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Development of safety proxy models for railroad grade crossings in Greater Cairo	**TOPIC:** People Aspects **SESSION:** Human Factors **ABSTRACT NO:** 8.6

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1 INTRODUCTION

The railroad-crossing environment in many countries of the developing world is known to be relatively unsafe, and uncomfortable. Several factors contribute to this situation. Some are related to the unsatisfactory design and layout of such crossings, and their associated control systems. Other problems are related to the condition of crossing vehicles. Most importantly, there is a general trend among drivers and pedestrians of violation and non-compliance with traffic rules and regulations. The situation is further aggravated by a deficiency in traffic legislation and a lack of serious management and enforcement.

This paper starts by presenting an overall analysis of railroad safety in Egypt. The railway network in Egypt consists of 43 lines/segments, with a total length of approximately 44000 kilometers contributing to the yearly transport of approximately 1090 million passengers in addition to the transport of about 13 million tons of freight between the different regions in Egypt. Official statistics classify train accidents in Egypt into 5 main classifications including train collisions/insertions, train derailment, train vehicle separation, train fires, and train collisions with other vehicles (including collisions at railroad grade crossings). A generic conceptualization of factors affecting safety of railroad grade crossings is presented. This is followed by a classification of the different types of railroad grade crossings in Egypt, where layers of hierarchical classifications were identified including formal versus informal crossings, public or private crossings, active (i.e. protected) crossings versus passive (i.e. unprotected crossings), etc. This is followed by assessing the safety features for four selected railroad grade crossings in Greater Cairo.

Probabilistic safety models are then developed, where accidents occurring at railroad grade intersections are defined as an outcome of a collision between a train and a vehicle(s) or a collision between a train and a pedestrian(s). Accidents could occur either as a result of violating crossing vehicles (pedestrians) or as a result of other factors. In this context, the relationship describing accidents as being a function of exposure multiplied by propensity is developed for accidents at railroad grade crossings. A program of traffic data collection was conducted for the four selected railroad grade crossings in Greater Cairo. This program covered four types of traffic flow data, namely crossing vehicles, crossing pedestrians, violating vehicles and violating pedestrians.

The research goes on to develop statistical models that relate crossing safety at railroad crossings, represented by the potentiality of accident occurrence, to exposure parameters such as vehicle and pedestrian flows. The potentiality of accident occurrence is being expressed in terms of crossing violations whether vehicle and/or pedestrian violations. Five functional forms were utilized, namely the linear, power, logarithmic, exponential and quadratic polynomial. To establish the goodness of fit and statistical significance of the calibrated models two statistical indicators were computed, namely the R^2 and the F-statistic. A total of 50 statistical models were calibrated. The power function was the most dominant function. Based on the above safety assessment and modelling, a review of the literature as well as on the experience of the authors, the paper concludes by proposing a package of countermeasures that is meant to improve the traffic safety conditions at railroad grade crossings in Greater Cairo. Policies and measures constituting such package are classified under ten categories, namely organizational, education, training, mass-media, train related, evaluation, engineering and maintenance, regulatory, enforcement, and intelligent transport systems.

2 ANALYSIS OF RAILROAD ACCIDENTS IN EGYPT

Under the Egyptian Ministry of Transport, the Egyptian National Railways (ENR) represents the official body responsible for providing intercity rail infrastructure and services for both passengers and freight trips. Its main activities include planning, construction, upgrading, maintenance, operation, and safety works, etc. for rail tracks and bridges all over the Egyptian rail network. The rail network of ENR consists of lines/segments, with a total length of approximately 4900 kilometers, see EMT, 2001. The rail track is classified into three classes in accordance with train speeds and/or passing tonnage.

In addition, ENR is responsible for the procurement/production of rail rolling stock, its operation and maintenance. In recent years, new locomotives entered the service, and air-conditioned passenger cars were renewed in the ENR workshops. This resulted in an increase of capacities, contributing to the transport of approximately 2300 thousand passengers per day in addition to about 11 million ton of freight per year between the different cities in Egypt. Five commodities account for 80% of all ENR freight volume, namely petroleum products, phosphate, iron ore, coal and coke and wheat. The control on the movement of trains was also enhanced by introducing automatic and central control systems, which led to the improvement of operation procedures and safety records. Operating revenues are still barely covering the operating costs. To improve this situation, there are directions to concession several passenger and freight services to the private sector.

