PERGAMON

Accident Analysis and Prevention 36 (2004) 149–163

ACCIDENT ANALYSIS & PREVENTION

www.elsevier.com/locate/aap

Traffic safety assessment and development of predictive models for accidents on rural roads in Egypt

Khaled A. Abbas*,[1]

Department of Urban and Regional Planning, College of Architecture and Planning, King Faisal University, P.O. Box 2397, Dammam 31451, Saudi Arabia

Received 6 June 2001; received in revised form 23 November 2002; accepted 2 December 2002

Abstract

This paper starts by presenting a conceptualization of indicators, criteria and accidents' causes that can be used to describe traffic safety. The paper provides an assessment of traffic safety conditions for rural roads in Egypt. This is done through a three-step procedure. First, deaths per million vehicle kilometers are obtained and compared for Egypt, three other Arab countries and six of the G-7 countries. Egypt stands as having a significantly high rate of deaths per 100 million vehicle kilometers. This is followed by compiling available traffic and accident data for five main rural roads in Egypt over a 10-year period (1990–1999). These are used to compute and compare 13 traffic safety indicators for these roads. The third step for assessing traffic safety for rural roads in Egypt is concerned with presenting a detailed analysis of accident causes.

The paper moves on to develop a number of statistical models that can be used in the prediction of the expected number of accidents, injuries, fatalities and casualties on the rural roads in Egypt. Time series data of traffic and accidents, over a 10 years period for the considered roads, is utilized in the calibration of these predictive models. Several functional forms are explored and tested in the calibration process. Before proceeding to the development of these models three ANOVA statistical tests are conducted to establish whether there are any significant differences in the data used for models' calibration as a result of differences among the considered five roads.

Keywords: Traffic safety; Assessment; Accident models; Rural roads; Egypt

1. Traffic safety in Egypt

The literature contains several studies that were conducted with the objective of establishing and comparing traffic safety for countries in the developed and the developing world (see Smeed, 1949; Haight, 1980; Preston, 1980; Andreassen, 1985; Jacobs and Cutting, 1986; Navin et al., 1994). Most of these studies used cross-sectional data to establish the relationship between fatality rates and some national-based exposure measures such as registered vehicles, population levels, etc. In this section, an attempt is made to draw data from several sources in order to conduct an international comparison of deaths per 100 million vehicle kilometers among Egypt, some Arab countries, and six of the G-7 countries (see Table 1). The table shows that Egypt stands as having a significantly very high rate of deaths per 100 million vehicle kilometers than all of the other countries. The average value for the G-7 countries is around 1.3, while for the four Arab countries including Egypt is about 15.1, i.e. 12 times higher. If Egypt is compared as an individual country, it could be deduced that deaths per million vehicle kilometers in Egypt is about 34 times higher than in the G-7 countries and about three times higher than countries in the Middle East region. However, caution must be used in drawing absolute conclusions about the relative road safety among the countries because of errors expected in data collection, compilation as well as in the estimation of vehicle road-kilometers. Still, this analysis shows the worsening situation of traffic safety in Egypt.

2. Analysis of traffic safety indicators for main rural roads in Egypt

The rural road network in Egypt is meant to connect the capital, Cairo and other big cities to each other. Several roads originate from Cairo forming a radial pattern. Five of these roads are selected to represent the rural network in Egypt. This selection is based on the importance of these roads as well as on the availability of historical traffic and accident

* Tel.: +20-2-2571734.
E-mail address: kaabbas13@yahoo.com (K.A. Abbas).
[1] On sabbatical leave from Transport Planning Department, Egyptian National Institute of Transport, P.O. Box 34, Abbassia, Nasr Road, Nasr City, Cairo, Egypt.

0001-4575/$ – see front matter © 2003 Elsevier Science Ltd. All rights reserved.
doi:10.1016/S0001-4575(02)00145-8

Table 1
Deaths per 100 million vehicle kilometers: an international comparison

Safety indicator	Countries									
	Canada	France	Germany	Italy	UK	USA	Bahrain	Egypt	Oman	Yemen
Deaths per 100 million vehicle kilometers	1.1	1.8	1.5	1.4	0.8	1.1	1.5	44.1	4.2	10.66

Data for G-7 countries is obtained from USDOT (1999, 2000). It reflects 1996 data. Data for the four Arab countries is obtained from IRF (1998). It reflects 1994 data.

data. Some basic features and statistics of these five roads are presented in Table 2.

A total of 13 traffic safety indicators were computed for the five selected roads. Eight of these indicators are indicative of risk (probability) of accident occurrence and the other five are indicative of the severity of accidents. These indicators were computed for different time periods to assist in conducting a time-based comparison as well as a cross-sectional comparison among roads (see Table 3). It is commonly accepted in accident analysis to collect data over at least 3–5 years period, see Zegeer (1982) reporting the US experience and Silcock and Smyth (1985) reporting the UK experience on this issue. A time period less than three years could be misleading as accidents can be considered as random occurrences and in order to identify some pattern, it is advisable to take 3 years as the minimum period of analysis. On the other hand, a period more than 5 years might also be misleading as changes occurring in factors causing accidents might have taken place, e.g. changes in land-use, traffic volumes, traffic laws, enforcement procedures, road and vehicle technology and standards, etc. Such time-based changes could be slower in their occurrence in developing countries. To take account of the above, the following time periods were considered in the computation of the indicators:

- Period 1: 3 years spanning from 1997 to 1999 (used for cross-sectional comparison among the five roads).
- Period 2: 5 years spanning from 1995 to 1999 (used for cross-sectional comparison among the five roads as well as for time-based comparison for the same road).
- Period 3: 10 years spanning from 1990 to 1999 (used for cross-sectional comparison among the five roads).
- Period 4: 5 years spanning from 1990 to 1994 (used for cross-sectional comparison among the five roads as well as for time-based comparison for the same road).

This research advocates the 5-year period as a basis for the analysis and comparison of safety indicators for the rural roads in Egypt. Data used for the computation of these indicators were compiled from several official sources as follows.

(a) Lengths of roads were compiled from the traffic police department who are responsible for the traffic operation on these roads (see EASRT, 1999). These lengths are pure rural lengths, i.e. these do not include the start and ending portions of the roads which run in urban areas.
(b) Annual average daily traffic (AADT) in two directions were compiled from General Authority for Roads, Bridges and Land Transport (GARBLT) traffic counting program (see GARBLT, 1999). For roads having more than one counting station, i.e. the Cairo–Alexandria agriculture and desert roads, a normalization procedure was applied based on the weighted length of the section with respect to the total road length.
(c) Statistics of accidents, fatalities, injuries and casualties for the years 1990–1997 were compiled from GARBLT (see Mostafa and Saleh, 1998).
(d) Statistics of accidents, fatalities, injuries and casualties for the year 1998 were compiled from Egypt Academy for Scientific Research and Technology (EASRT) study (see EASRT, 1999).
(e) Statistics of accidents, fatalities, injuries and casualties for the year 1999 were compiled from the Egyptian traffic police department.

Two exposure measures were used in the computation of risks (probability of occurrence), of accidents, injuries, fatalities and casualties. The first is a static measure representing the length of roads. The second is a dynamic measure representing the vehicle. kilometers traveled on the road. In addition to showing the computed traffic safety indicators for

Table 2
Basic features and statistics of five main rural roads in Egypt

Road name	Land-use	No. of sections[a]	Rural length	Cross-section	Toll	AADT in 1999	Accidents in 1999	Fatalities in 1999
Cairo–Alexandria	Agriculture	4	203	2 × 3	No	35225	390	172
Cairo–Alexandria	Desert	2	191	2 × 2	Yes	19020	181	40
Cairo–Fayoum	Desert	1	65	2 × 2	Yes	8417	41	16
Cairo–Suez	Desert	1	93	2 × 2	No	10043	96	38
Cairo–Ismailia	Desert	1	84	2 × 2	Yes (part)	28794	84	20

[a] Each section has a traffic counting station.

