0.06	0.04	0.02	0.03		0.041	0.039	0.00033	0.018
Poor	No	Adequate	No	Yes	No	0.07	0.03	0.07	0.04	0.02	0.04		0.046	0.044	0.00031	0.018
Poor	No	Adequate	No	Yes	Yes	0.06	0.04	0.08	0.05	0.04	0.04		0.054	0.049	0.00019	0.014
Poor	No	Adequate	Yes	No	No	0.06	0.04	0.09	0.05	0.03	0.04		0.054	0.049	0.00037	0.019
Poor	No	Adequate	Yes	No	Yes	0.07	0.05	0.1	0.05	0.06	0.05		0.066	0.059	0.00029	0.017
Poor	No	Adequate	Yes	Yes	No	0.07	0.05	0.11	0.05	0.04	0.05		0.064	0.053	0.00055	0.023

Table 6 Conditional probability mean values (partial) table for no accident.

															Page 2
						PM1	PM2	PM3	PM4	PM5	PM6				
Road condition	Road obstruction	Traffic control devices	Reckless driving	Mechanical failure	Driver fatigue	No	No	No	No	No	No		Average	Median	Standard deviation
Poor	No	Inadequate	No	No	No	99.93	99.97	99.95	99.95	99.97	99.96		99.951	99.951	0.015
Poor	No	Inadequate	No	No	Yes	99.93	99.97	99.94	99.95	99.97	99.96		99.949	99.951	0.016
Poor	No	Inadequate	No	Yes	No	99.93	99.96	99.93	99.95	99.96	99.95		99.943	99.946	0.014
Poor	No	Inadequate	No	Yes	Yes	99.93	99.95	99.92	99.94	99.95	99.95		99.936	99.941	0.013
Poor	No	Inadequate	Yes	No	No	99.92	99.95	99.91	99.94	99.95	99.94		99.931	99.936	0.016
Poor	No	Inadequate	Yes	No	Yes	99.92	99.95	99.92	99.94	99.94	99.94		99.931	99.936	0.012
Poor	No	Inadequate	Yes	Yes	No	99.92	99.95	99.91	99.94	99.95	99.93		99.929	99.931	0.016
Poor	No	Inadequate	Yes	Yes	Yes	99.92	99.94	99.9	99.93	99.95	99.93		99.924	99.926	0.017
Poor	No	Adequate	No	No	No	99.95	99.98	99.96	99.96	99.98	99.97		99.963	99.961	0.012
Poor	No	Adequate	No	No	Yes	99.94	99.98	99.95	99.96	99.98	99.97		99.959	99.961	0.016
Poor	No	Adequate	No	Yes	No	99.94	99.97	99.94	99.96	99.98	99.96		99.954	99.956	0.016
Poor	No	Adequate	No	Yes	Yes	99.94	99.96	99.93	99.95	99.96	99.96		99.946	99.951	0.013
Poor	No	Adequate	Yes	No	No	99.94	99.96	99.92	99.95	99.97	99.96		99.946	99.951	0.018
Poor	No	Adequate	Yes	No	Yes	99.93	99.95	99.91	99.95	99.94	99.96		99.936	99.941	0.018
Poor	No	Adequate	Yes	Yes	No	99.93	99.95	99.9	99.95	99.96	99.96		99.938	99.946	0.023

Table 7 Highway contracts performance.

	Overall contract performance in percentage									
Highway contracts	PM1	PM2	PM3	PM4	PM5	PM6	PM7	Total	Average	Median
New road construction	10	20	45	50	40	25	45	235	33.571	40
Existing road expansion	20	16	25	30	10	30	35	166	23.714	25
Road maintenance	70	64	30	20	50	45	20	299	42.714	45
Percentage executed	80	16	65	70	40	20	20	311	44.429	40
Percentage abandoned	20	84	35	30	60	80	80	389	55.571	60

Table 8 Reasons for contract abandonment.

