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The Effect of Pavement Damage on Number of Accidents and on Traffic Congestion on Roads Using Multivariate Analysis of Variance

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Abstract: Traffic road accidents are a concern for every elected government since it affects the socio and economic well-being of a country. Kenya has experienced high number of road accidents claiming more than three thousands lives every year. The cause of traffic road accidents is usually blamed on the drivers, pedestrians, lack of adequate enforcement of traffic laws, quality of roads among other reasons. The government has tried to address this road carnage by coming up with road safety measures and improvement of road infrastructure. In this paper Multivariate Analysis of Variance (MANOVA) has been used to study the effect of pavement damage on number of accidents and on time spent on roads. By considering two dependent variables (the number of accidents and traffic congestion on roads) and two factors (damage on pavement and type of vehicle), a 2×3 design with 4 replications, for a total of 24 observation vectors has been developed. Significance tests involving the individual dependent variables have been carried out. Using the sampled data from Nairobi, it has been determined that type of vehicle has a significant effect on the number of accidents and traffic congestion on roads. It is also determined that damage of pavements does not have significant effect on the number of accidents and traffic congestion on roads.

Keywords: Multivariate Analysis of Variance, Dependent Variables, Factors, Replications, Damage of Pavements

1. Introduction

Road accidents ranks high among the major development challenges currently facing many countries of the world [1]. An estimated 85% of the deaths occur in developing countries where 65% of the deaths are pedestrians, of which 35% are children [2]. A World Bank report on road accidents in developing countries depicts worrying trends as the number continues to rise and causing more harm to the economies of these countries as compared to developed countries [3]. According to [4] the largest mode of transport in Africa is road, which originates from the port of Mombasa through to the eastern part of DRC. A report by World Bank indicated that poor road designs is a major cause of road traffic accidents in developing countries since most of these countries modify road designs borrowed from developed countries [5]. A report by Asian Development Bank lauded the effort of the China government of improving road network coupled with adequate road designs which has greatly reduced traffic road accidents considerably [6]. The roads in bad condition gives only two choices, either you travel on them at a very low speed or you drive very fast thus most properly having road accident. The study by [7] was carried out to review various research works carried out by researchers on the effects of poor drainage on road pavement. A report by World Bank indicated that poor road designs is a major cause of road traffic accidents in developing countries since most of these countries modify road designs borrowed from developed countries [8]. A report by Asian Development Bank lauded the effort of the China government of improving road network coupled with adequate road designs which has greatly reduced traffic road accidents considerably [9]. The report recommended that developing countries need to learn a lesson from China to address poor road designs in an effort to address road carnage. A study conducted in Kenya in 2011 on whether road accidents are caused by human error or poor roads found that the condition of roads contributed to less road traffic accidents as compared to human error by [10]. In a study conducted in Kenya on road traffic injuries, [11] established that 5.1 percent of the road accidents are caused by poor road designs. Studies done shows that these types of vehicles have a potential of causing traffic road accidents at different magnitudes in different types of roads. In United Arab Emirates (UAE) studies on driver and vehicle type parameters' contribution to traffic safety was found that light vehicles which consisted of private vehicles in four years from 2007 -2010 on average contributed to 80.93 percent of the accidents reported on all roads [12]. In Japan the major contributor of road accidents are personal vehicles at 47.9 percent as compared to heavy commercial at 3.8 percent reported on all roads [13]. The same trend of personal vehicles causing accidents was noted in United Kingdom where 73 percent of private passenger's vehicles were largely involved in road accidents as compared to other categories of vehicles [14]. In most countries, personal vehicles on average accounts between 58 ¨C 62 percent of all categories of vehicles [15]. According to [16] in a study done in Kenya it emerged that human error and over speeding other that the type of vehicles are the major causes of 85.5 percent of all road accidents reported in police stations.

Pavement damage can be defined as pavement distress (potholes). Road accidents ranks high among the major development challenges currently facing many countries of the world.

There has been increased number of road accidents and traffic congestion on Kenyan roads in the year 2015-2016. This is evident from National Transport and Safety Authority (NTSA) website, the total number of victims in the first three months of 2016 increased by 1,233- from 2,699 in 2015 to 3,932 in 2016.

Traffic congestion is a condition on transport networks that occurs as use increases, and is characterized by slower speeds, longer trip times, and increased vehicular queueing. When traffic demand is great enough that the interaction between vehicles slows the speed of the traffic stream, this results in some congestion. While congestion is a possibility for any mode of transportation, this paper focuses on auto-mobile congestion on public roads.

2. Description of the Multivariate Analysis of Variance (MANOVA)

Multivariate Analysis of Variance (MANOVA) has been used because of the two dependent variables, the number of accidents (y_1) and traffic congestion on roads (y_2). A 2X3 design with 4 replications, for a total of 24 observation vectors has been developed by considering two factors; damage on pavement (damaged pavement P_1 and undamaged pavement P_2) and type of vehicle (Personal C_1, Motor Cycle C_2 and Lorries/Trucks C_3). As is typical with MANOVA, this has been followed with significance tests involving the individual dependent variables separately.