Table 3
Accident risk and severity indicators for five main rural roads in Egypt[a]

Risk and severity indicators	Period of analysis (years)	Cairo–Alexandria agriculture road	Cairo–Alexandria desert road	Cairo–Fayoum desert road	Cairo–Suez desert road	Cairo–Ismailia desert road	Network of five rural roads
Accidents/kilometer risk index	1997–1999 (last 3)	1.71	1.0	0.9	1.45	1.67	1.37
	1995–1999 (last 5)	1.99	0.98	0.77	1.31	1.92	1.45
	1990–1999 (last 10)	2.32	1.02	0.55	1	1.95	1.51
	1990–1994 (first 5)	2.65	1.07	0.34	0.69	1.98	1.56
Change between (%)	1990–1994, 1995–1999	−25	−9	126	91	−3	−7
Injuries/kilometer risk index	1997–1999 (last 3)	3.54	1.98	1.88	2.55	2.79	2.66
	1995–1999 (last 5)	4.15	1.97	1.58	2.39	3.22	2.85
	1990–1999 (last 10)	4.72	2.07	1.22	2.07	3.49	3.01
	1990–1994 (first 5)	5.28	2.17	0.87	1.75	3.75	3.18
Change between (%)	1990–1994, 1995–1999	−21	−10	83	37	−14	−10
Fatalities/kilometer risk index	1997–1999 (last 3)	0.74	0.24	0.15	0.37	0.29	0.42
	1995–1999 (last 5)	0.77	0.25	0.15	0.33	0.31	0.42
	1990–1999 (last 10)	0.76	0.31	0.11	0.27	0.33	0.43
	1990–1994 (first 5)	0.74	0.38	0.07	0.22	0.35	0.44
Change between (%)	1990–1994, 1995–1999	3	−32	113	48	−12	−3
Casualties/kilometer risk index	1997–1999 (last 3)	4.28	2.23	2.03	2.91	3.08	3.08
	1995–1999 (last 5)	4.92	2.22	1.73	2.71	3.53	3.28
	1990–1999 (last 10)	5.47	2.38	1.33	2.34	3.81	3.44
	1990–1994 (first 5)	6.02	2.55	0.94	1.97	4.1	3.61
Change between (%)	1990–1994, 1995–1999	−18	−13	85	38	−14	−9
Accidents/million vehicle kilometer risk index	1997–1999 (last 3)	0.14	0.18	0.33	0.45	0.18	0.18
	1995–1999 (last 5)	0.18	0.2	0.31	0.47	0.26	0.21
	1990–1999 (last 10)	0.23	0.25	0.26	0.44	0.36	0.26
	1990–1994 (first 5)	0.29	0.33	0.19	0.38	0.59	0.33
Change between (%)	1990–1994, 1995–1999	−39	−39	61	23	−57	−34
Injuries/million vehicle kilometer risk index	1997–1999 (last 3)	0.29	0.36	0.68	0.79	0.3	0.35
	1995–1999 (last 5)	0.37	0.4	0.63	0.86	0.43	0.42
	1990–1999 (last 10)	0.46	0.5	0.57	0.9	0.64	0.52
	1990–1994 (first 5)	0.58	0.66	0.49	0.97	1.13	0.66
Change between (%)	1990–1994, 1995–1999	−36	−40	30	−12	−62	−36
Fatalities/million vehicle kilometer risk index	1997–1999 (last 3)	0.06	0.045	0.054	0.114	0.031	0.055
	1995–1999 (last 5)	0.067	0.051	0.060	0.117	0.041	0.063
	1990–1999 (last 10)	0.073	0.076	0.052	0.119	0.060	0.074
	1990–1994 (first 5)	0.081	0.114	0.040	0.122	0.104	0.091
Change between (%)	1990–1994, 1995–1999	−17	−55	51	−5	−61	−31

Table 3 (*Continued*)

Risk and severity indicators	Period of analysis (years)	Cairo–Alexandria agriculture road	Cairo–Alexandria desert road	Cairo–Fayoum desert road	Cairo–Suez desert road	Cairo–Ismailia desert road	Network of five rural roads
Casualties/million vehicle kilometer risk index	1997–1999 (last 3)	0.35	0.41	0.74	0.91	0.33	0.41
	1995–1999 (last 5)	0.43	0.45	0.69	0.97	0.47	0.48
	1990–1999 (last 10)	0.53	0.58	0.62	1.02	0.7	0.6
	1990–1994 (first 5)	0.66	0.77	0.53	1.1	1.23	0.75
Change between (%)	1990–1994, 1995–1999	−34	−42	32	−11	−62	−36
Casualties/accident severity index	1997–1999 (last 3)	2.51	2.24	2.26	2.01	1.85	2.25
	1995–1999 (last 5)	2.47	2.28	2.26	2.07	1.84	2.26
	1990–1999 (last 10)	2.36	2.33	2.42	2.34	1.96	2.29
	1990–1994 (first 5)	2.28	2.38	2.76	2.87	2.07	2.31
Change between (%)	1990–1994, 1995–1999	9	−4	−18	−28	−11	−2
Injuries/accident severity index	1997–1999 (last 3)	2.07	1.99	2.10	1.76	1.68	1.94
	1995–1999 (last 5)	2.09	2.02	2.06	1.82	1.68	1.97
	1990–1999 (last 10)	2.03	2.02	2.21	2.07	1.79	2.00
	1990–1994 (first 5)	2.00	2.03	2.55	2.55	1.89	2.03
Change between (%)	1990–1994, 1995–1999	5	−0.5	−19	−28	−11	−3
Fatalities/accident severity index	1997–1999 (last 3)	0.43	0.25	0.17	0.25	0.17	0.30
	1995–1999 (last 5)	0.38	0.26	0.20	0.25	0.16	0.29
	1990–1999 (last 10)	0.33	0.31	0.20	0.27	0.17	0.29
	1990–1994 (first 5)	0.28	0.35	0.21	0.32	0.18	0.28
Change between (%)	1990–1994, 1995–1999	37	−26	−6	−22	−9	5
Injuries/casualties severity index	1997–1999 (last 3)	0.83	0.89	0.93	0.87	0.91	0.86
	1995–1999 (last 5)	0.84	0.89	0.91	0.88	0.91	0.87
	1990–1999 (last 10)	0.86	0.87	0.92	0.88	0.91	0.88
	1990–1994 (first 5)	0.88	0.85	0.92	0.89	0.92	0.88
Change between (%)	1990–1994, 1995–1999	−4	4	−1	−1	−0.25	−1
Fatalities/casualties severity index	1997–1999 (last 3)	0.17	0.11	0.07	0.13	0.094	0.14
	1995–1999 (last 5)	0.16	0.11	0.09	0.12	0.087	0.13
	1990–1999 (last 10)	0.14	0.13	0.08	0.12	0.086	0.12
	1990–1994 (first 5)	0.12	0.15	0.08	0.11	0.085	0.12
Change between (%)	1990–1994, 1995–1999	26	−22	15	7	3	7

[a] Data used in the computation of these indicators was aggregated from annual values over the considered time periods of the analysis, except for the kilometer length of considered roads/networks.

each of the five roads, the above table displays the computation of these indicators for a network composed of these five roads. Following an in depth examination of the displayed indicators, the following conclusions can be deduced.

In using the first exposure measure, all of the computed traffic safety risk indicators for the Cairo–Alexandria agriculture road proved to be highest in comparison to the other roads (i.e. accidents per kilometer is around 1.99 which is above the network value by 37%, injuries per kilometer is around 4.15 which is above the network value by 46%, fatalities per kilometer is around 0.77, which is above the network value by 83% and casualties per kilometer is around 4.92 which is above the network value by 50%). In using the second exposure measure, all of the computed traffic safety risk indicators for the Cairo–Suez desert road proved to be the highest in comparison to the other roads (i.e. accidents per million vehicle kilometer is around 0.47 which is above the network value by 124%, injuries per million vehicle kilometer is around 0.86 which is above the network value by 105%, fatalities per million vehicle kilometer is around 0.117, which is above the network value by 86% and casualties per million vehicle kilometer is around 0.97 which is above the network value by 102%).

It is common in most international studies and comparisons to use vehicle kilometer as an exposure measure that represents spatial and time dimensions. In this context, it is obvious that the most dangerous road of the five is Cairo–Suez desert road. This road has very high-risk indicators compared to the rest of the considered roads.

Casualties per accident for the Cairo–Alexandria agriculture road is the highest (around 2.47 and is above the network value by 9%). Injuries per accident for both Cairo–Alexandria agriculture road (around 2.09 and is above the network value by 6%) and Cairo–Fayoum desert road (around 2.06 and is above the network value by 4.6%) are the highest. Fatalities per accident for Cairo–Alexandria agriculture road is the highest (around 0.38 and is above the network value by 31%). Injuries per casualties for Cairo–Fayoum desert road is the highest (around 91% and is above the network value by 4.6%). Fatalities per casualties for Cairo–Alexandria desert road is the highest (around 0.16 and is above the network value by 23%). The above conclusions demonstrate the extreme severity of accidents occurring on the Cairo–Alexandria agriculture road and that fatality rates are very high on this road compared to the other roads. Another conclusion can be drawn with reference to the Cairo–Fayoum road in terms of its high rates of accident injuries.

Accidents per kilometer reduced over the past 5 years in comparison with the previous 5 years for all of the considered roads except for Cairo–Fayoum and Cairo–Suez desert roads where it increased by 126 and 91%, respectively. An overall reduction of 7% can be noted for the network of five roads. Injuries per kilometer reduced over the past 5 years in comparison with the previous 5 years for all of the considered roads except for Cairo–Fayoum and Cairo–Suez desert roads where it increased by 83 and 37%, respectively. An overall reduction of 10% can be noted for the network of five roads.

Fatalities per kilometer reduced over the past 5 years in comparison with the previous 5 years for Cairo–Alexandria and Cairo–Ismailia desert roads. However, for the other three roads this risk rate index increased. Still, an overall reduction of 3% can be noted for the network of five roads. Casualties per kilometer reduced over the past 5 years in comparison with the previous 5 years for all of the considered roads except for Cairo–Fayoum and Cairo–Suez desert roads where it increased by 85 and 38%, respectively. An overall reduction of 9% can be noted for the network of five roads.