	Reasons for contract abandonment						
Highway contracts	PM1	PM2	PM3	PM4	PM5	PM6	PM7
Lack of funding	x			x	x	x	x
Design modifications						x	x
Poor contractor performance	x	x	x		x	x	x
Ghost contracts					x		x
Other reasons			Corrupt contractors	Poor contract knowledge			Hostile indigenes

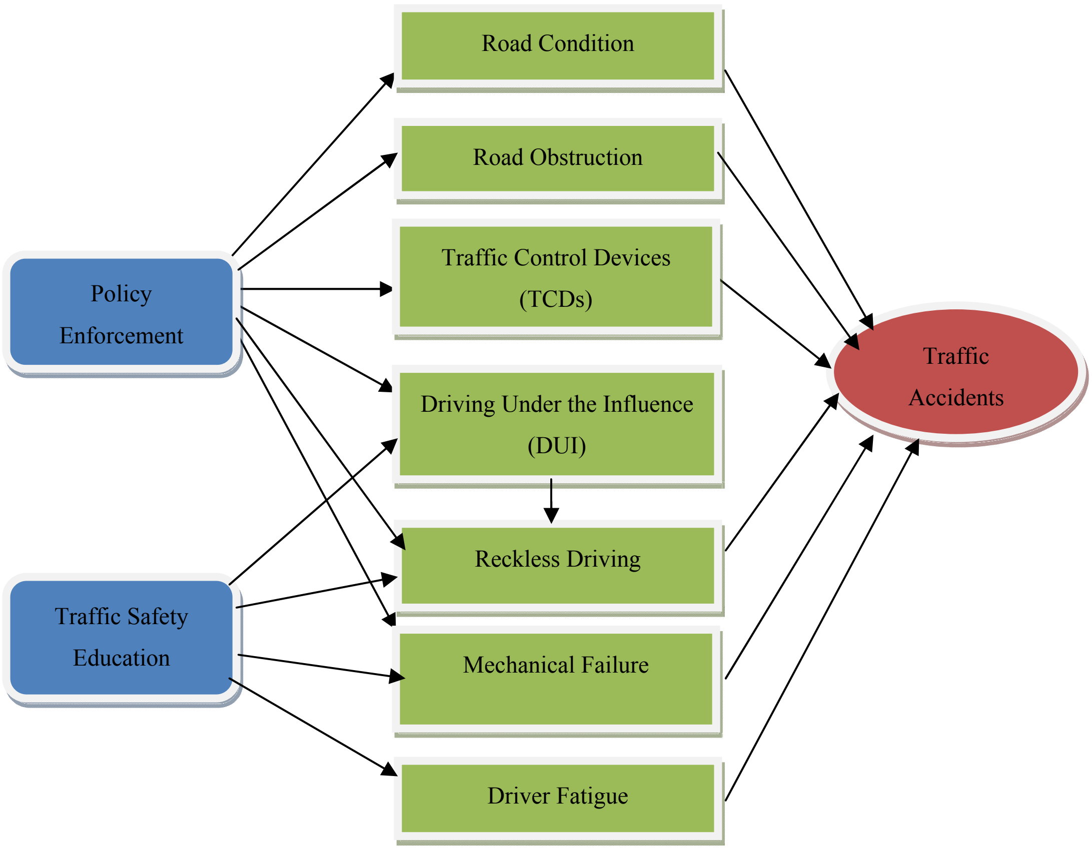

Fig. 1 Bayesian network of highway traffic accident causes.