In accordance with ENR classification of accidents, table 1 depicts the number of accidents and their percentage for the years 82/83 to 94/95. This 13-year period does not include accident data for the years 85/86, 90/91 and 91/92. During these three years, no official reports were published by ENR that displayed the accident situation in a similar manner as the other years. Despite that data for these years could be obtained from other sources, fear of comparative inconsistency presented an obstacle for doing so. The table shows train accidents classified into 5 classifications and 10 sub-classifications as follows:

a) Train Collisions/Insertions (passenger or freight trains)
b) Train Derailment (passenger or freight trains)
c) Train Vehicle Separation (passenger or freight trains)
d) Train Fires (locomotives, passenger or freight trains)
e) Train collisions with other vehicles (i.e. mainly collisions at railroad grade crossings)

Several insights and conclusions can be drawn from table 1. For nine years of the analysis period, derailment accidents involving freight trains were the most frequently occurring accidents. This is followed by either accidents involving vehicle separation from the trains or accidents involving train collisions with other vehicles. During the year 94/95 the situation changed, where the frequency of accidents involving train collisions with other vehicles reached its highest values in relative terms i.e. 172 accidents with a percentage contribution of 54%. On the other hand, the frequency of accidents involving train derailment reached its lowest values in relative terms i.e. 101 accidents with a percentage contribution of 32%.

Total numbers of accidents categorized in accordance with passenger versus freight trains versus locomotives are displayed in table 2. The table shows that the frequencies of freight train accidents are the highest for all of the considered years of the analysis except for 86/87 where passenger train accidents were higher and for the year 94/95 where locomotive related accidents were also the highest.

This supports the previous conclusion that accidents involving train-vehicle collisions are increasing, where mainly these accidents take place at railroad grade crossings. The table also shows an overall decrease in the number of train accidents over the years with a significant reduction of around 51% over the 10-year period spanning from 84/85 to 94/95. The table shows the difficulty of identifying a rising or a falling trend in the frequency of injuries. However, for the frequency of fatalities the table depicts a significant reduction of almost 89% over the same 10 years period. Another significant reduction can be noted in the frequency of casualties, which fell by about 52% over the 10 years period.

2.1 Safety Indicators of Railroad in Egypt

Absolute numbers of traffic accidents do not represent indicative figures to be used for assessment and comparison of traffic safety. In this context, a total of 9 traffic safety indicators were computed for each of the years for which accident data is available, see table 3. Four of these indicators are indicative of the risk of accident occurrence and the other five are indicative of the severity of accidents. To overcome the randomness associated with accidents' occurrence, it is commonly accepted to compute such indicators over a period of at least 3 to 5 years. Thus, the 9 indicators were aggregated over two time periods, see table 3:

a) Period 1: spanning from 87/88 to 89/90
b) Period 2: spanning from 92/93 to 94/95

Three of the computed risk indicators showed significant reductions over the two time periods selected for comparison. The biggest reduction was in the fatalities per million train-kilometer, which dropped from 1.27 to 0.23 with a percentage decrease of 82%. Similarly, reductions of 45% in accidents per million train-kilometers and 36% in casualties per million train-kilometers were also noted. On the other hand a slight increase of 3% in injuries per million train-kilometers was noted.

As for the other five severity indicators, the table shows reductions in fatality related indicators where fatalities per accidents and fatalities per casualties reduced by more than 67% and 72% respectively. As for injury related indicators,

Table 1: Trends of Accidents by Type for the Railway Network in Egypt

Year	Train Collisions/Insertions			Train Derailment			Train Vehicle Separation			Train Fires				Train Collisions With Other Vehicles (%)
	Passenger Trains	Freight Trains	Total (%)	Pass. Trains	Freight Trains	Total (%)	Pass. Trains	Freight Trains	Total (%)	Locomotives	Pass. Trains	Freight Trains	Total (%)	
82/83	45	10	55 (7)	117	396	513 (65)	0	0	0 (0)	17	24	54	95 (12)	130 (16)
83/84	17	16	33 (4)	125	272	397 (53)	0	157	157 (21)	17	9	23	49 (7)	115 (15)
84/85	19	16	35 (5)	74	188	262 (40)	0	167	167 (25)	14	13	42	69 (11)	124 (19)
85/86	N.R.	N.R.	N.R.	N.R.	N.R.	N.R.	N.R.	N.R.	N.R.	N.R.	N.R.	N.R.	N.R.	N.R.
86/87	3	7	10 (2)	75	109	184 (45)	84	0	84 (21)	5	0	0	5 (1)	122 (30)
87/88	0	9	9 (2)	72	107	179 (38)	75	70	145 (31)	1	0	0	1 (0.2)	132 (28)
88/89	2	8	10 (3)	64	108	172 (46)	42	63	105 (28)	0	1	1	2 (1)	84 (23)
89/90	3	5	8 (2)	63	101	164 (43)	42	65	107 (28)	2	0	0	2 (1)	102 (27)
90/91	N.R.	N.R.	N.R.	N.R.	N.R.	N.R.	N.R.	N.R.	N.R.	N.R.	N.R.	N.R.	N.R.	N.R.
91/92	N.R.	N.R.	N.R.	N.R.	N.R.	N.R.	N.R.	N.R.	N.R.	N.R.	N.R.	N.R.	N.R.	N.R.
92/93	3	2	5 (2)	41	61	102 (47)	0	44	44 (20)	4	2	0	6 (3)	61 (28)
93/94	0	0	0 (0)	21	67	88 (43)	2	48	50 (24)	2	2	0	4 (2)	64 (31)
94/95	3	1	4 (1)	46	55	101 (32)	9	29	38 (12)	2	3	0	5 (2)	172 (54)