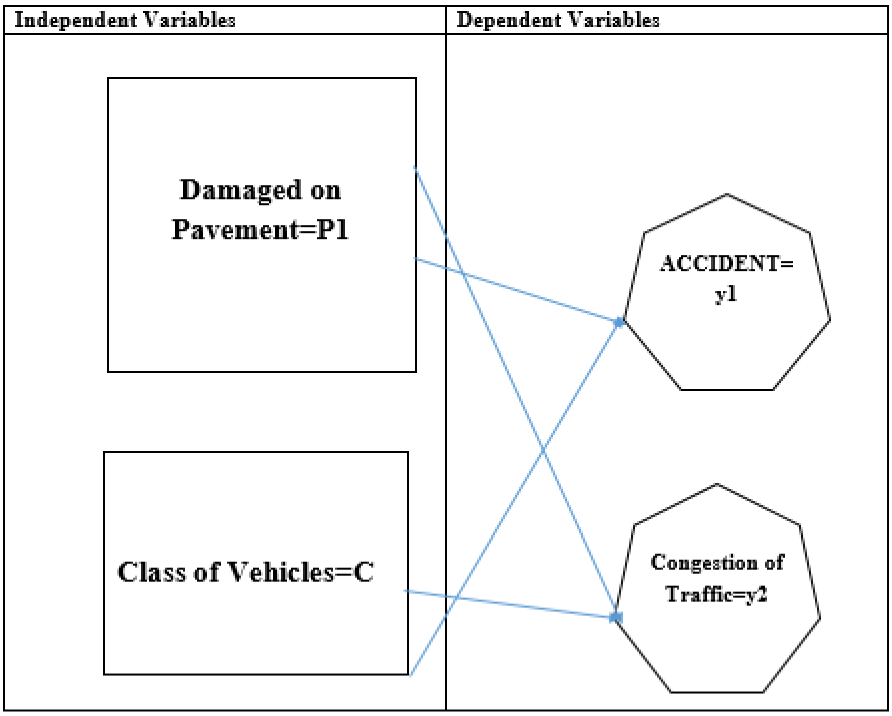


Figure 1. *The Conceptual Framework.*

Definitions
Damage on Pavement
P1-Damaged Pavement
P2-Undamaged Pavement
Class of Vehicles
C1-Personal Vehicles
C2-Motor Cycle
C3-Lorries and Trucks
Factors
Accident Y1
Traffic Congestion Y2
KEY

1. $Y_1(c_1p_1)(M)$ - Number of accidents on damaged pavement by personal cars in the morning;
2. $Y_2(c_2p_1)(A)$ - Traffic congestion on road on damaged pavement by motor cycles in the afternoon;
3. $Y_1(c_3p_2)(E)$ - Number of accidents on undamaged pavement by lorries/truck in the evening;
4. $Y_2(c_3p_2)(N)$ - Traffic congestion on road on undamaged pavement by lorries/trucks at night.

Table 1. *Number of accidents and traffic congestion on roads by damage on pavement and type of vehicle.*

	Damaged Pavement (P_1) [Mauritina round about to first Avenue, to and fro including diverts]		**Undamaged Pavement (P_2)** [Kariokor round about to Mauritina street, to and fro including diverts]	
Type of vehicle	**Number of accidents 2014 - 2018 (Y_1)**	**Traffic congestion (2 km-daily) (Y_2)**	**Number of accidents 2014 - 2018 (Y_1)**	**Traffic congestion (2 km-daily) (Y_2)**
C_1	$p_1c_1y_1(m)$	$p_1c_1y_2(m)$	$p_2c_1y_1(m)$	$p_2c_1y_2(m)$
	$p_1c_1y_1(a)$	$p_1c_1y_2(a)$	$p_2c_1y_1(a)$	$p_2c_1y_2(a)$
	$p_1c_1y_1(e)$	$p_1c_1y_2(e)$	$p_2c_1y_1(e)$	$p_2c_1y_2(e)$
	$p_1c_1y_1(n)$	$p_1c_1y_2(n)$	$p_2c_1y_1(n)$	$p_2c_1y_2(n)$
C_2	$p_1c_2y_1(m)$	$p_1c_2y_2(m)$	$p_2c_2y_1(m)$	$p_2c_2y_2(m)$
	$p_1c_2y_1(a)$	$p_1c_2y_2(a)$	$p_2c_2y_1(a)$	$p_2c_2y_2(a)$
	$p_1c_2y_1(e)$	$p_1c_2y_2(e)$	$p_2c_2y_1(e)$	$p_2c_2y_2(e)$
	$p_1c_2y_1(n)$	$p_1c_2y_2(n)$	$p_2c_2y_1(n)$	$p_2c_2y_2(n)$
C_3	$p_1c_3y_1(m)$	$p_1c_3y_2(m)$	$p_2c_3y_1(m)$	$p_2c_3y_2(m)$
	$p_1c_3y_1(m)$	$p_1c_3y_2(m)$	$p_2c_3y_1(m)$	$p_2c_3y_2(m)$
	$p_1c_3y_1(a)$	$p_1c_3y_2(a)$	$p_2c_3y_1(a)$	$p_2c_1y_2(a)$
	$p_1c_3y_1(e)$	$p_1c_3y_2(e)$	$p_2c_3y_1(e)$	$p_2c_3y_2(e)$