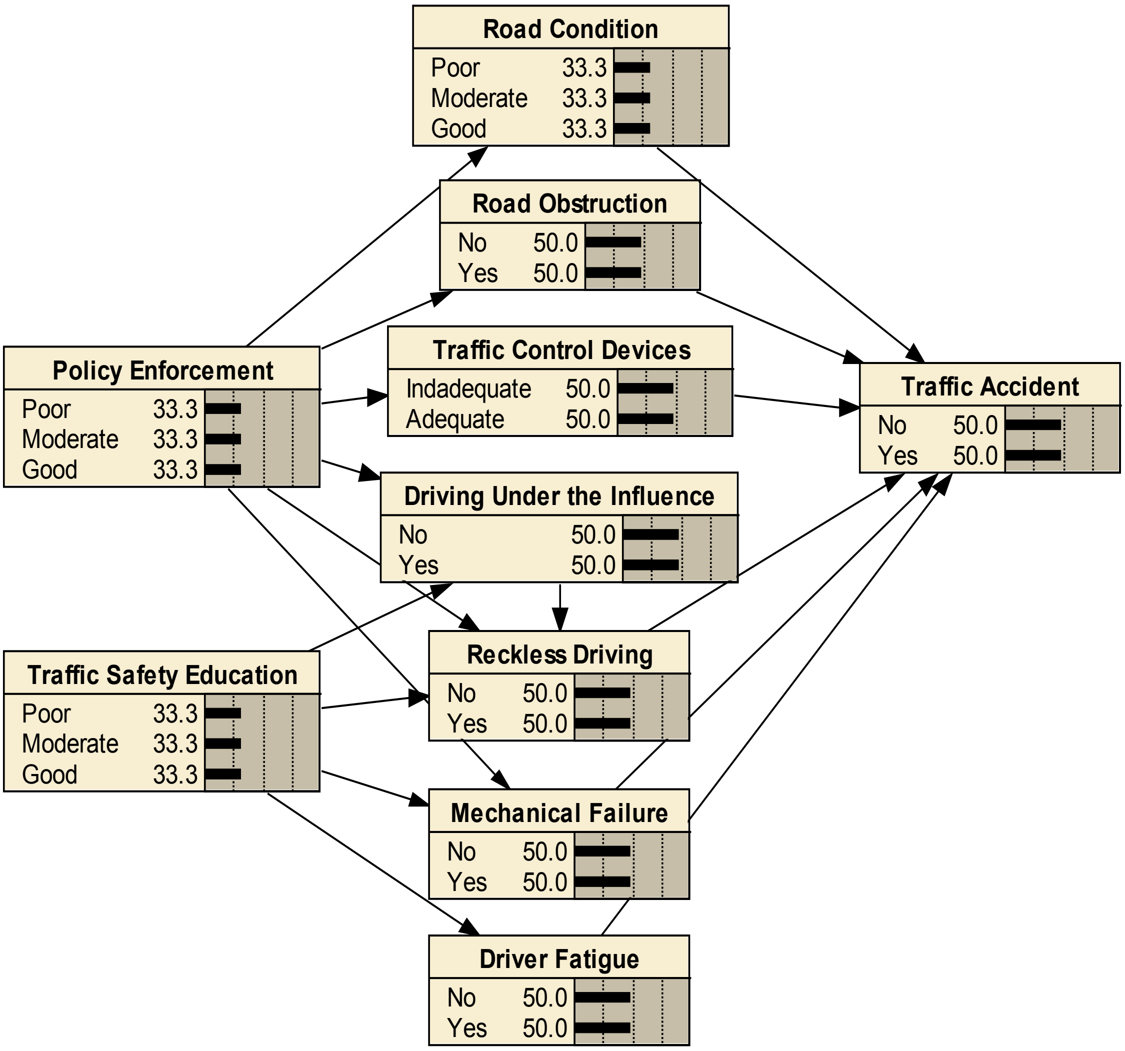

Fig. 2 Initial probability distribution of nodes in the network.