Table 2: Frequencies of Passenger, Freight and Locomotive Related Accidents, Injuries, Fatalities & Casualties

Year	Passenger Train Accidents (%)	Freight Train Accidents (%)	Locomotive Related Accidents (%)	Total Train Accidents	Injuries by Type		Total Injuries	Fatalities by Type		Total Fatalities	Casualty by Type		Total Casualty
					Public	ENR Workers		Public	ENR Workers		Public	ENR Workers	
82/83	186 (23)	460 (58)	147 (19)	793	189	32	221	221	11	232	410	43	453
83/84	151 (20)	468 (62)	132 (18)	751	151	32	183	138	9	147	289	41	330
84/85	106 (16)	413 (63)	138 (21)	657	69	28	97	148	6	154	217	34	251
85/86	N.R.	N.R.	N.R.	N.R.	N.R.	N.R.	N.R.	N.R.	N.R.	N.R.	N.R.	N.R.	N.R.
86/87	162 (40)	116 (29)	127 (31)	405	38	25	63	74	8	82	112	33	145
87/88	147 (32)	186 (40)	133 (29)	466	29	12	41	44	2	46	73	14	87
88/89	109 (29)	180 (48)	84 (23)	373	27	11	38	34	3	37	61	14	75
89/90	110 (29)	171 (45)	102 (27)	383	113	7	120	79	4	83	192	11	203
90/91	N.R.	N.R.	N.R.	N.R.	N.R.	N.R.	N.R.	N.R.	N.R.	N.R.	N.R.	N.R.	N.R.
91/92	N.R.	N.R.	N.R.	N.R.	N.R.	N.R.	N.R.	N.R.	N.R.	N.R.	N.R.	N.R.	N.R.
92/93	46 (21)	107 (49)	65 (30)	218	51	0	51	6	0	6	57	0	57
93/94	25 (12)	115 (56)	66 (32)	206	75	0	75	10	0	10	85	0	85
94/95	61 (19)	85 (27)	174 (54)	320	103	0	103	17	0	17	120	0	120

Source: ENR Annual Reports 87/88, 88/89, 89/90, 93/94, 94/95
N.R. = Not Reported

Table 3: Accident Risk and Severity Indicators for the Railway Network in Egypt

Years	Train-Km in Millions	Accident and Severity Risk Indicators				Accident and Casualty Based Severity Indicators				
		Accidents per Million Train. Km	Injuries per Million Train. Km	Fatalities per Million Train. Km	Casualties per Million Train. Km	Injuries per Accident	Fatalities per Accident	Casualties per Accident	Injuries per Casualty	Fatalities per Casualty
82/83	47959129	16.53	4.61	4.84	9.45	0.28	0.29	0.57	0.49	0.51
83/84	50967196	14.73	3.59	2.88	6.47	0.24	0.20	0.44	0.55	0.45
84/85	51896892	12.66	1.87	2.97	4.84	0.15	0.23	0.38	0.39	0.61
85/86										
86/87	44549434	9.09	1.41	1.84	3.25	0.16	0.20	0.36	0.43	0.57
87/88	45937323	10.14	0.89	1.00	1.89	0.09	0.10	0.19	0.47	0.53
88/89	42423582	8.79	0.90	0.87	1.77	0.10	0.10	0.20	0.51	0.49
89/90	42209816	9.07	2.84	1.97	4.81	0.31	0.22	0.53	0.59	0.41
87/88 to 89/90		9.36	1.52	1.27	2.80	0.16	0.14	0.30	0.55	0.45
90/91										
91/92										
92/93	47176647	4.62	1.08	0.13	1.21	0.23	0.03	0.26	0.89	0.11
93/94	49209532	4.19	1.52	0.20	1.73	0.36	0.05	0.41	0.88	0.12
94/95	49211425	6.50	2.09	0.35	2.44	0.32	0.05	0.38	0.86	0.14
92/93 to 94/95		5.11	1.57	0.23	1.80	0.31	0.04	0.35	0.87	0.13
%age change		–45.40%	3.20%	–82.17%	–35.63%	89.01%	–67.35%	17.90%	60.31%	–72.31%