The totals for each variable are displayed for use in computations and the numbers inside the box will be cell totals (over the four replications), and marginal totals are for each level of P and C will be obtained as illustrated below:

Table 2. *Number of accidents and type of vehicle.*

	Totals for y_1		
	p_1	p_2	
C_1	T_{p1c1y1}	T_{p2c1y1}	$T_{c1}(1)$
C_2	T_{p1c2y1}	T_{p2c2y1}	$T_{c2}(1)$
C_3	T_{p1c3y1}	T_{p2c3y1}	$T_{c3}(1)$
	$T_{p1}(1)$	$T_{p2}(1)$	T_{y1}

Table 3. *Traffic congestion and type of vehicle.*

	Totals for y_2		
	p_1	p_2	
C_1	T_{p1c1y2}	T_{p2c1y2}	$T_{c1}(2)$
C_2	T_{p1c2y2}	T_{p2c2y2}	$T_{c2}(2)$
C_3	T_{p1c3y2}	T_{p2c3y2}	$T_{c3}(2)$
	$T_{p1}(2)$	$T_{p2}(2)$	T_{y2}

Since this is a two-way model, the total sum of squares and product matrix is partitioned as

$$T = H_P + H_C + H_{PC} + E \quad (1)$$

The structure of H_P is such that on the diagonal has the sum of squares for factor P for each of the two dependent variables $(y_1 and y_2)$. The off-diagonal elements of H_P are corresponding sums of the products of the two pairs the dependent variables.

Thus, the 1^{st} diagonal element of H_P corresponding to the 1^{st} variable, is given by

$$h_{P11} = nc\sum_{i=1}^{p}((\bar{y}_{i..1} - \bar{y}_{i..1})^2 = \sum_{i=1}^{p}\left(\frac{y_{i..1}^2}{nc} - \frac{y_{...1}^2}{npc}\right) \quad (2)$$

$$= \frac{(T_{p1}(1))^2 + (T_{p2}(1))^2}{12} - \frac{(T_{y1})^2}{24} \quad (3)$$

$$h_{P22} = nc\sum_{i=1}^{p}((\bar{y}_{i..2} - \bar{y}_{i..2})^2 = \sum_{i=1}^{p}\left(\frac{y_{i..2}^2}{nc} - \frac{y_{...2}^2}{npc}\right) \quad (4)$$

$$= \frac{(T_{p1}(2))^2 + (T_{p2}(2))^2}{12} - \frac{(T_{y2})^2}{24} \quad (5)$$

$$h_{C22} = np\sum_{i=1}^{c}((\bar{y}_{i..2} - \bar{y}_{i..2})^2 = \sum_{i=1}^{c}\left(\frac{y_{i..2}^2}{np}\frac{y_{...2}^2}{npc}\right) \tag{6}$$

$$= \frac{(T_{c1}(2))^2 + (T_{c2}(2))^2 + (T_{c3}(2))^2}{8} - \frac{(T_{y2})^2}{24} \tag{7}$$

$$h_{C11} = np\sum_{i=1}^{c}((\bar{y}_{i..2} - \bar{y}_{i..2})^2 = \sum_{i=1}^{c}\left(\frac{y_{i..2}^2}{np}\frac{y_{...2}^1}{npc}\right) \tag{8}$$

$$= \frac{(T_{c1}(1))^2 + (T_{c2}(1))^2 + (T_{c3}(1))^2}{8} - \frac{(T_{y1})^2}{24} \tag{9}$$

$$h_{PC11} = n\sum_{ij}\left(\frac{y_{ij.1}^2}{n} - \frac{y_{..1}^2}{ncp}\right) - h_{P11} - h_{C11} \tag{10}$$

$$= \frac{(T_{C_1P_1y_1})^2 + ...(T_{C_3P_2y_1})^2}{n} - \frac{(T_{y1})^2}{24} - h_{P11} - h_{C11} \tag{11}$$

$$h_{PC22} = \sum_{ij}\left(\frac{y_{ij.2}^2}{n} - \frac{y_{..2}^2}{ncp}\right) - h_{P22} - h_{C22} \tag{12}$$

$$= \frac{(T_{C_1P_1y_2})^2 + ...(T_{C_3P_2y_2})^2}{n} - \frac{(T_{y2})^2}{24} - h_{P22} - h_{C22} \tag{13}$$

where $\bar{y}_{i..r}$ and $\bar{y}_{i..r}$ represent the r^{th} components of $\bar{y}_{i...}$ and $\bar{y}_{...}$, respectively, and $y_{i..r}$ and $y_{i..r}$ are totals corresponding to $\bar{y}_{i..r}$ and $\bar{y}_{...r}$. The rs^{th} off-diagonal element of H_P and H_P are

$$h_{P12} = nc\sum_{i=1}^{p}((\bar{y}_{i..1} - \bar{y}_{i..1})((\bar{y}_{i..2} - \bar{y}_{i..2}) = \sum_{i=1}^{p}\left(\frac{y_{i..1}y_{i..2}}{nc} - \frac{y_{...1}y_{...2}}{npc}\right) \tag{14}$$

$$= \frac{(T_{p1}(1))(T_{p1}(2)) + (T_{p2}(1))(T_{p2}(2))}{12} - \frac{(T_{y1})(T_{y2})}{24} \tag{15}$$