Accidents per million vehicle kilometer reduced over the past 5 years in comparison with the previous 5 years for all of the considered roads except for Cairo–Fayoum and Cairo–Suez desert roads where it increased by 61 and 23%, respectively. An overall reduction of 34% can be noted for the network of five roads. Injuries per million vehicle kilometer reduced over the past 5 years in comparison with the previous 5 years for all of the considered roads except for Cairo–Fayoum desert road where it increased by 30%. An overall reduction of 36% can be noted for the network of five roads.

Fatalities per million vehicle kilometer reduced over the past 5 years in comparison with the previous 5 years for all of the considered roads except for Cairo–Fayoum desert road where it increased by 51%. An overall reduction of 31% can be noted for the network of five roads. Casualties per million vehicle kilometer reduced over the past 5 years in comparison with the previous 5 years for all of the considered roads except for Cairo–Fayoum desert road where it increased by 32%. An overall reduction of 36% can be noted for the network of five roads. In conclusion, significant reductions in all of the considered risk-based indicators were noted on the network level.

Casualties per accidents reduced over the past 5 years in comparison with the previous 5 years for all of the considered roads except for Cairo–Alexandria agriculture road where it increased by 9%. An overall reduction of 2% can be noted for the network of five roads. Injuries per accidents reduced over the past 5 years in comparison with the previous 5 years for all of the considered roads except for Cairo–Alexandria agriculture road where it increased by 5%. An overall reduction of 3% can be noted for the network of five roads.

Fatalities per accidents reduced over the past 5 years in comparison with the previous 5 years for all of the considered roads except for Cairo–Alexandria agriculture road where it increased by 37%. However, an overall increase of 5% can be noted for the network of five roads. Injuries per casualties reduced over the past 5 years in comparison with the previous 5 years for all of the considered roads except for Cairo–Alexandria desert road where it increased by 4%. An overall reduction of 1% can be noted for the network of five roads.

Fatalities per casualties increased over the past 5 years in comparison with the previous 5 years for all of the considered roads except for Cairo–Alexandria desert road where it reduced by 22%. An overall increase of 7% can be noted for the network of five roads. In conclusion, slight reductions in the casualties and injuries severity indicators were noted on the network level. On the other hand, increases in the fatalities severity indicators were noted on the network level.

3. Analysis of accident causes for main rural roads in Egypt

In Egypt, only two major accident investigation programs took place. The first was initiated in the early 1980s, when a national study funded by EASRT was conducted (see EASRT, 1991). In this study, accident and traffic behavior data were collected for five main rural roads in Egypt and three major districts in Greater Cairo. The study was undertaken by the Traffic Police Department in conjunction with Egyptian academics and with the cooperation of the UK Transport and Road Research Laboratory. The accident management system developed by this study was not fully pursued due mainly to lack of allocated resources and the sophistication and length of the data collection forms. The second program, which was also funded by EASRT, looked at developing an accident management system with an easy to use accident-reporting form. The developed system was applied for the collection, analysis and reporting of traffic accidents for 14 sections of roads representing eight major rural roads in Egypt. The traffic police department in conjunction with Egyptian academics undertook this study. Data collection spanned over the period 1997–1998 and is currently being maintained by the traffic police department in accordance with the developed system.

In this section an analysis of causes of accidents on the five considered rural roads is undertaken. This analysis relies on accident data collected in the course of the second study for the year 1998. The developed accident reporting form contains 27 causes of accidents. A traffic police at an accident site can mark one or more of these as causes for an accident. These causes are listed in Table 4. The table categorizes these causes into six categories, namely:

(a) driver related causes (six causes);
(b) pedestrian related causes (two causes);
(c) vehicle related causes (12 causes);
(d) road related causes (five causes);
(e) environment related causes (one cause); and
(f) other causes.

For each of the five roads as well as their network, Table 4 shows the frequency and contributing percentage of each of the considered accident causes. Most of the highly contributing causes are driver related. These include loss of control of driving wheel, over speed, misjudgment of traffic gap, sudden slowing/stoppage. Two other causes related to the vehicle are frequently mentioned, i.e. tire burst and vehicle turnover or vehicle turn off the road. Together, these six causes contribute around 83% of all accident causes on the five roads.

In general, driver related causes contribute around 59–73%. This is followed by vehicle related causes contributing in the range of 23%. Pedestrian related causes also contribute around 4%, while road related causes contribute only 3.5%. Environment and other related causes are also in the range of 3.5%. Based on the above analysis, the following recommendations can be suggested.

(a) Increasing drivers' awareness of the need for caution when using the driving wheel. This can be attained through mass media campaigns showing that a big number of accidents are caused as a result of drivers' negligence when operating the wheel. In addition, more rest stations ought to be constructed along the roads to allow drivers to rest during their journeys.
(b) Increasing drivers' awareness of the importance of tire inspection and checking before starting their journeys. In addition, a set of technical and safety standards should be issued and becoming mandatory for all parties dealing with tires including producers, importers, distributors and inspection workshops. Tire workshops should be inspected and licensed in accordance with adequately developed technical and safety standards.
(c) Increasing drivers' awareness of the importance to avoid over speeding. This can be also attained through mass media campaigns as well as by increasing radar over speed detection and inflicting heavy penalties on violators.
(d) More stringent driving tests should be adopted.
(e) Missing road shoulders should be constructed. Road shoulders should be adequately maintained and kept clear so as to allow for broken vehicles to slow down and stop if necessary.
(f) Proper and adequate road signing and marking should be maintained.

4. Modeling of traffic safety on rural roads in Egypt

In the course of conducting the above traffic safety assessment of rural roads in Egypt, it became evident that there is a lack of past sustainable and detailed accident data collection programs as well as a lack of accident prediction models. This research develops a number of accident prediction models.

Several studies have developed accident explanatory models. Traditionally, linear, non-linear and generalized linear modeling are used in the development of such models (see Kulmala and Roine, 1988; Amis, 1996). In their study of accidents on sections of principal arterials in Washington State, Milton and Mannering (1998) used the negative binomial regression to model the effects of various highway

Table 4
Share of accidents' causes for five main rural roads in Egypt (based on 1998 data)

Accidents' causes	Roads											
	Cairo agriculture (no.)	Alexandria road (%)	Cairo desert (no.)	Alexandria road (%)	Cairo desert (no.)	Fayoum road (%)	Cairo desert (no.)	Suez road (%)	Cairo desert (no.)	Ismailia road (%)	All five (no.)	Considered roads (%)
User related causes (driver)												
Loss of control of driving wheel	97	19.32	97	38.96	19	15.57	58	35.80	107	29.16	378	26.96
Over speed	119	23.71	18	7.23	32	26.23	4	2.47	1	0.27	174	12.41
Misjudgment of traffic gap	41	8.17	35	14.06	5	4.10	27	16.67	59	16.08	167	11.91
Sudden slowing/stoppage	48	9.56	13	5.22	13	10.66	4	2.47	32	8.72	110	7.85
Careless lane changing	15	2.99	17	6.83	0	0.00	1	0.62	15	4.09	48	3.42
Overtaking from the right	19	3.78	3	1.20	3	2.46	1	0.62	11	3.00	37	2.64
Sub-total	339	67.53	183	73.49	72	59.02	95	58.64	225	61.31	914	65.19
User related causes (Pedestrian)												
Misjudging traffic speed while crossing	27	5.38	2	0.80	1	0.82	3	1.85	12	3.27	45	3.21
Standing/walking on road shoulder	7	1.39	3	1.20	3	2.46	0	0.00	2	0.54	15	1.07
Sub-total	34	6.77	5	2.01	4	3.28	3	1.85	14	3.81	60	4.28
Vehicle related causes												
Tire burst and vehicle turnover	44	8.76	35	14.06	32	26.23	43	26.54	50	13.62	204	14.55
Tire burst and vehicle turn off road	23	4.58	14	5.62	0	0.00	1	0.62	33	8.99	71	5.06
Tire separation	3	0.60	2	0.80	0	0.00	3	1.85	4	1.09	12	0.86
Brake deficiency	3	0.60	2	0.80	5	4.10	0	0.00	1	0.27	11	0.78
Trailer separation	1	0.20	2	0.80	2	1.64	1	0.62	1	0.27	7	0.50
Non-operable vehicle lights	1	0.20	0	0.00	0	0.00	1	0.62	1	0.27	3	0.21
Reflective mirrors missing	1	0.20	0	0.00	0	0.00	0	0.00	1	0.27	2	0.14
Deficiency in window screens	0	0.00	0	0.00	0	0.00	0	0.00	1	0.27	1	0.07
Vehicle overloaded	1	0.20	0	0.00	0	0.00	0	0.00	0	0.00	1	0.07
Load length beyond permissible	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
Load height beyond permissible	0	0.00	0	0.00	1	0.82	0	0.00	0	0.00	1	0.07
Load falling (trailer connection defect)	1	0.20	0	0.00	0	0.00	0	0.00	1	0.27	2	0.14
Sub-total	78	15.54	55	22.09	40	32.79	49	30.25	93	25.34	315	22.47
Road related causes												
U-turns	14	2.79	1	0.40	4	3.28	7	4.32	12	3.27	38	2.71
Skidding surface	2	0.40	0	0.00	0	0.00	0	0.00	2	0.54	4	0.29
Dangerous curve/gradient	1	0.20	1	0.40	1	0.82	0	0.00	1	0.27	4	0.29
Road works	0	0.00	1	0.40	0	0.00	1	0.62	0	0.00	2	0.14
Poor road condition	1	0.20	0	0.00	0	0.00	0	0.00	0	0.00	1	0.07
Sub-total	18	3.59	3	1.20	5	4.10	8	4.94	15	4.09	49	3.50
Environment related causes												
Bad weather conditions	21	4.18	0	0.00	0	0.00	4	2.47	16	4.36	41	2.92
Sub-total	21	4.18	0	0.00	0	0.00	4	2.47	16	4.36	41	2.92
Other causes												
Sub-total	12	2.39	3	1.20	1	0.82	3	1.85	4	1.09	23	1.64
Total and percentage relative to five roads	502	35.81	249	17.76	122	8.70	162	11.55	367	26.18	1402	100