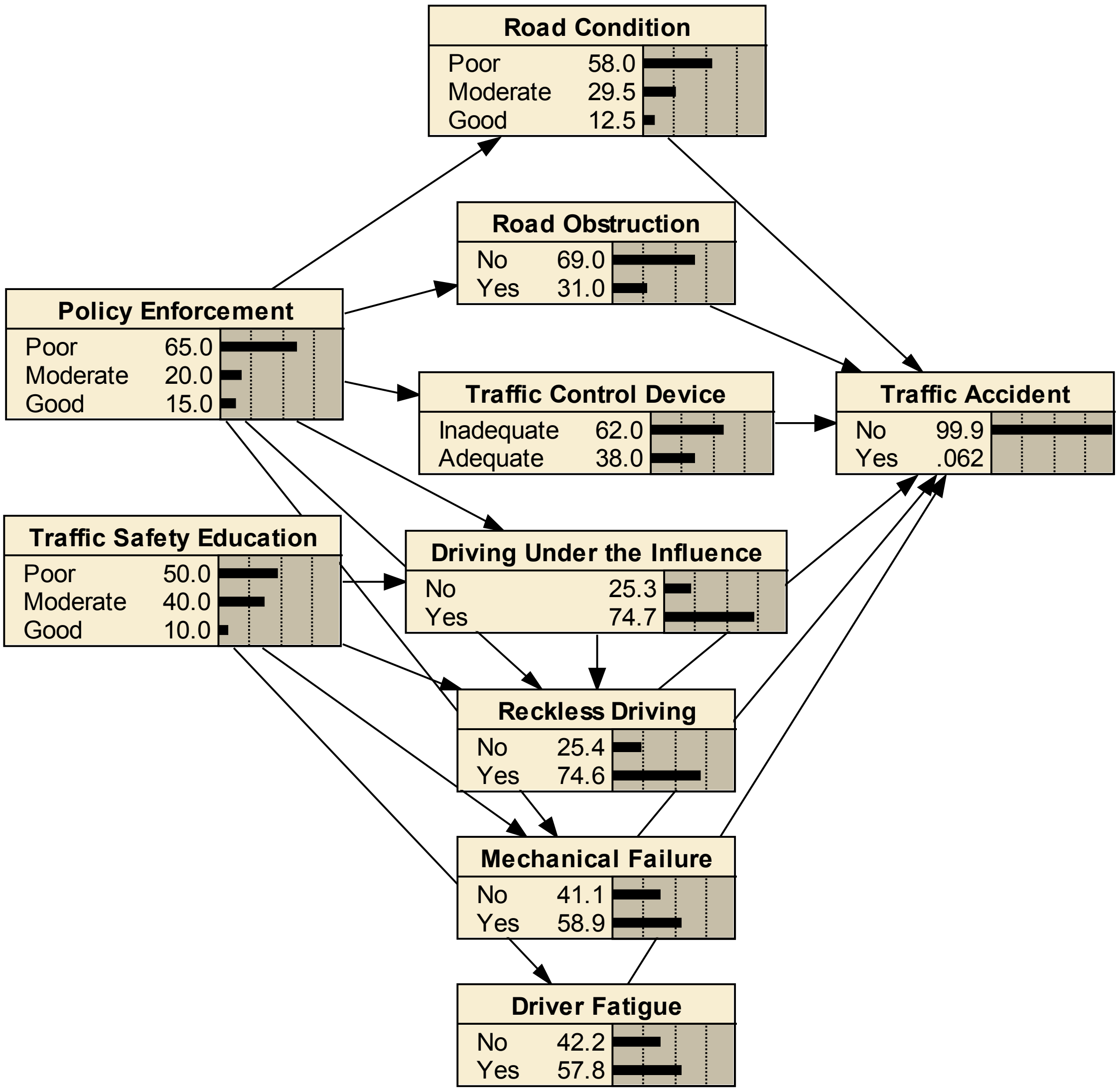

Fig. 3 Probability distribution for all nodes in the network.

Automobiles count aids in determining why the fatality rate is high because a rising automobile count coupled with bad roads, reckless driving, DUI (driving under the influence), and poor policy enforcement translate into higher incidence of accidents which impact the casualty count as well. The difference (55.57 displayed in Table 7) between the percentage of awarded contracts and the percentage actually constructed gives the impact of the deviant behavior of those involved in various highway contracts. The reasons for contract abandonment expose the low level (poor state) overall policy enforcement practices in the country.

The Bayesian network model generated can be expressed as:

$$P(X_1, X_2, X_3, X_4, X_5, X_6, X_7, X_8, X_9, X_{10}) = P(X_{10} \mid X_9, X_8, X_7, X_5, X_4, X_3) P(X_9 \mid X_2)P(X_8 \mid X_1, X_2)P(X_7 \mid X_1, X_2, X_6)P(X_6 \mid X_1, X_2) P(X_5 \mid X_1)P(X_4 \mid X_1)P(X_3 \mid X_1)P(X_2)P(X_1) \quad (1)$$

$$P(X_{10} \mid X_9, X_8, X_7, X_5, X_4, X_3) = [P(X_9, X_8, X_7, X_5, X_4, X_3 \mid X_{10})P(X_{10})]/P(X_9, X_8, X_7, X_5, X_4, X_3) \quad (2)$$

$$P(X_9 \mid X_2) = [P(X_2 \mid X_9)P(X_9)]/P(X_2) \quad (3)$$

$$P(X_8 \mid X_1,X_2) = [P(X_1, X_2 \mid X_8)P(X_8)]/P(X_1, X_2) \quad (4)$$

$$P(X_7 \mid X_1, X_2, X_6) = [P(X_1, X_2, X_6 \mid X_7)P(X_7)]/P(X_1, X_2, X_6) \quad (5)$$

$$P(X_6 \mid X_1, X_2) = [P(X_1, X_2 \mid X_6)P(X_6)]/P(X_1, X_2) \quad (6)$$

$$P(X_5 | X_1) = [P(X_1 | X_5)P(X_5)]/P(X_1) \quad (7)$$

$$P(X_4 | X_1) = [P(X_1 | X_4)P(X_4)]/P(X_1) \quad (8)$$

$$P(X_3 | X_1) = [P(X_1 | X_3)P(X_3)]/P(X_1) \quad (9)$$

X_1 = policy enforcement;

X_2 = traffic safety education;

X_3 = road condition;