$$h_{C12} = nc\sum_{i=1}^{c}((\bar{y}_{i..1} - \bar{y}_{i..1})((\bar{y}_{i..2} - \bar{y}_{i..2}) = \sum_{i=1}^{c}\left(\frac{y_{i..1}y_{i..2}}{np} - \frac{y_{...1}y_{...2}}{npc}\right) \tag{16}$$

$$= \frac{(T_{c1}(1))(T_{c1}(2)) + (T_{c2}(1))(T_{c2}(2)) + (T_{c3}(1))(T_{c3}(2))}{8} - \frac{(T_{y1})(T_{y2})}{24} \tag{17}$$

$$h_{PC12} = \sum_{ij}\left(\frac{y_{ij.1}y_{ij.2}}{n} - \frac{y_{..1}y_{..2}}{ncp}\right) - h_{P12} - h_{C12} \tag{18}$$

$$= \frac{(T_{C_1P_1y_1})(T_{C_1P_1y_2}) + ...(C_3P_2y_1)(C_3P_2y_2)}{4} - \frac{(T_{y1})(T_{y2})}{24} - h_{P12} - h_{C12} \tag{19}$$

For the E matrix, computational formulas are

$$E = T - H_P - H_C - H_{PC} \tag{20}$$

Thus the elements of E have the form

$$e_{11} = \sum_{ijk} \left(y_{ijk1}^2 - \frac{y_{..1}^2}{ncp} \right) - h_{P11} - h_{C11} - h_{PC11} \tag{21}$$

$$= (p_1 c_1 y_1(m))^2 + ...(p_2 c_3 y_1(e))^2 - \frac{(T_{y1})^2}{24} - \quad h_{P11} - h_{C11} - h_{PC11} \tag{22}$$

$$e_{22} = \sum_{ijk} \left(y_{ijk2}^2 - \frac{y_{..2}^2}{ncp} \right) - h_{P22} - h_{C22} - h_{PC22} \tag{23}$$

$$= (p_1 c_1 y_2(m))^2 + ...(p_2 c_3 y_2(e))^2 - \frac{(T_{y2})^2}{24} - \quad h_{P22} - h_{C22} - h_{PC22} \tag{24}$$

$$e_{12} = \sum_{ijk} \left(y_{ijk1} y_{ijk2} - \frac{y_{..1} y_{..2}}{ncp} \right) - h_{P12} - h_{C12} - h_{PC12} \tag{25}$$

$$= (p_1 c_1 y_1(m))(p_1 c_1 y_2(m)) + ...(p_2 c_3 y_1(m))(p_2 c_3 y_2(e)) - \frac{(T_{y1})(T_{y2})}{24} - h_{P12} - h_{C12} - h_{PC12} \tag{26}$$

$$H_P = \begin{pmatrix} h_{P11} & h_{P12} \\ h_{P21} & h_{P22} \end{pmatrix} \tag{27}$$

.

$$H_C = \begin{pmatrix} h_{C11} & h_{C12} \\ h_{C21} & h_{C22} \end{pmatrix} \tag{28}$$

.

$$H_{PC} = \begin{pmatrix} h_{PC11} & h_{PC12} \\ h_{PC21} & h_{PC22} \end{pmatrix} \tag{29}$$

.

$$E = \begin{pmatrix} e_{11} & e_{12} \\ e_{21} & e_{22} \end{pmatrix} \tag{30}$$

2.1. Property of Error

Error-distributionn (0, Variance).

There are four different multivariate tests that are made on E-1H. Each of the four test statistics has its own associated F ratio. In some cases, the four tests give an exact F ratio for testing the null hypothesis and in other cases the F ratio is approximated.

$$E = \begin{pmatrix} e_{11} & e_{12} \\ e_{21} & e_{22} \end{pmatrix} \tag{31}$$

The hypothesis matrices for interaction and main effects, in this fixed-effects model will be compared to E to make a test. Thus for Wilk's Λ, we use E to test each of P, C, and PC:

$$\Lambda_P = \frac{|E|}{|E + H_P|} \quad \textit{is } \Lambda_{2,p-1,pc(n-1)} \tag{32}$$

$$\Lambda_C = \frac{|E|}{|E + H_C|} \quad \textit{is } \Lambda_{2,c-1,pc(n-1)} \tag{33}$$

$$\Lambda_{PC} = \frac{|E|}{|E + H_{PC}|} \quad \textit{is } \Lambda_{2,(p-1)(c-1),pc(n-1)} \tag{34}$$

The conclusion will be as follows:

1. For $\Lambda_P < \Lambda_{2,p-1,pc(n-1)}$, it would imply that damage of pavements has significant effect on traffic congestion on the roads and on the number of accidents.
2. For $\Lambda_C > \Lambda_{2,c-1,pc(n-1)}$, it would imply that type of vehicle does not have significant effect on traffic congestion on the roads and on the number of accidents.