geometric and traffic characteristics on annual accident frequency. Another study that also used the negative binomial function to relate accident occurrence on a principal arterial in Florida with traffic and road geometric characteristics was reported in Abdel-Aty and Radwan (2000). In a recent study, Poisson regression models were estimated for predicting highway crash rates in Connecticut as a function of traffic density and land-use as well as ambient light condition and time of day (see Ivan et al., 2000). Directed graphs as an alternative to regression-based accident prediction procedures was recently advocated by Roh et al. (1999). It can be concluded that several types of models were used to relate accidents to road and/or traffic variables. These include linear, non-linear, Poisson and negative binomial regression models.

This research attempts to develop models that show the relationships between the number of accidents, casualties, fatalities, and injuries as dependent variables and other independent variables representing traffic exposure, such as AADT or annual average vehicle kilometers (AAVK). Time series data of traffic and accidents, over a 10 years period for the considered roads, is utilized in the calibration of these predictive models. Several functional forms are explored and tested in the calibration process. These include linear, exponential, power, logarithmic and polynomial functions.

4.1. ANOVA tests to establish traffic and accident related differences among considered roads

Before proceeding to the development of these models three ANOVA statistical tests are conducted using SPSS package (see Norusis, 1993). The purpose of these tests is to establish whether there are any significant differences in the data used for models' calibration as a result of differences among the considered five roads. This could assist in deciding whether it is appropriate to increase the data set by using the data of several roads in the calibration of the models or it is better to develop separate predictive models for each of the considered roads.

The first test is the one way analysis of variance *F*-test. Using this test, one can examine the null hypothesis that the available data represents a sample from populations in which the means of the test variables (i.e. AADT, AAVK, accidents, injuries, fatalities and casualties) are similar in several independent groups (i.e. the five main rural roads or the four main desert rural roads). Hence, in this research H_0 for the *F*-test states that population means of accident and traffic related variables of considered rural roads are the same. Results of this test are displayed in Table 5, where it is shown that H_0 is rejected for all of the considered variables. In these situations, it would be advisable to develop separate predictive models for each of these roads.

However, a significant *F*-value can only demonstrate that the population means of considered variables are probably not all equal. It does not show which pairs of groups (roads) appear to have different means. In the *F*-test, the null hypothesis that all population means are equal is rejected if any two means are unequal. In this case if one would like to establish the group pairs that are significantly different, separate *t*-tests can be conducted for each pair of roads. This is similar to the *F*-test but restricted to a comparison of only two groups at a time. In this research, the least significant difference multiple *T*-tests are used to perform all pair wise comparisons of means of accident and traffic related variables between each possible pair of the five considered roads. Results of these tests are shown in Table 5, where in some cases H_0 is not rejected, i.e. there is no difference in population means of considered variables that may be a result of differences in roads. Thus, one can conclude that it would be safe to combine the data of the considered roads and develop models that represent these roads on an aggregate basis.

Still, when many comparisons are made involving the same means, the probability that one comparison will turn out to be statistically significant increases. This is known as the error rate resulting of multiple comparisons. Multiple comparison procedures protect from calling too many differences significant. This is done by adjusting for the number of comparisons. One of the simplest multiple comparison procedures is known as Bonferroni test. This test uses *t*-tests to perform pair wise comparisons between group means, but controls overall error rate by setting it for each test to the experiment-wise error rate divided by the total number of tests. For further discussion of multiple comparison techniques (see Winer et al., 1991). Results of these tests are shown in Table 5, where in similar cases as the previous test, H_0 is not rejected, i.e. there is no difference in population means of considered variables that may be a result of differences in roads. This supports the conclusion that it could be safe combine the data of the considered roads and develop models that represent these roads on an aggregate basis.

4.2. Development of predictive models for accidents, injuries, fatalities and casualties on rural roads in Egypt

A set of statistical models were developed to predict the expected numbers of accidents, injuries, fatalities and casualties. The developed models are based on an a priori assumption that the number of accidents, injuries, fatalities and casualties are function of exposure measures taken here as AADT and AAVK. For each of the five considered roads as well as for the network composed of these five roads, five functional forms were utilized, namely the linear, power, logarithmic, exponential and quadratic polynomial (see Table 6). The data used for the calibration of these models spanned over a period of 10 years (1990–1999). To establish the goodness of fit and statistical significance of the calibrated models two statistics were computed, namely, the R^2 and the F statistics. The table shows all of the calibrated models. Those models producing the highest correlation values as well as significant F statistics are shaded.

Table 5
ANOVA tests to establish population differences among the five considered rural roads

Variables	ANOVA tests			
	F-test among five rural roads (one way ANOVA)	*F*-test among four rural desert roads (one way ANOVA)	Least significant difference multiple *T*-tests between each pair of five considered rural roads	Bonferroni multiple comparison procedure *T*-tests between each pair of five considered rural roads
AADT	H_0 rejected	H_0 rejected	H_0 not rejected for Cairo–Suez road in comparison to Cairo–Fayoum road H_0 not rejected for Cairo–Alexandria road in comparison to Cairo–Ismailia road H_0 rejected for all other pairs of roads	H_0 not rejected for Cairo–Suez road in comparison to Cairo–Fayoum road as well as in comparison to Cairo–Alexandria road H_0 not rejected for Cairo–Alexandria road in comparison to Cairo–Ismailia road H_0 rejected for all other pairs of roads
AAVK	H_0 rejected	H_0 rejected	H_0 not rejected for Cairo–Suez road in comparison to Cairo–Fayoum road H_0 rejected for all other pairs of roads	H_0 not rejected for Cairo–Suez road in comparison to Cairo–Fayoum road H_0 not rejected for Cairo–Suez road in comparison to Cairo–Ismailia road H_0 rejected for all other pairs of roads
Accidents	H_0 rejected	H_0 rejected	H_0 not rejected for Cairo–Alexandria road in comparison to Cairo–Ismailia road H_0 rejected for all other pairs of roads	H_0 not rejected for Cairo–Suez road in comparison to Cairo–Fayoum road H_0 not rejected for Cairo–Alexandria road in comparison to Cairo–Ismailia road H_0 not rejected for Cairo–Suez road in comparison to Cairo–Ismailia road H_0 rejected for all other pairs of roads
Injuries	H_0 rejected	H_0 rejected	H_0 not rejected for Cairo–Suea road in comparison to Cairo–Fayoum road H_0 rejected for all other pairs of roads	H_0 not rejected for Cairo–Suez road in comparison to Cairo–Fayoum road H_0 not rejected for Cairo–Suez road in comparison to Cairo–Ismailia road H_0 rejected for all other pairs of roads
Fatalities	H_0 rejected	H_0 rejected	H_0 not rejected for Cairo–Suez road in comparison to Cairo–Ismailia road H_0 rejected for all other pairs of roads	H_0 not rejected for Cairo–Suez road in comparison to Cairo–Fayoum road H_0 not rejected for Cairo–Suez road in comparison to Cairo–Ismailia road
Casualties	H_0 rejected	H_0 rejected	H_0 not rejected for Cairo–Suez road in comparison to Cairo–Fayoum road H_0 not rejected for Cairo–Suez road in comparison to Cairo–Ismailia road H_0 rejected for all other pairs of roads	H_0 not rejected for Cairo–Suez road in comparison to Cairo–Fayoum road H_0 not rejected for Cairo–Alexandria road in comparison to Cairo–Ismailia road H_0 not rejected for Cairo–Suez road in comparison to Cairo–Ismailia road H_0 rejected for all other pairs of roads

H_0 for ANOVA *F*-test states that population means of the five considered rural roads are the same; H_0 for least significant difference multiple *T*-tests states that population means of each two considered rural roads are the same; H_0 for Bonferroni multiple comparison procedure (a modified least significant difference *T*-tests) states that population means of each two considered rural roads are the same.

The table also shows the calibration of models for the four desert roads based on a 40 point data obtained as a result of using time series data for the four considered desert roads. Similarly models were calibrated for the five considered rural roads based on a 50 point data obtained as a result of using time series data for the five roads. As shown in Table 6, not all models were significant. The following conclusions can be deduced from this exhaustive modeling exercise.

A total of 200 statistical models were calibrated. These represent combinations of eight roads/networks, four dependent variables, two explanatory variables and five functional forms. Of these, a total of 31 models proved to be statistically sound. The power function was the most dominant function, where 16 of these models followed this function (i.e. more than 50%). Five models followed the logarithmic function, four followed the exponential, three followed the linear and another thee followed the polynomial.