X_4 = road obstruction;

X_5 = traffic control devices;

X_6 = driving under the influence;

X_7 = reckless driving;

X_8 = mechanical failure;

X_9 = driver fatigue;

X_{10} = traffic accident;

$P(X_j | X_k)$ = conditional probability of event X_j occurring, given the occurrence of event X_k;

$P(X_1)$ = probability of event X_1 occurring;

$P(X_1, X_2, \ldots, X_{10}) = P(X_1 \cap X_2 \cap \ldots \cap X_{10}) = \cap_i P(X_i | X_{v,i})$ or $\pi_i P(X_i | X_{v,i})$, i = 1,…,10;

$X_{v,i}$ = parent of X_i.

To forecast highway traffic accidents, findings are inserted into the network which allow the network to be used for scenario analysis. This is done by selecting the state of nodes and observing the changes that occur in the probability distributions of the offspring nodes. The selected node appears grey and the specific state chosen is assigned 100%. The probability distributions for all nodes compiled in the network are displayed as Fig. 3 which shows policy enforcement and traffic safety education as parent nodes.

From the results, the data in the case file show a policy enforcement rating of 65.0% poor, 20.0% moderate, and 15.0% good. Similarly, traffic safety education is 50% poor; 40.0% moderate, and 10.0% good. However, if the poor state for policy enforcement is selected (Fig. 4), the probability distributions for the rest of the (offspring) nodes update to show the effect of this scenario. Its accident probability is 0.066%. Choosing moderate state of policy enforcement gives probability of 0.060% (figure left out due to space limitation). This reflects a 9.10% drop in traffic accidents. Selecting good state in policy enforcement (Fig. 5) shows accident probability of 0.050%, a 24.24% drop in accident from poor state. Conversely, if the two parent nodes are both in poor states, the probability distributions of the offspring nodes adjust to show 0.066% probability of accident. However, if the two parent nodes are in moderate states, changes that reflect this combination occur in the probability distributions of offspring nodes. The net effect is that accident drops to 0.059%, a 10.61% drop.

A summary of all the scenarios tested is presented as Table 9. The method of inserting findings into offspring nodes instead of the parent nodes is called diagnosis. It should be noted that policy enforcement has more effect on accident reduction than traffic safety education (Table 7). While policy enforcement and traffic safety education complement each other, a greater priority should be given to good policy enforcement. It does not, however, imply that traffic safety education should be placed at a low priority.

4. Research Results

It is evident from the data that a major portion of the accidents in Nigeria is caused by human actions. Adequate policy and traffic safety regulation enforcements and good public education would produce great improvement in crash and casualty reduction. Evidently, the number of accidents in Nigeria has not risen as sharply as was anticipated at the onset of this research given the numerous safety problems. Overall, the data show slight decrease in the number of accidents putting into perspective the 10 years utilized in this study. This is not a reason to jubilate because there are numerous traffic safety problems still in Nigeria, and the validity of the officially reported accidents remains questionable.

Of the accident contributing factors (Table 1), three of them—reckless driving (27%), DUI (22%), and road condition (22%)—stand out to be responsible for about 71% of the total accidents. It is apparent that Nigeria is not channeling its resources towards the right places to improve safety. This is highlighted by the percentage