3. Application of the Multivariate Analysis of Variance

KEY

M - From 6:31am to 12:30pm
A - From 12:31pm to 6:30pm
E - From 6:31pm to 12:30am
N - From 12:31am to 6:30am

Table 4. *Comparison of number of accidents and traffic congestion across different types of vehicles.*

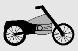
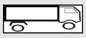
Name of the Road	**Time**	**Damaged Pavement (P_1) Mauritina Round about to First Avenue to and fro including all the diverts on**		**Undamaged Pavement (P_2) Kariokor Round about to Mauritina street to and fro including all the diverts**	
Types of Vehicles	**Time**	**No. of Accidents 2014-2018 (Y_1)**	**Traffic Congestion (2 km) (Daily)) (Y_2)**	**No. of Accidents 2014-2018 (Y_1)**	**Traffic Congestion (2 km) (Daily)) (Y_2)**
Light Cars (C_1) 	M	0 (m)	4894(m)	1(m)	6850(m)
	A	4 (a)	4990(a)	6(a)	8607(a)
	E	2 (e)	3878(e)	1(e)	3532(e)
	N	0 (n)	3289(n)	5(n)	1208(n)
Motor cycles (C_2) 	M	0(m)	1824(m)	0(m)	2040(m)
	A	1(a)	2303(a)	0(a)	2523(a)
	E	0(e)	1326(e)	1(e)	483(e)
	N	0(n)	1367(n)	1(n)	73(n)
Heavy Lorries/Trucks (C_3) 	M	3(m)	303(m)	0(m)	451(m)
	A	2(a)	332(a)	1(a)	612(a)
	E	3(e)	170(e)	0(e)	113(e)
	N	0(n)	186(n)	0(n)	73(n)

Table 5. *Number of accidents and traffic congestion on roads (both damaged and undamaged) and type of vehicle.*

	P_1		P_2	
	Y_1	Y_2	Y_1	Y_2
C_1	0	4,894	1	6,850
	4	4,990	6	8,607
	2	3,878	1	3,532
	0	3,289	5	1,208
C_2	0	1,824	0	2,040
	1	2,303	0	2,523
	0	1,326	1	483
	0	1,367	1	73
C_3	3	303	0	451
	2	332	1	612
	3	170	0	113
	0	186	0	73

Table 6. *Total sum of accidents in different vehicle types.*

	Totals for y_1		
	p_1	p_2	
C_1	6	13	19
C_2	1	2	3
C_3	8	1	9
TOTAL	15	16	31

Table 7. *Total sum of traffic congestion in different vehicle types.*

	Totals for y_2		
	p_1	p_2	
C_1	17,051	20,197	37,248
C_2	6,820	5,119	11,939
C_3	991	1,249	2,240
TOTAL	24,862	26,565	51,427

3.1. Pavement Damage P

The elements of H_P corresponding to the 1^{st} variable, pavement damage, are

$$h_{P11} = \frac{(15)^2 + (16)^2}{12} - \frac{(31)^2}{24} \quad (35)$$

$$= 0.0416666 \quad (36)$$

$$h_{P22} = \frac{(24,862)^2 + (26,565)^2}{12} - \frac{(51,427)^2}{24} \quad (37)$$

$$= 120,842.0416667 \quad (38)$$

$$h_{P12} = \frac{(15)(24,862) + (16)(26,565)}{12} - \frac{(31)(51,427)}{24} \quad (39)$$

$$= 70.958333 \quad (40)$$

$$H_P = \begin{pmatrix} 0.041667 & 70.958333 \\ 70.958333 & 120,842.0417 \end{pmatrix}$$

3.2. Type of Vehicle C

The elements of H_C corresponding to the 2^{nd} variable, type of vehicle, are

$$h_{C11} = \frac{(19)^2 + (3)^2 + (9)^2}{8} - \frac{(31)^2}{24} \tag{41}$$

$$= 16.3333 \tag{42}$$

$$h_{C22} = \frac{(37,248)^2 + (11,939)^2 + (2,240)^2}{8} - \frac{(51,427)^2}{24} \tag{43}$$

$$= 81,674,006.08333 \tag{44}$$

$$h_{C12} = \frac{(19)(3,248) + (3)(11,939) + (9)(2,240)}{8} - \frac{(31)(51,427)}{24} \tag{45}$$

$$= 29,034.583334 \tag{46}$$

$$H_C = \begin{pmatrix} 16.333 & 29,034.583334 \\ 29,034.583334 & 81,674,006.08333 \end{pmatrix} \tag{47}$$

3.3. The Interaction Effect PC

The elements of H_{PC} corresponding to the interaction effect are

$$h_{PC11} = \frac{6^2 + 13^2 + 1^2 + 2^2 + 8^2 + 1^2}{4} - \frac{(31)^2}{24} - h_{P22} - h_{C22} \tag{48}$$

$$= 12.33 \tag{49}$$

$$h_{PC22} = \frac{17,051^2 + 20,197^2 + 6,820^2 + 5,119^2 + 991^2 + 1,249^2}{4} - \frac{51,427^2}{24} - h_{P22} - h_{C22} \tag{50}$$

$$= 1,486,318.0833 \tag{51}$$

$$h_{PC12} = \frac{6 \times 17,051 + 13 \times 20,197 + 1 \times 6,820 + 2 \times 5,119 + 8 \times 991 + 1 \times 1,249}{4} - \frac{31 \times 51,427}{24} - h_{P12} - h_{C12} \tag{52}$$

$$= 2,243.416727 \tag{53}$$

$$H_{PC} = \begin{pmatrix} 12.33 & 2,243.416727 \\ 2,243.416727 & 1,486,318.0833 \end{pmatrix} \tag{54}$$