Three models proved to be significant for the Cairo–Alexandria agriculture road. These are power functional models relating accidents, injuries and casualties as dependent variables to AADT. No model could be obtained to predict the number of fatalities on the Cairo–Alexandria agriculture road. Also, none of the models calibrated for the Cairo–Alexandria desert road proved to be significant.

Four models proved to be significant for the Cairo–Fayoum desert road. Two of these are power functional relating accidents and fatalities as dependent variables to AADT. The other two models have the logarithmic form relating injuries and casualties as dependent variables to AADT.

Table 6
Prediction models of accidents, injuries, fatalities and casualties for rural roads in Egypt

Road	Data				
	Functional form	Accidents vs. AADT	Injuries vs. AADT	Fatalities vs. AADT	Casualties vs. AADT
Cairo–Alexandria agriculture rural road	Linear	$Y = -0.0209X + 1060$ $R^2 = 0.573$, $F = 10.7$, Sig.	$Y = -0.0399X + 2082.6$ $R^2 = 0.635$, $F = 13.9$, Sig.	$Y = 1E - 4X + 150.42$ $R^2 = 0.0005$, $F = 0.004$, Insig.	$Y = -0.0398X + 2232.9$ $R^2 = 0.577$, $F = 10.9$, Sig.
	Power	$Y = 7E + 8X^{-1.3892}$ $R^2 = 0.6$, $F = 12$, Sig.	$Y = 6E + 8X^{-1.3067}$ $R^2 = 0.669$, $F = 16.1$, Sig.	$Y = 123.7X^{0.0202}$ $R^2 = 0.0005$, $F = 0.004$, Insig.	$Y = 1E + 8X^{-1.1119}$ $R^2 = 0.605$, $F = 12.2$, Sig.
Annual time series data (1990–1999) 10 points	Logarithmic	$Y = -615.16\ \ln(X) + 6768.1$ $R^2 = 0.575$, $F = 10.8$, Sig.	$Y = -1173.4\ \ln(X) + 12969.9$ $R^2 = 0.637$, $F = 14$, Sig.	$Y = 2.7567\ \ln(X) + 124.98$ $R^2 = 0.0004$, $F = 0.003$, Insig.	$Y = -1170.7\ \ln(X) + 13094$ $R^2 = 0.578$, $F = 11$, Sig.
	Exponential	$Y = 1730e^{-5E-5X}$ $R^2 = 0.596$, $F = 11.8$, Sig.	$Y = 3275.7e^{-4E-5X}$ $R^2 = 0.666$, $F = 16$, Sig.	$Y = 149.13e^{7E-7X}$ $R^2 = 0.0006$, $F = 0.005$, Insig.	$Y = 3165.4e^{-4E-5X}$ $R^2 = 0.602$, $F = 12.1$, Sig.
	Polynomial (quadratic)	$Y = 1E - 6X^2 - 0.0873X + 2024$ $R^2 = 0.581$, $F = 4.8$, Sig.	$Y = 2E - 6X^2 - 0.1405X + 3542$ $R^2 = 0.641$, $F = 6.3$, Sig.	$Y = 2E - 7X^2 - 0.0109X + 310$ $R^2 = 0.0085$, $F = 0.03$, Insig.	$Y = 2E - 6X^2 - 0.1514X + 3853$ $R^2 = 0.583$, $F = 4.9$, Sig.
Cairo–Alexandria desert rural road	Linear	$Y = -0.0024X + 222.6$ $R^2 = 0.128$, $F = 1.2$, Insig.	$Y = -0.0044X + 445.27$ $R^2 = 0.058$, $F = 0.5$, Insig.	$Y = -0.0036X + 100.15$ $R^2 = 0.217$, $F = 2.22$, Insig.	$Y = -0.008X + 545.42$ $R^2 = 0.119$, $F = 1.08$, Insig.
	Power	$Y = 859.86X^{-0.1598}$ $R^2 = 0.138$, $F = 1.28$, Insig.	$Y = 1747.3X^{-0.1609}$ $R^2 = 0.069$, $F = 0.6$, Insig.	$Y = 97692X^{-0.8025}$ $R^2 = 0.28$, $F = 3.11$, Insig.	$Y = 4384X^{-0.2448}$ $R^2 = 0.133$, $F = 1.23$, Insig.
Annual time series data (1990–1999) 10 points	Logarithmic	$Y = -31.66\ \ln(X) + 489.92$ $R^2 = 0.134$, $F = 1.24$, Insig.	$Y = -60.97\ \ln(X) + 962.4$ $R^2 = 0.067$, $F = 0.58$, Insig.	$Y = -47.07\ \ln(X) + 497.7$ $R^2 = 0.23$, $F = 2.39$, Insig.	$Y = -108.04\ \ln(X) + 1460.1$ $R^2 = 0.132$, $F = 1.22$, Insig.
	Exponential	$Y = 222.88e^{-1E-5X}$ $R^2 = 0.13$, $F = 1.2$, Insig.	$Y = 445.4e^{-1E-5X}$ $R^2 = 0.058$, $F = 0.5$, Insig.	$Y = 111.3e^{-6E-5X}$ $R^2 = 0.265$, $F = 2.88$, Insig.	$Y = 550.36e^{-2E-5X}$ $R^2 = 0.118$, $F = 1.07$, Insig.
	Polynomial (quadratic)	$Y = 2E - 7X^2 - 0.0083X + 259.2$ $R^2 = 0.139$, $F = 0.56$, Insig.	$Y = 1E - 6X^2 - 0.0336X + 627.4$ $R^2 = 0.095$, $F = 0.37$, Insig.	$Y = 4E - 7X^2 - 0.0138X + 163.8$ $R^2 = 0.243$, $F = 1.12$, Insig.	$Y = 1E - 6X^2 - 0.0474X + 791.2$ $R^2 = 0.161$, $F = 0.67$, Insig.
Cairo–Fayoum desert rural road	Linear	$Y = 0.0114X - 31.088$ $R^2 = 0.581$, $F = 11.1$, Sig.	$Y = 0.0231X - 55.482$ $R^2 = 0.667$, $F = 16$, Sig.	$Y = 0.0025X - 7.3142$ $R^2 = 0.432$, $F = 6.1$, Sig.	$Y = 0.0255X - 62.796$ $R^2 = 0.707$, $F = 19.3$, Sig.
	Power	$Y = 2E - 7X^{2.1785}$ $R^2 = 0.654$, $F = 15.1$, Sig.	$Y = 3E - 6X^{1.9749}$ $R^2 = 0.674$, $F = 16.6$, Sig.	$Y = 2E - 7X^{2.0152}$ $R^2 = 0.475$, $F = 7.2$, Sig.	$Y = 2E - 6X^{1.9967}$ $R^2 = 0.691$, $F = 17.9$, Sig.
Annual time series data (1990–1999) 10 points	Logarithmic	$Y = 74.827\ \ln(X) - 611.7$ $R^2 = 0.637$, $F = 14$, Sig.	$Y = 148.17\ \ln(X) - 1202.9$ $R^2 = 0.706$, $F = 19.3$, Sig.	$Y = 15.449\ \ln(X) - 126.51$ $R^2 = 0.43$, $F = 6$, Sig.	$Y = 163.62\ \ln(X) - 1329.4$ $R^2 = 0.745$, $F = 23.3$, Sig.
	Exponential	$Y = 4.4888e^{0.0003X}$ $R^2 = 0.592$, $F = 11.6$, Sig.	$Y = 11.96e^{0.0003X}$ $R^2 = 0.628$, $F = 13.5$, Sig.	$Y = 0.9196e^{0.0003X}$ $R^2 = 0.469$, $F = 7.1$, Sig.	$Y = 12.764e^{0.0003X}$ $R^2 = 0.646$, $F = 14.6$, Sig.
	Polynomial (quadratic)	$Y = -8E - 6X^2 + 0.1092X - 330$ $R^2 = 0.845$, $F = 19$, Sig.	$Y = -9E - 6X^2 + 0.1448X - 428$ $R^2 = 0.783$, $F = 12.6$, Sig.	$Y = 1E - 7X^2 + 0.0012X - 3.448$ $R^2 = 0.432$, $F = 2.7$, Insig.	$Y = -9E - 6X^2 + 0.146X - 431.74$ $R^2 = 0.805$, $F = 14.5$, Sig.