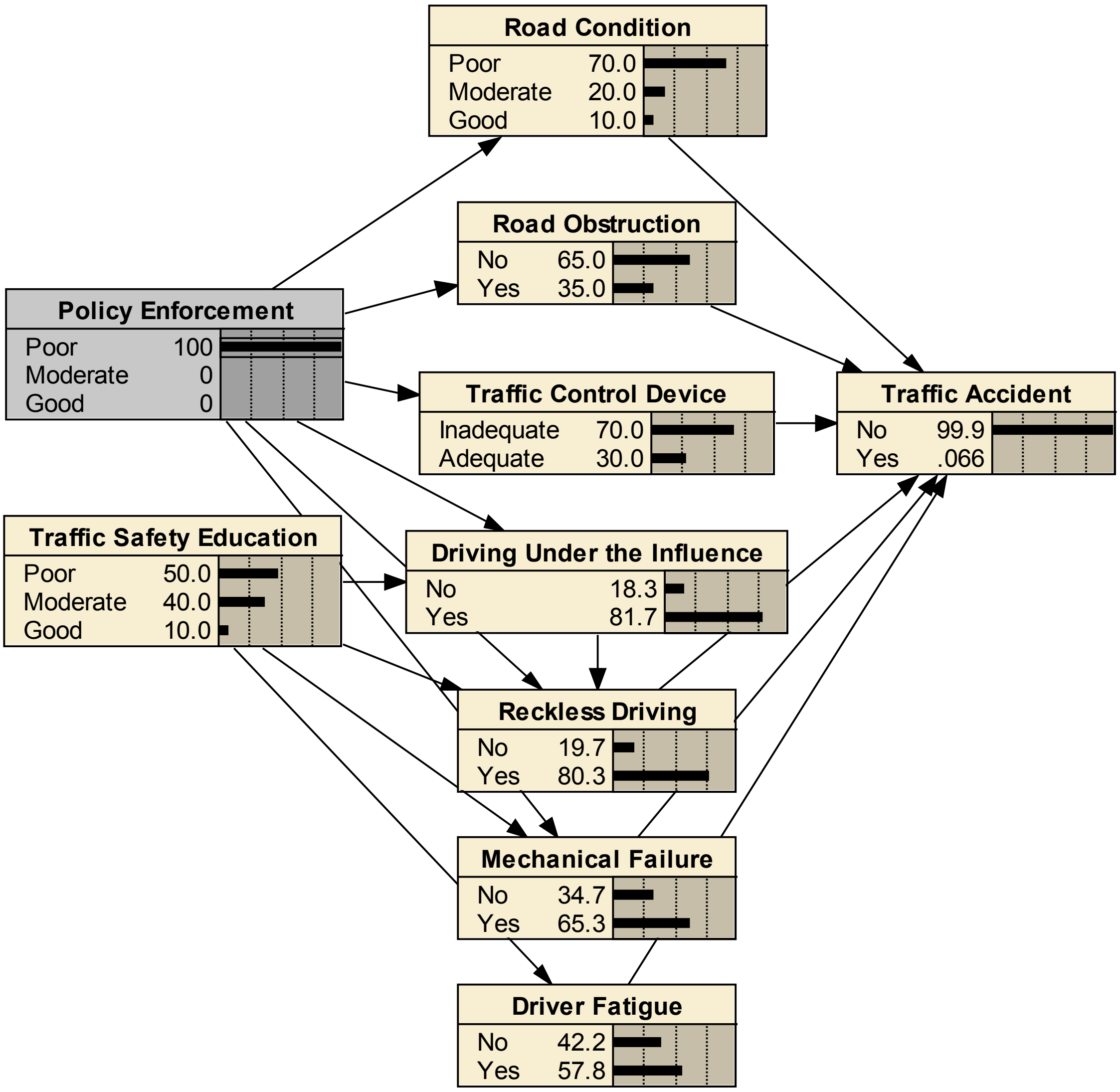

Fig. 4 Scenario analysis for poor policy enforcement in the network.