3.4. Error Effect E

The elements of E corresponding to the error effect, are Thus the elements of E have the form

$$e_{11} = 0^2 + 4^2 + 2^2 + 0^2 + 0^2 + 1^2 + 0^2 + 0^2 + 3^2 + 2^2 + 3^2 + 0^2$$
$$1^2 + 6^2 + 1^2 + 5^2 + 0^2 + 0^2 + 1^2 + 1^2 + 0^2 + 1^2 + 0^2 + 0^2$$
$$- \frac{(31)^2}{24} - h_{P11} - h_{C11} - h_{PC11} \tag{55}$$

$$= 40.25 \tag{56}$$

$$e_{22} = 4,894^2 + 4990^2 + 3878^2 + 3289^2 + 1824^2 + 2303^2 + 1326^2 + 1367^2 + 303^2 +$$
$$332^2 + 170^2 + 186^2 + 6850^2 + 8607^2 + 3532^2 + 1208^2 + 2040^2 + 2523^2 +$$
$$483^2 + 73^2 + 451^2 + 612^2 + 113^2 + 73^2 - \frac{(51427)^2}{24} - h_{P12} - h_{C12} - h_{PC12}$$
$$= 40,051,533.75 \tag{57}$$

$$e_{12} = 0 \times 4,894 + 4 \times 4990 + 2 \times 3878 + 0 \times 3289 + 0 \times 1824 + 1 \times 2303 + 0 \times 1326 +$$
$$0 \times 1367 + 3 \times 303 + 2 \times 332 + 3 \times 170 + 0 \times 186 + 1 \times 6850 + 6 \times 8607$$
$$+ 1 \times 3532 + 5 \times 1208 + 0 \times 2040 + 0 \times 2523 + 1 \times 483 + 1 \times 73 +$$
$$0 \times 451 + 1 \times 612 + 0 \times 113 + 0 \times 73 - \frac{31 \times 51427}{24} - h_{P12} - h_{C12} - h_{PC12}$$
$$= 3,558.50 \tag{58}$$

$$E = \begin{pmatrix} 40.25 & 3,558.50 \\ 3,558.50 & 40,051,533.75 \end{pmatrix}$$

$$|E| = \begin{vmatrix} 40.25 & 3,558.50 \\ 3,558.50 & 40,051,533.75 \end{vmatrix} = 1.59941 \times 10^9$$

$$|E + H_P| = \begin{vmatrix} 40.29 & 3,629.46 \\ 3,629.46 & 40,172,375.79 \end{vmatrix} = 1.6053 \times 10^9$$

$$|E + H_C| = \begin{vmatrix} 56.58 & 32,593.08 \\ 32,593.08 & 121,725,539.83 \end{vmatrix} = 5.82492 \times 10^9$$

$$|E + H_{PC}| = \begin{vmatrix} 52.58 & 5,801.92 \\ 5,801.92 & 41,537,851.83 \end{vmatrix} = 2.1504 \times 10^9$$

3.5. Wilk's λ Test

Using the Wilk's Λ test,

$$\Lambda_P = \frac{|E|}{|E + H_P|} = 0.996330904 > \Lambda_{0.05,2,p-1,pc(n-1)} = \Lambda_{0.05,2,1,18} = 0.703 \tag{59}$$

$$\Lambda_C = \frac{|E|}{|E + H_C|} = 0.274580595 < \Lambda_{0.05,2,c-1,pc(n-1)} = \Lambda_{0.05,2,2,18} = 0.581 \tag{60}$$

$$\Lambda_{PC} = \frac{|E|}{|E + H_{PC}|} = 0.743773251 > \Lambda_{0.05,2,c-1,pc(n-1)} = \Lambda_{0.05,2,2,18} = 0.581 \quad (61)$$

4. Conclusions and Recommendations

4.1. Conclusions

The conclusion is as follows:

1. Since $\Lambda_P > \Lambda_{2,p-1,pc(n-1)}$, it implies that damage of pavements does not have significant effect on traffic congestion on the roads and on the number of accidents.
2. Since $\Lambda_C > \Lambda_{2,c-1,pc(n-1)}$, it implies that type of vehicle does not have significant effect on traffic congestion on the roads and on the number of accidents.

4.2. Recommendations

It has been determined, using the Wilk's Lambda Test, that damage of pavements does not have significant effect on congestion on the roads and on the number of accidents.

We therefore recommend further research to determine the actual causes of congestion and the causes of accidents on the roads studied.

Using the Wilk's Lambda Test, it was also determined that the type of vehicle (categorized as light cars, motor cycles and heavy lorries/trucks) has significant effect on congestion and on the number of accidents on the roads studied.

We therefore recommend further research to determine the category of vehicles that cause more congestion and the category of vehicles that causes more accidents. Such a study should also strive to determine the interventions that would reduce congestion and the number of accidents on the roads studied.