Table 6 (*Continued*)

Road	Data				
	Functional form	Accidents vs. AADT	Injuries vs. AADT	Fatalities vs. AADT	Casualties vs. AADT
Cairo–Suez desert rural road	Linear	$Y = 0.0139X + 5.8333$ $R^2 = 0.426$, $F = 5.9$, Sig.	$Y = 0.0129X + 111.36$ $R^2 = 0.15$, $F = 1.4$, Insig.	$Y = 0.0037X + 2.3341$ $R^2 = 0.535$, $F = 9.2$, Sig.	$Y = 0.0165X + 113.69$ $R^2 = 0.241$, $F = 2.5$, Insig.
	Power	$Y = 0.0046X^{1.1295}$ $R^2 = 0.559$, $F = 10.1$, Sig.	$Y = 1.7055X^{0.5373}$ $R^2 = 0.216$, $F = 2.21$, Insig.	$Y = 0.0095X^{0.8986}$ $R^2 = 0.456$, $F = 6.7$, Sig.	$Y = 1.1601X^{0.5967}$ $R^2 = 0.319$, $F = 3.7$, Insig.
Annual time series data (1990–1999) 10 points	Logarithmic	$Y = 104.05\ \ln(X) - 813.19$ $R^2 = 0.509$, $F = 8.3$, Sig.	$Y = 103.63\ \ln(X) - 710.22$ $R^2 = 0.205$, $F = 2.1$, Insig.	$Y = 24.7\ \ln(X) - 189.78$ $R^2 = 0.517$, $F = 8.6$, Sig.	$Y = 128.33\ \ln(X) - 900$ $R^2 = 0.307$, $F = 3.5$, Insig.
	Exponential	$Y = 33.139e^{0.0002X}$ $R^2 = 0.474$, $F = 7.2$, Sig.	$Y = 120.16e^{7E-5X}$ $R^2 = 0.161$, $F = 1.5$, Insig.	$Y = 10.38e^{0.0001X}$ $R^2 = 0.467$, $F = 7$, Sig.	$Y = 128.78e^{8E-5X}$ $R^2 = 0.253$, $F = 2.7$, Insig.
	Polynomial (quadratic)	$Y = -1E - 5X^2 + 0.1737X - 522$ $R^2 = 0.922$, $F = 41$, Sig.	$Y = -2E - 5X^2 + 0.2817X - 776$ $R^2 = 0.72$, $F = 9$, Sig.	$Y = 4E - 7X^2 - 0.002X + 20.998$ $R^2 = 0.547$, $F = 4.2$, Insig.	$Y = -2E - 5X^2 + 0.2798X - 755.4$ $R^2 = 0.774$, $F = 12$, Sig.
Cairo–Ismailia desert rural road	Linear	$Y = -0.002X + 193$ $R^2 = 0.157$, $F = 1.5$, Insig.	$Y = -0.0051X + 368.89$ $R^2 = 0.448$, $F = 6.5$, Sig.	$Y = -0.0003X + 32.134$ $R^2 = 0.152$, $F = 1.43$, Insig.	$Y = -0.0054X + 401.02$ $R^2 = 0.433$, $F = 6.1$, Sig.
	Power	$Y = 1727X^{-0.2514}$ $R^2 = 0.189$, $F = 1.85$, Insig.	$Y = 6725.7X^{-0.3325}$ $R^2 = 0.45$, $F = 6.5$, Sig.	$Y = 148.79X^{-0.1804}$ $R^2 = 0.137$, $F = 1.3$, Insig.	$Y = 6516.3X^{-0.3196}$ $R^2 = 0.44$, $F = 6.3$, Sig.
Annual time series data (1990–1999) 10 points	Logarithmic	$Y = -29.752\ \ln(X) + 446.22$ $R^2 = 0.132$, $F = 1.2$, Insig.	$Y = -81.853\ \ln(X) + 1070.2$ $R^2 = 0.425$, $F = 5.9$, Sig.	$Y = -5.2128\ \ln(X) + 77$ $R^2 = 0.157$, $F = 1.49$, Insig.	$Y = -87.066\ \ln(X) + 1147.2$ $R^2 = 0.413$, $F = 5.62$, Sig.
	Exponential	$Y = 202.98e^{-2E-5X}$ $R^2 = 0.222$, $F = 2.3$, Insig.	$Y = 390.34e^{-2E-5X}$ $R^2 = 0.48$, $F = 7.4$, Sig.	$Y = 31.569e^{-1E-5X}$ $R^2 = 0.136$, $F = 1.3$, Insig.	$Y = 422.05e^{-2E-5X}$ $R^2 = 0.468$, $F = 7$, Sig.
	Polynomial (quadratic)	$Y = -3E - 7X^2 + 0.0088X + 115$ $R^2 = 0.216$, $F = 0.96$, Insig.	$Y = -2E - 7X^2 + 0.0014X + 322$ $R^2 = 0.457$, $F = 2.9$, Insig.	$Y = 1E - 8X^2 - 0.0008X + 35.43$ $R^2 = 0.156$, $F = 0.65$, Insig.	$Y = -2E - 7X^2 + 0.0006X + 357$ $R^2 = 0.44$, $F = 2.8$, Insig.
Network of five rural roads	Linear	$Y = -0.0174X + 1233.6$ $R^2 = 0.377$, $F = 4.8$, Insig.	$Y = -0.0428X + 2596.2$ $R^2 = 0.522$, $F = 8.7$, Sig.	$Y = -0.0007X + 285.06$ $R^2 = 0.006$, $F = 0.05$, Insig.	$Y = -0.0436X + 2881.2$ $R^2 = 0.469$, $F = 7$, Sig.
	Power	$Y = 17987X^{-0.3044}$ $R^2 = 0.357$, $F = 4.4$, Insig.	$Y = 77313X^{-0.3837}$ $R^2 = 0.528$, $F = 8.9$, Sig.	$Y = 384.32X^{-0.0361}$ $R^2 = 0.038$, $F = 0.03$, Insig.	$Y = 57560X^{-0.3393}$ $R^2 = 0.473$, $F = 7$, Sig.
Annual time series aggregated data (1990–1999) 10 points	Logarithmic	$Y = -285.34\ \ln(X) + 3711.9$ $R^2 = 0.35$, $F = 4.3$, Insig.	$Y = -716.62\ \ln(X) + 8832.4$ $R^2 = 0.503$, $F = 8.1$, Sig.	$Y = -13.9\ \ln(X) + 407.3$ $R^2 = 0.007$, $F = 0.05$, Insig.	$Y = -730.52\ \ln(X) + 9239.7$ $R^2 = 0.454$, $F = 6.6$, Sig.
	Exponential	$Y = 1279.8e^{-2E-5X}$ $R^2 = 0.386$, $F = 5$, Insig.	$Y = 2743.3e^{-2E-5X}$ $R^2 = 0.55$, $F = 9.8$, Sig.	$Y = 279.23e^{-2E-6X}$ $R^2 = 0.003$, $F = 0.02$, Insig.	$Y = 3004.6e^{-2E-5X}$ $R^2 = 0.49$, $F = 7.7$, Sig.
	Polynomial (quadratic)	$Y = -3E - 6X^2 + 0.0798X + 424$ $R^2 = 0.441$, $F = 2.8$, Insig.	$Y = -3E - 6X^2 + 0.0511X + 1814$ $R^2 = 0.536$, $F = 4$, Insig.	$Y = 6E - 7X^2 - 0.0209X + 452.8$ $R^2 = 0.028$, $F = 0.1$, Insig.	$Y = -2E - 6X^2 + 0.0302X + 2267$ $R^2 = 0.477$, $F = 3.2$, Insig.

Table 6 (*Continued*)