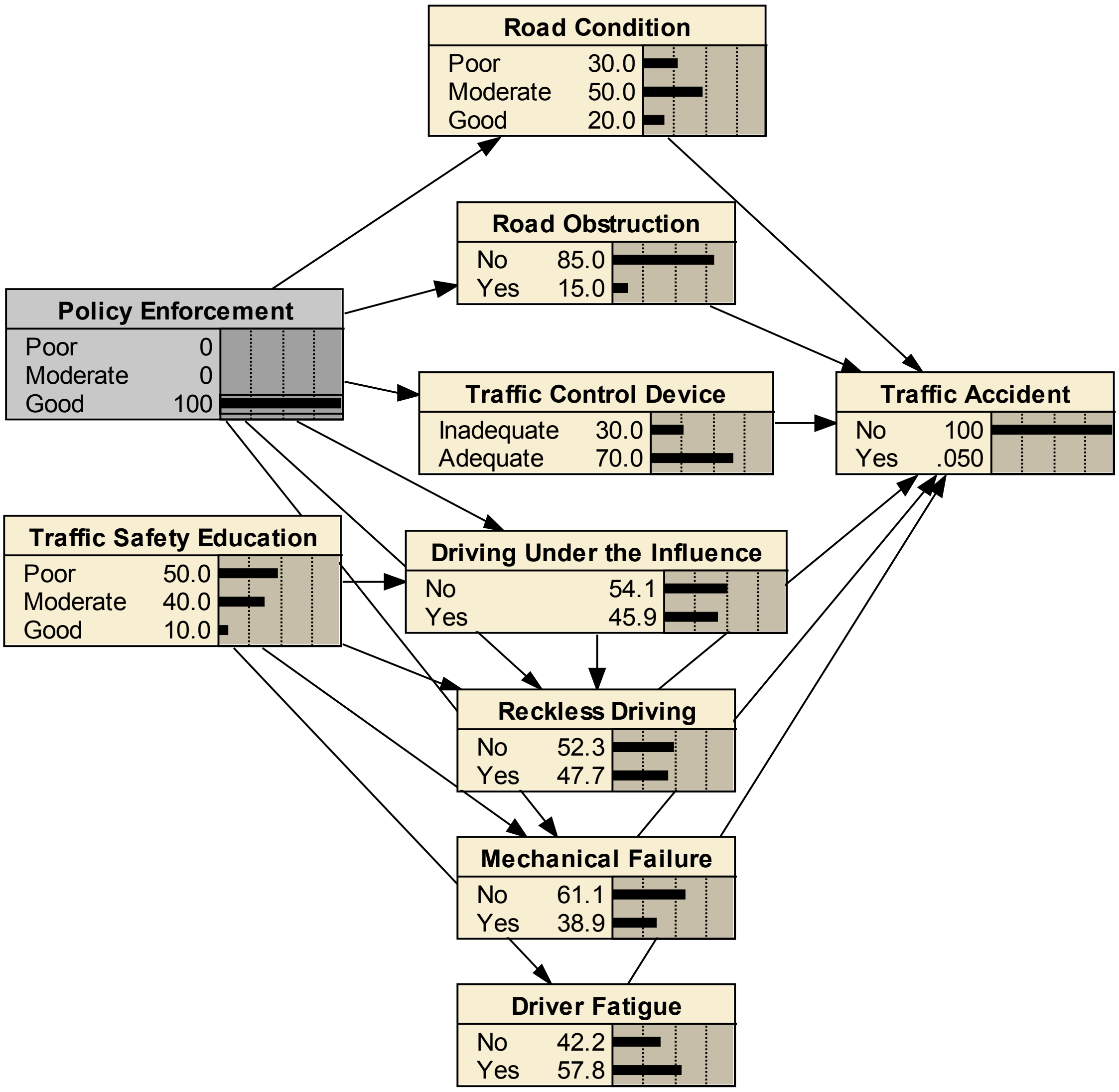

Fig. 5 Scenario analysis for good policy enforcement in the network.

Table 9 Summary of traffic accident probabilities for all scenarios tested.

Traffic accident scenario	% Δ from state	Probability	Poor state
	Poor	0.066%	-
PE	Moderate	0.060%	9.1%
	Good	0.050%	24.24%
	Poor/Poor	0.066%	-
PE* & TSE**	Poor/Moderate	0.066%	-
	Poor/Good	0.065%	1.52%
	Moderate/Poor	0.061%	5.58%
PE & TSE	Moderate/Moderate	0.059%	10.61%
	Moderate/Good	0.058%	12.12%
	Good/Poor	0.051%	22.73%
PE & TSE	Good/Moderate	0.049%	25.76%
	Good/Good	0.047%	28.79%

* PE denotes policy enforcement;

** TSE denotes traffic safety education.

contribution of three factors that are basically policy related. With proper resources and the right personnel, these major contributors can be cut down significantly. Moreover, the amount of money spent on actual transportation related contracts is insufficient considering that almost 56% of the highway-related contracts are abandoned for lack of funding and poor contractor performance (Table 6). This probably explains why there are numerous dilapidated roads; hence, road condition is one of the top three major accident contributors in Nigeria.

Further, there were lots of contracts awarded to improve the infrastructure, but corruption imbedded in the system prevented implementation. The percentage difference between the fully funded but not constructed projects and the actual percentage constructed is 55.57%. If past highway contracts had been implemented, clearly the state of the infrastructure would have changed and the outlook could have been moderate at the minimum. This is the impact of the deviant behaviors mentioned earlier. The opportunity cost is the extremely terrible road conditions. Modeling Moderate level enforcement in the Bayesian Network shows a significant reduction of the accident rate in Nigeria.

The average number of registered vehicles and fatality rate for the 10 year research period are 6,361,000 and 17.3 per 10,000 vehicles annually. Clearly, there is an average of 11,005 annual fatalities on Nigerian roads for the past 10 years. The Bayesian network result gave a fatality value of 10,814, which compares very closely with the Delphi figure. Therefore, the network has performed well. This number of deaths is too many based on the registered vehicles in Nigeria. Korea has an average of 14,410,646 registered vehicles and 7,342 fatalities over the past 10 years. The fatality-to-vehicle ratio between Nigeria and Korea is 17 to 5.