Table 8. *Data of Accident from NTSA-Eastleigh.*

	Place	Victim Type	Time in 24hrs	Fatalities	Date	Type of Vehicle
ROAD, 2014						
EASTLEIGH	1ST AVENUE	PEDESTRIANS	1240	1	15TH MAY 2014	MOTOR CYCLE
EASTLEIGH SECTION THREE	EASTLEIGH	PEDESTRIANS	1830	1	6th July 2014	PSV
	WITHIN EASTLEIGH SHOPPING CENTRE	PEDESTRIANS	1430	2	19TH JULY 2014	PRIVATE CAR
ROAD, 2015						
EASTLEIGH	FIRST AVENUE	PEDESTRIANS	1530	1	Friday, April 3, 2015	COMMERCIAL
ROAD, 2016						
EASTLEIGH	FIRST AVENUE	PEDESTRIANS	630	1	Monday, May 23, 2016	COMMERCIAL
2ND AVENUE	AT JOSCA EASTLEIGH	PEDESTRIANS	1355	1	Sunday, October 2, 2016	COMMERCIAL
EASTLEIGH FIRST AVENUE	GARAGE	PEDESTRIANS	1900	1	Friday, November 4, 2016	PSV
EASTLIGHT 1ST AVENUE	NEAR ST TERESA CATHOLIC CHURCH	PASSENGERS	2030	1	Sunday, April 3, 2016	COMMERCIAL
EASTLIGHT 1ST AVENUE ROAD	NEAR NATIONAL BANK	PEDESTRIANS	2030	1	Tuesday, November 29, 2016	PSV
EATLEIGH	FIRST AVENUE	PEDESTRIANS	2030	1	Monday, December 19, 2016	COMMERCIAL
ROAD, 2017						
EASTLEIGH	BIAFRA	PASSENGERS	940	1	Saturday, March 4, 2017	COMMERCIAL
EASTLEIGH	EASTLEIGH AREA	PEDESTRIANS	1830	1	Wednesday, October 25, 2017	PRIVATE
FIRST AVENUE EASTLEIGH	NEAR MARIE STORES	PEDESTRIANS	1440	1	Thursday, July 20, 2017	COMMERCIAL
ROAD, 2018						
1ST AVENUE ROAD	OPPOSITE EASTLEIGH AP CAMP	PEDESTRIANS	2330	1	Saturday, January 13, 2018	COMMERCIAL
EASTLEIGH FIRST AVENUE	ST. THERESA'S CHURCH	PEDESTRIANS	1100	1	Tuesday, February 13, 2018	COMMERCIAL

Table 9. *Data of Accident from NTSA-Kariokor.*

Year	Date	Day	Time in 24 Hours	Country	Road	Place
2018	11/17/2018	SATURDAY	13.30	NAIROBI		KARIOKOR ROUNDABOUT
2018	1/22/2018	MONDAY	20.50	NAIROBI	GENERAL WARUINGE	KARIOKOR MARKET
2018	2/24/2018	SATURDAY	1.10	NAIROBI	RING ROAD	KARIOKOR MARKET
2018	7/24/2018	TUESDAY	3.0	NAIROBI	KARIOKOR ROUND ABOUT	KARIOKOR ROUNDABOUT
2018	10/17/2018	WEDNESDAY	21.20	NAIROBI	RING ROAD PUMWANI	KARIOKOR ROUNDABOUT
2017	6/22/2017	THURSDAY	22.00	NAIROBI	NEW PUMWANI ROAD	KARIOKOR ROUNDABOUT
2016	13/2/2016	SATURDAY	19.30	NAIROBI	RING ROAD PUMWANI ROAD	KARIOKOR ROUNDABOUT
2016	15/7/2016	FRIDAY	13.00	NAIROBI	RACE COURSE ROAD	KARIOKOR ROUNDABOUT
2016	11/7/2016	MONDAY	3.00	NAIROBI	GENERAL WARUINGE	KARIOKOR
2015	15/4/2015	WEDNESDAY	100	NAIROBI	RING ROAD	NEAR KARIOKOR MARKET
2015	29/5/2015	FRIDAY	1045	NAIROBI	RACE	OPPOSITE KARIOKOR MARKET
2015	15/6/2015	MONDAY	16.00	NAIROBI	RACE COURSE ROAD	NEAR KARIOKOR MARKET
2015	4/7/2015	SATURDAY	6.30	NAIROBI	RACE COURSE	KARIOKOR ROUNDABOUT
2015	29/10/2015	THURSDAY	30	NAIROBI	RING ROAD	KARIOKOR MARKET
2015	15/12/2015	TUESDAY	13.00	NAIROBI	RING ROAD	KARIOKOR
2014	15/9/2014	MONDAY	4.30	NAIROBI	KARIOKOR ROUND ABOUT	KARIOKOR ROUNDABOUT