Road	Data: Functional form	Accidents vs. AADT	Injuries vs. AADT	Fatalities vs. AADT	Casualties vs. AADT
Main desert rural roads	Linear	$Y = 0.0055X + 69.557$ $R^2 = 0.2$, $F = 9.5$, Sig.	$Y = 0.0083X + 160.58$ $R^2 = 0.131$, $F = 5.7$, Sig.	$Y = 0.0008X + 22.194$ $R^2 = 0.04$, $F = 1.6$, Insig.	$Y = 0.0091X + 182.77$ $R^2 = 0.12$, $F = 5.2$, Sig.
Annual time series (1990–1999) of geographical cross-sectional (four roads) data 10 × 4 = 40 points	Power	$Y = 0.0052X^{1.0854}$ $R^2 = 0.42$, $F = 27.5$, Sig.	$Y = 0.0672X^{0.8825}$ $R^2 = 0.346$, $F = 20.1$, Sig.	$Y = 0.0038X^{0.9549}$ $R^2 = 0.255$, $F = 13$, Sig.	$Y = 0.0729X^{0.8858}$ $R^2 = 0.34$, $F = 19.6$, Sig.
	Logarithmic	$Y = 91.696 \ln(X) - 706.9$ $R^2 = 0.4$, $F = 25.4$, Sig.	$Y = 148.72 \ln(X) - 1104.4$ $R^2 = 0.303$, $F = 16.5$, Sig.	$Y = 17.182 \ln(X) - 125.3$ $R^2 = 0.126$, $F = 5.5$, Sig.	$Y = 165.91 \ln(X) - 1229.7$ $R^2 = 0.286$, $F = 15.2$, Sig.
	Exponential	$Y = 50.637e^{7E-5X}$ $R^2 = 0.218$, $F = 10.6$, Sig.	$Y = 119.06e^{5E-5X}$ $R^2 = 0.167$, $F = 7.6$, Sig.	$Y = 12.732e^{6E-5X}$ $R^2 = 0.118$, $F = 5.1$, Sig.	$Y = 133.37e^{5E-5X}$ $R^2 = 0.162$, $F = 7.4$, Sig.
	Polynomial (quadratic)	$Y = -1E - 6X^2 + 0.0383X - 111$ $R^2 = 0.64$, $F = 32.74$, Sig.	$Y = -2E - 6X^2 + 0.0691X - 172.9$ $R^2 = 0.565$, $F = 24$, Sig.	$Y = -3E - 7X^2 + 0.0093X - 24.5$ $R^2 = 0.304$, $F = 8.1$, Sig.	$Y = -2E - 6X^2 + 0.0784X - 197.4$ $R^2 = 0.548$, $F = 22.4$, Sig.
Main rural roads in Egypt	Linear	$Y = 0.0133X + 14.712$ $R^2 = 0.581$, $F = 66.54$, Sig.	$Y = 0.0266X + 29.666$ $R^2 = 0.575$, $F = 64.91$, Sig.	$Y = 0.0046X - 6.9794$ $R^2 = 0.616$, $F = 77.04$, Sig.	$Y = 0.0313X + 22.686$ $R^2 = 0.589$, $F = 68.8$, Sig.
Annual time series (1990–1999) of geographical cross-sectional (five roads) data 10 × 5 = 50 points	Power	$Y = 0.0021X^{1.1889}$ $R^2 = 0.641$, $F = 85.84$, Sig.	$Y = 0.0099X^{1.0996}$ $R^2 = 0.62$, $F = 78.2$, Sig.	$Y = 0.0001X^{1.3224}$ $R^2 = 0.574$, $F = 64.71$, Sig.	$Y = 0.0091X^{1.1213}$ $R^2 = 0.621$, $F = 78.79$, Sig.
	Logarithmic	$Y = 196.26 \ln(X) - 1629.4$ $R^2 = 0.625$, $F = 80.0$, Sig.	$Y = 387.22 \ln(X) - 3209.5$ $R^2 = 0.602$, $F = 72.75$, Sig.	$Y = 64.56 \ln(X) - 544.41$ $R^2 = 0.592$, $F = 69.54$, Sig.	$Y = 451.78 \ln(X) - 3754$ $R^2 = 0.61$, $F = 74.92$, Sig.
	Exponential	$Y = 48.731e^{7E-5X}$ $R^2 = 0.504$, $F = 48.7$, Sig.	$Y = 105.81e^{7E-5X}$ $R^2 = 0.505$, $F = 48.93$, Sig.	$Y = 10.129e^{9E-5X}$ $R^2 = 0.493$, $F = 46.65$, Sig.	$Y = 116.79e^{7E-5X}$ $R^2 = 0.51$, $F = 49.93$, Sig.
	Polynomial (quadratic)	$Y = -6E - 7X^2 + 0.0359X - 120$ $R^2 = 0.643$, $F = 42.27$, Sig.	$Y = -1E - 6X^2 + 0.0646X - 197.5$ $R^2 = 0.618$, $F = 38.03$, Sig.	$Y = -1E - 8X^2 + 0.0051X - 9.98$ $R^2 = 0.616$, $F = 37.76$, Sig.	$Y = -1E - 6X^2 + 0.0697X - 207.5$ $R^2 = 0.622$, $F = 38.67$, Sig.
		Accidents vs. annual vehicle kilometer	Injuries vs. annual vehicle kilometer	Fatalities vs. annual vehicle kilometer	Casualties vs. annual vehicle kilometer
Main desert rural roads	Linear	$Y = 2E - 7X + 60.017$ $R^2 = 0.455$, $F = 31.7$, Sig.	$Y = 3E - 7X + 123.72$ $R^2 = 0.46$, $F = 32.4$, Sig.	$Y = 4E - 8X + 12.264$ $R^2 = 0.333$, $F = 19$, Sig.	$Y = 3E - 7X + 135.98$ $R^2 = 0.464$, $F = 32.9$, Sig.
Annual time series (1990–1999) of geographical cross-sectional (four roads) data 10 × 4 = 40 points	Power	$Y = 3E - 6X^{0.8766}$ $R^2 = 0.636$, $F = 66.4$, Sig.	$Y = 6E - 5X^{0.7707}$ $R^2 = 0.614$, $F = 60.4$, Sig.	$Y = 2E - 7X^{0.9457}$ $R^2 = 0.581$, $F = 52.7$, Sig.	$Y = 5E - 5X^{0.7866}$ $R^2 = 0.622$, $F = 62.5$, Sig.
	Logarithmic	$Y = 77.311 \ln(X) - 1388.4$ $R^2 = 0.661$, $F = 74.1$, Sig.	$Y = 142.05 \ln(X) - 2535.2$ $R^2 = 0.641$, $F = 67.9$, Sig.	$Y = 21.678 \ln(X) - 393.52$ $R^2 = 0.465$, $F = 33$, Sig.	$Y = 163.73 \ln(X) - 2928.7$ $R^2 = 0.647$, $F = 69.6$, Sig.
	Exponential	$Y = 48.538e^{2E-9X}$ $R^2 = 0.405$, $F = 25.9$, Sig.	$Y = 107.37e^{2E-9X}$ $R^2 = 0.399$, $F = 25.3$, Sig.	$Y = 10.285e^{2E-9X}$ $R^2 = 0.381$, $F = 23$, Sig.	$Y = 118.74e^{2E-9X}$ $R^2 = 0.404$, $F = 25.7$, Sig.

Table 6 (*Continued*)

		Accidents vs. annual vehicle kilometer	Injuries vs. annual vehicle kilometer	Fatalities vs. annual vehicle kilometer	Casualties vs. annual vehicle kilometer
	Polynomial (quadratic)	$Y = -3E - 16X^2 + 5E - 7X - 4.26$ $R^2 = 0.664$, $F = 36.5$, Sig.	$Y = -5E - 16X^2 + 9E - 7X + 16.9$ $R^2 = 0.626$, $F = 30.9$, Sig.	$Y = -1E - 16X^2 + 2E - 7X - 8.22$ $R^2 = 0.523$, $F = 20.2$, Sig.	$Y = -6E - 16X^2 + 1E - 6X + 8.73$ $R^2 = 0.643$, $F = 33.3$, Sig.
Main rural roads in Egypt	Linear	$Y = 2E - 7X + 55.521$ $R^2 = 0.73$, $F = 129.6$, Sig.	$Y = 4E - 7X + 105$ $R^2 = 0.756$, $F = 148.4$, Sig.	$Y = 7E - 8X + 5.2779$ $R^2 = 0.839$, $F = 250$, Sig.	$Y = 4E - 7X + 110.28$ $R^2 = 0.778$, $F = 168.5$, Sig.
Annual time series (1990–1999) of geographical cross-sectional (five roads) data 10 × 5 = 50 points	Power	$Y = 8E - 6X^{0.8358}$ $R^2 = 0.773$, $F = 163.4$, Sig.	$Y = 4E - 5X^{0.7912}$ $R^2 = 0.782$, $F = 172.4$, Sig.	$Y = 9E - 8X^{0.9865}$ $R^2 = 0.779$, $F = 169.3$, Sig.	$Y = 3E - 5X^{0.8106}$ $R^2 = 0.792$, $F = 182.7$, Sig.
	Logarithmic	$Y = 135.76 \ln(X) - 2512.5$ $R^2 = 0.729$, $F = 129.3$, Sig.	$Y = 272.62 \ln(X) - 5047$ $R^2 = 0.728$, $F = 128.6$, Sig.	$Y = 46.392 \ln(X) - 869.46$ $R^2 = 0.745$, $F = 140.2$, Sig.	$Y = 319.01 \ln(X) - 5916.5$ $R^2 = 0.741$, $F = 137.4$, Sig.
	Exponential	$Y = 63.338e^{1E-9X}$ $R^2 = 0.576$, $F = 65.1$, Sig.	$Y = 132.32e^{1E-9X}$ $R^2 = 0.617$, $F = 77.4$, Sig.	$Y = 13.029e^{1E-9X}$ $R^2 = 0.637$, $F = 84.1$, Sig.	$Y = 146.36e^{1E-9X}$ $R^2 = 0.629$, $F = 81.3$, Sig.
	Polynomial (quadratic)	$Y = -7E - 17X^2 + 4E - 7X + 7.19$ $R^2 = 0.771$, $F = 79$, Sig.	$Y = -1E - 16X^2 + 7E - 7X + 22$ $R^2 = 0.786$, $F = 86.1$, Sig.	$Y = -3E - 18X^2 + 8E - 8X + 3.06$ $R^2 = 0.84$, $F = 123.1$, Sig.	$Y = -1E - 16X^2 + 8E - 7X + 25.08$ $R^2 = 0.802$, $F = 95.1$, Sig.

F-test serves to test how well the regression model fits the data; H_0, there is no relationship between X and Y; $R^2 = 0$, i.e. that the slope of the population regression line is 0; Sig., F is statistically significant, i.e. H_0 is rejected; Insig., F is statistically insignificant, i.e. H_0 is not rejected.

Four models proved to be significant for the Cairo–Suez desert road. Three of these took the quadratic polynomial shape. These three models are relating accidents, injuries and casualties as dependent variables to AADT. The fourth significant model is a linear function relating fatalities to AADT. It is to be noted that the polynomial models seem to indicate that beyond a certain level of AADT, accidents, injuries and casualties start dropping. This might be attributed to the fact that with the increase in traffic volumes, the road starts approaching capacity, forcing drives to reduce speed and become more cautious. A similar phenomenon was reported by Frantzeskakis (1983) when relating accidents to vehicle kilometers for a national highway in Greece. As for the Cairo–Ismailia desert road, only two models proved to be significant. Both followed the exponential form. The first model relates injuries to AADT, while the second relates casualties to AADT.