5. Conclusion

Many studies have shown that casualties from highway accidents are high in developing countries, although these countries have less number of vehicles than the industrialized nations. Industrialized nations also have less number of casualties than the developing countries. Nigeria fits into the category of countries that have elevated number of deaths and injuries from highway crashes; however, Nigeria has no reliable and comprehensive database of traffic accidents and casualties.

Consequently, the Delphi technique was utilized in generating the required data such as number of registered automobiles, number of licensed drivers, and annual fatality count for modeling and forecasting accident rates in Nigeria. A Bayesian network model was developed and used, with the data obtained from Delphi process, to demonstrate possible traffic safety responses to different scenarios of changes in the Nigerian socio-political culture.

Although the Delphi technique and the Bayesian network model only estimate the accident and safety data, which are not actual, those methods can be a realistic option when those data are not available, especially for the developing countries.

The conclusions that are drawn from the output of the Bayesian network and the analysis of the research results support the notion that the major accident contributors have been identified and the top three contributors—road condition, DUI, and reckless driving—are policy related. The Nigerian traffic safety outlook would improve significantly if the existing laws and policies can be enforced, even at a very moderate level.

From policy enforcement standpoint, it is not lack of policy that is the problem, or lack of proper training on the part of the enforcement personnel, but lack of dedication and discipline to enforce existing safety laws. Even though the traffic laws enforcement officers are blamed for not performing their duties due to their corrupt practices, there is enough blame to go around in the sense that most of the policymakers themselves are equally corrupt. Not booting out the dishonest traffic enforcement officers compounds a complex situation.

In a situation where everybody knows everybody and those that are delegated to enforce the policies are family members or their close relatives, sticky situations are created whereby the majority adapts to the culture of turning the other way. The end result is that the deplorable situation simply deteriorates even further. With this as a prevailing condition, the entire country is entrenched much deeper into a state of despondency; the best possible available conditions are utterly rejected by well-meaning Nigerians who are ceaselessly in search of better and lasting commonsense highway safety solutions.

References

[1] World Health Organization. 2004. *World Report on Road Traffic Injury*. Prevention, Genève.

[2] Nantulya, V. M., and Reich, M. R. 2002. "The Neglected epidemic: Road Traffic Injuries in Developing Countries." *BMJ* 324: 1139-41.

[3] Wang, Z. G. 2005. "Some Aspects of Road Traffic Injuries." *World Journal of Surgery* 29: S105-7.

[4] Asogwa, S. E. 1978. "Kola Nut and Road Traffic Accidents in Nigeria." *American Journal of Public Health* 68 (12): 1228.

[5] Adefolalu, A. A. 1981. "Towards Realization of Better Transport Services in Nigeria." In *Proceedings of a National Conference: Transportation in Nigerian National Development*, 158-78.

[6] Ottong, J. G. 1981. "Road Accident and Traffic Education in Nigeria: The Role of the Government, Police, and the Public." In *Proceedings of a National Conference: Transportation in Nigerian National Development*, 432-44.

[7] Sleet, D. A., and Blanche, C. M. 2004. "Road Safety Is No Accident." *Journal of Safety Research* 35 (2): 173-4.

[8] Ghee, C., Silcock, D., Astrop, A., and Jacobs, G. 1997. *Socio-Economic Aspects of Road Accidents in Developing Countries*. TRL report 247, Transport Research Laboratory, Crowthorne, UK.

[9] Cline, A. 2000. "Prioritization Process Using Delphi Technique." White Paper, Garrola Development, Inc.

[10] Shuttleworth, M. 2009. "Bayesian Probability—Predicting Likelihood of Future Events." Experiment-Resources.com.

[11] Bruyninckx, H. 2002. "Bayesian Probability." A paper of Dept. of Mechanical Engineering, K. U. Leuven, Belgium.

[12] Heckerman, D., and Breese, J. S. 1994. *Casual Independence for Probability Assessment and Inference Using Bayesian Networks*. Microsoft Research Technical Report MSR-TR-94-08, Microsoft Research.

[13] Mbakwe, A. C., Saka, A. A., Choi, K., and Lee, Y.-J. 2016. "Alternate Method of Highway Traffic Safety Analysis for Developing Countries Using Delphi Technique and Bayesian Network." *Accident Analysis and Prevention* 93: 135-46.