Year	MV Involved	Type of Vehicle	Gender	Age	Victim	Fatalities
2018	HAND CART PUSHER	HAND CART	M	A	DRIVER	1
2018	UNKNOWN M/V	UNKNOWN	M	28	PEDESTRIAN	1
2018	UNKNOWN M/V & KMDP 377E BOXER	UNKNOWN MOTOR CYCLE	M	43	MOTOR CYCLIST	1
2018	UNKNOWN	UNKNOWN	M	15	PEDESTRIAN	1
2018	KCJ657A ISUZU MINI BUS & KBQ0011Z ISUZU BUS	PSV	F	A	PASSENGER	1
2017	KBT958R ISUZU BUS & KMCJ 461ZBAJAJ	PSV & MOTOR CYCLE	M	30	MOTOR CYCLIST	1
			M			1
2016	T446DBP MITSUBISH BUS (DOLPHIN COACH)	PSV	M	A	PEDESTRIAN	1
2016	KBJ605E ISUZU MINIIBUS	PSV	M	37	PEDESTRIAN	1
2016	KAW610G MITSUBISHI LORRY	COMMERCIAL	M	A	PEDESTRIAN	1
					PEDESTRIAN	
2015	KAS228B PEUGEOT SALOON	PRIVATE	M	30	PEDESTRIAN	1
2015	KCA952G MITSUBISHI M/BUS	PSV	M	25	PEDESTRIAN	1
2015	KAS454Y ISUZU MINIBUS	PSV	M	10	PEDESTRIAN	1
2015	KBW873U ISUZU MINIBUS	PSV	M	12	PEDESTRIAN	1
2015	KAY671S TOYOTA VITS	PRIVATE	M	35	DRIVER	1
2015	KCC870E ISUZU MINI BUS	PSV	M	18	PEDESTRIAN	1
2014		PRIVATE	M	22	PEDESTRIAN	1

Table 10. *An Example of traffic congestion along Karioko.*

Hourly Traffic Count Summary
Manual Classified Count
Location of Survey OLD RACE COURSE JUNCTION
Time of count from 6.30am to 6.30p.m
Day of the Week: Sat
Date of count (dd/mm/yyyy):8-06-2014
Enumerator name: Fredrick/Mboya
Weather: Rainy/Sunny

	6.30am-7.30am	7.30am-8.30am	8.30am-9.30am	9.30am-10.30am	10.30am-11.30am	11.30am-12.30pm	12.30pm-1.30pm	1.30pm-2.30pm	2.30pm-3.30pm	3.30pm-4.30p.m	4.30pm-5.30pm	5.30pm-6.30pm	TOTAL
MOTOR CYCLE	45	28	71	95	125	130	171	160	170	111	122	130	1348
CARS	115	57	180	225	225	410	420	420	440	285	408	384	3570
MATATUS	25	82	90	121	128	133	135	135	135	135	125	135	1380
BUSES	1	1	3	12	3	5	45	16	42	45	70	2	272
LIGHT GOODS VEHICLES (LGV)	1	6	7	20	3	16	8	22	7	15	12	3	20
MEDIUM GOODS VEHICLES(MGV)		1	10	21		1	7	5	6	5	15	2	72
HEAVY GOODS VEHICLES	2		3			2	2		1	2	5	2	24
OTHER VEHICLES									1		2		2

Table 11. *An Example of traffic congestion along Eastleigh.*

Hourly Traffic Count Summary

Manual Classified Count

Location of Survey OLD RACE COURSE JUNCTION

Time of count from 6.30am to 6.30p.m

Day of the Week: Sat

Date of count (dd/mm/yyyy): 5-06-2014

Enumerator name: JACKSON OCHIENG AND NAFTAU MAAKE

Weather: Rainy/Sunny

TRAFFIC DIRECTION FROM: F/AVENUE R/ABT

TRAFFIC DIRECTION TO: MURATINA R/ABT

	6.30am-7.30am	**7.30am-8.30am**	**8.30am-9.30am**	**9.30am-10.30am**	**10.30am-11.30am**	**11.30am-12.30pm**	**12.30pm-1.30pm**	**1.30pm-2.30pm**	**2.30pm-3.30pm**	**3.30pm-4.30p.m**	**4.30pm-5.30pm**	**5.30pm-6.30pm**	**TOTAL**
Motor Cycle	110	190	193	190	195	215	219	252	356	215	190	121	2446
Cars	117	208	247	260	330	320	327	310	382	263	240	200	3258
Matatus	211	221	200	117	99	113	100	86	94	91	95	126	1553
Buses	6	4	9	7	7	3	4	4	1	4	4	5	58
Light Goods Vehicles (LGV)			1	1	2	4	2	2	2	3	3	3	23
Medium Goods Vehicles (MGV)	10	21	13	26	31	24	19	25	27	27	20	20	263
Heavy Goods Vehicles	2	3	3	6	10	3	10	1	1	8	10	8	65
Other Vehicles			1		1		1				4		7

Table 12. *Classification of Motorized Traffic.*

Classification of Motorised Traffic		
No.	**Vehicle Category**	**Description**
1	Motor cycles 	All motobikes and motor tricyles(tuktuks)
2	Cars 	Include saloon cars, station wagon passenger cars,jeeps, 4WD's,pick-ups and private vans with seating capacity less than 9
3	Matatus 	All public service vehicles with seating capacity more than 9 but less than 25.
4	Buses  	All public service vehicles with seating capacity more 25
5	Light Goods Vehicles (LGV) 	2 Axle trucks with single rear wheels(3-6 Tonne payload)
6	Medium Goods Vehicles (MGV) 	2 Axle trucks with double rear wheels(7-10 Tonne payload)
7	Heavy Goods Vehicles 	All trucks with 3-7 axles
8	Other vehicles	Tractors, construction equipment, etc

5. Conclusion

The quantity E(Λ^n $e^{-\Lambda\ t}$ characterises exponential mixtures and can be used to obtain identities that simplify summations.

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