As for the network composed of the five considered roads, only two models proved to be significant. Both followed the exponential form. The first model relates injuries to AADT, while the second relates casualties to AADT. Models developed to represent the four considered desert roads are marginally significant. These models were calibrated using 40 data points. All of the developed models followed the power function. These models are based on using AADT as the independent variable representing traffic exposure.

Models developed to represent the five considered rural roads proved to be highly significant. These models were calibrated using 50 data points. Three of the developed models followed the power function, namely models relating accidents, injuries and casualties as dependent variables to AADT. The fourth model took the linear form relating fatalities to AADT.

Models based on AAVK and developed to represent the four considered desert roads proved to be highly significant. These models were calibrated using 40 data points. Three of the developed models followed the logarithmic function, namely models relating accidents, injuries and casualties as dependent variables to AAVK. The fourth model took the power form relating fatalities to AAVK. Models based on AAVK and developed to represent the five considered rural roads proved to be highly significant. These models were calibrated using 50 data points. Three of the developed models followed the power function, namely models relating accidents, injuries and casualties as dependent variables to AAVK. The fourth model took the linear form relating fatalities to AAVK.

In using the developed models for future forecast one has to be careful as this entails extrapolating outside the range where the real observations were made. These models can be used for short-term forecast of 1–3 years. It is advisable that whenever data is available, these models should be updated through recalibration. It has to be noted that attempts were also made to relate accident rates in the form of accidents per AADT or per AAVK to AADT or AAVK as independent variables. However, most of these models proved to be significantly weak.

5. Summary and conclusions

This paper started by presenting an assessment of traffic safety conditions for rural roads in Egypt. Several conclusions were deduced as a result of this comparison. These were stated in the body of the paper and can be summarized as follows.

(a) The most dangerous road of the five considered rural roads is Cairo–Suez desert road. This road has very high-risk indicators compared to the rest of the roads.
(b) Accidents occurring on the Cairo–Alexandria agriculture road are extremely severe, where fatality rates are very high on this road compared to the other roads. Also, Cairo–Fayoum road has very high rates of accident injuries.
(c) On the network level, significant reductions in all of the considered risk-based indicators were noted over the past five years as compared to the previous ones.
(d) On the network level, slight reductions in the casualties and injuries severity indicators were noted over the past 5 years as compared to the previous ones. However, increases in the fatalities severity indicators were also noted on the network level.

The paper presented an analysis of accidents' causes. This analysis is based on all accident records collected in 1998 for the five considered rural roads in Egypt. More than 26 causes are included. These are categorized under six main categories, namely, driver related, pedestrian related, vehicle related, road related, environment-related causes and other causes. Most of the highly contributing causes proved to be driver related. These include loss of control of driving wheel, over speed, misjudgment of traffic gap, sudden slowing/stoppage. Two other causes related to the vehicle were frequently mentioned, i.e. tire burst and vehicle turnover or vehicle turn off the road. Together, these six causes contributed around 83% of all accident causes on the five roads. In general driver related causes contributed around 59–73%. This is followed by vehicle related causes contributing in the range of 23%. Pedestrian related causes also contributed around 4%, while road related causes contributed only 3.5%. Environment and other related causes are also in the range of 3.5%. Based on this analysis, a set of specific recommendations was suggested.

In the course of conducting the above traffic safety assessment of rural roads in Egypt, it became evident that there is a lack of past sustainable and detailed accident data collection programs as well as a lack of accident prediction models. The research developed a number of statistical models that can be used in the prediction of the expected number of accidents, injuries, fatalities and casualties on the rural roads in Egypt. Such models are meant to establish the relationships between the number of accidents, casualties fatalities, injuries as the dependent variables and other independent variables representing traffic exposure, such as AADT or AAVK. Time series data of traffic and accidents, over a 10 years period for the considered roads, was utilized in the calibration of these predictive models. Several functional forms were explored and tested in the calibration process. These include linear, exponential, power, logarithmic and polynomial functions.

Before proceeding to the development of these models three ANOVA statistical tests were conducted. The purpose of these tests was to establish whether there are any significant differences in the data used for models' calibration as a result of differences among the considered five roads. This could assist in deciding whether it is appropriate to increase the data set, by using the data of several roads, in the calibration of the models or it is better to develop separate predictive models for each of the considered roads. The *F*-test showed that it could be safe to combine all of the data of the five considered roads and develop models that represent the five roads on an aggregate basis. On the other hand, the least significant difference multiple *T*-tests and Bonferroni test showed that still it would be advisable to develop separate predictive models for each of these roads.

A total of 200 statistical models were then calibrated. These represent combinations of 8 roads/networks, four dependent variables, two explanatory variables and five functional forms. Of these, a total of 31 models proved to be statistically sound. The power function was the most dominant function, where 16 of these models followed this function (i.e. more than 50%). Five models followed the logarithmic function, four followed the exponential, three followed the linear and another thee followed the polynomial. Models based on AAVK and developed to represent the network of the four considered desert roads or the network of the five considered rural roads proved to be highly significant.

References

Abdel-Aty, M.A., Radwan, A.E., 2000. Modeling traffic accident occurrence and involvement. Accid. Anal. Prev. 32, 633–642.

Amis, G., 1996. An application of generalized linear modeling to the analysis of traffic accidents. Traffic Eng. Control 37 (12), 691–696.

Andreassen, D.C., 1985. Linking deaths with vehicles and population. Traffic Eng. Control 26 (11), 547–549.

EASRT (Egypt Academy for Scientific Research and Technology), 1991. Road traffic accident analysis. Final report conducted for the Transport and Communications Research Committee, Egyptian Traffic Police Department and Academics.

EASRT (Egypt Academy for Scientific Research and Technology), 1999. Investigation of traffic accidents on intercity roads in Egypt. Final report conducted for the Transport Research Council, Egyptian Traffic Police Department and Academics.

Frantzeskakis, J.M., 1983. Accident analysis on two non-controlled access national highways in Greece. Inst. Transport. Eng. J. 53 (2), 26–32.

GARBLT (General Authority for Roads, Bridges and Land Transport), 1999. Annual Report for 1999.

Haight, F.A., 1980. Traffic safety in developing countries. J. Safety Res. 12 (20), 50–58.

IRF (International Road Federation), 1998. World Road Statistics 98—Data 1992–1996. Geneva, Switzerland.

Ivan, J.N., Wang, C., Bernardo, N.R., 2000. Explaining two-lane highway crash rates using land-use and hourly exposure. Accid. Anal. Prev. 32, 787–795.

Jacobs, G.D., Cutting, C.A., 1986. Further research on accident rates in developing countries. Accid. Anal. Prev. 18 (2), 119–127.

Kulmala, R., Roine, M., 1988. Accident prediction models for two lane roads in Finland. In: Proceedings of Traffic Safety Theory and Research Methods, Section 4: Statistical Analysis and Models. SWOV, The Netherlands.

Milton, J., Mannering, 1998. The relationship among highway geometrics, traffic-related elements and motor-vehicle accident frequencies. Transportation 25, 395–413.

Mostafa, M., Saleh, M., 1998. Efforts of Egyptian roads and bridges authority (ERBA) in relieving severity of road traffic accidents during 1990–1997 period. In: Arab Roads, vol. 46, Issue 3. Arab Roads Association, Cairo, Egypt.

Navin, F., Bergan, A., Qi, J., 1994. Fundamental relationship for roadway safety: model for global comparisons. Transport. Res. Rec. 1441, 53–58.

Norusis, M.J., 1993. Statistical package for social sciences (SPSS) for Windows. Base System User Guide, Release 6.0. Spss Inc., USA.

Preston, B., 1980. Road safety: international comparisons. Transport Rev. 1 (1), 75–98.

Roh, J.W., Bessler, D.A., Gilbert, R.F., 1999. Traffic fatalities, Peltzman's model, and directed graphs. Accid. Anal. Prev. 31, 55–61.

Silcock, D.T., Smyth, A.W., 1985. Methods of identifying accident blackspots. Transport and Operations Research Group Report 57, University of Newcastle, Tyne, UK.

Smeed, R.J., 1949. Some statistical aspects of road safety research. J. R. Stat. Soc. Ser. A 112, 1–23.

USDOT (US Department of Transportation), 1999. Bureau of Transportation Statistics 1999. G-7 Countries: Transportation Highlights. BTS99-01, Washington, DC.

USDOT (US Department of Transportation), 2000. National Highway Traffic Safety Administration 2000. Traffic safety facts 1999: a compilation of motor vehicle crash data from the fatality analysis reporting system and the general estimates system. DOT HS 809 100, Washington, DC.

Winer, B.J., Brown, D.R., Michels, K.M., 1991. Statistical Principles in Experimental Design, Third ed. McGraw-Hill, New York.

Zegeer, C.V., 1982. Highway accident analysis system. National Cooperative Highway Research Program: Synthesis of Highway Practice 91. National Research Council, Washington, DC.