significant increases were noted where injuries per accident rose from 0.16 to 0.31 (i.e. an increase of 89%), while injuries per casualties rose from 0.55 to 0.87 (i.e. an increase of 60%).

Furthermore, in an effort to compare safety levels between the road and the rail network in Egypt, table 4 shows values of three generic risk indicators for both networks. The indicators for the road network were obtained from IRF, 1998. These represent 1994 data. To ensure consistency in comparison, the indicators for the rail network were computed based on averaging of the two fiscal years 93/94 and 94/95, see ENRA, 1994 & 1995.

Table 4: Comparison of Safety Indicators for Road Versus Rail Network in Egypt

Safety Indicator	Road*	Rail**	Road Versus Rail
Accidents/million veh.km. (train.km.)	1.847	5.35	0.34
Injuries/million veh.km. (train.km.)	2.22	1.8	1.23
Fatalities/million veh.km. (train.km.)	0.441	0.25	1.76

* Accident rates for the road network in Egypt were obtained from (13)
** Accident rates for the rail network in Egypt were computed based on averaging of data obtained from (8) & (9).

As can be noted from the table that the rate of occurrence of an accident per million train km. is 1.9 times higher than the rate of occurrence of an accident per million vehicle-kilometer. On the other hand the situation is reversed when it comes to the rate of an injury per million train km. being 0.23 times lower than the rate of an injury per million vehicle-kilometer. The same applies for the rate of a fatality per million train-kilometer being 0.76 times lower than the rate of a fatality per million vehicle-kilometer.

Caution must be used in drawing absolute conclusions about the relative safety between the road and rail networks in Egypt because of errors expected in definitions, data collection and compilation procedures as well as in the estimation of vehicle-kilometers versus train kilometers. Still, this analysis shows that while the safety situation in terms of rate (risk) of accidents occurrence is better for the road network, however the rate (risk) of being injured or killed in a road accident is higher than for a rail accident.

3 CONCEPTUALIZATION OF SAFETY AT RAILROAD GRADE CROSSINGS

In the previous section, collisions of trains with other vehicles were identified as the most dominant accident type in 94/95. In this section, a generic conceptualization of factors affecting the safety at railroad grade crossings is thought, see figure 1. At least 14 factors were identified. These include crossing vehicles, passing trains, approaching sections of road, railtrack, trains' drivers, vehicles' drivers, crossing pedestrians, manning of railroad crossings, type of railroad crossing, train detection system, message transmission system, control system, land use in the vicinity, legislation, levels of enforcement as well as other environmental factors.

Vehicle related factors include the intensity of crossing flows, as it is expected that the higher the crossing flows the more is the propensity for an accident to occur. The type of crossing vehicles is also important. Occasionally vehicles can get stranded over the rail as a result of their physical condition in terms of low deck, long body or slow moving vehicles such as animal drawn carts that are still allowed in some developing countries. In addition, vehicles carrying protruded or heavy cargo take longer times to fully cross the railroad grade crossings. This increases their vulnerability in being involved in crossing accidents. Similar reasoning applies to train related factors, i.e. the higher the numbers of passing trains the more is the propensity for an accident to occur. The type, condition and loading of passing trains all play important roles in determining the speeds of passing trains and consequently the momentum of eventual collisions.

Road related factors include the geometric of railroad approaches, specifically the alignment, sight distance, crossing angle, storage space and the physical layout of the crossing vicinity, all affecting the visibility and maneuverability of crossing drivers. Similar considerations for the rail track are applicable. Users of railroad crossings include drivers of crossing vehicles, crossing pedestrians, train drivers and personnel responsible for manning the railroad grade crossing. Issues of behaviour, attitude, skills, familiarity, expectations, experience, education and training of those involved are detrimental to the safety of railroad crossings. A literature review on driver behaviour at rail-highway grade crossings in the US was reported by Lerner and Ratte, 1996.

The type of railroad crossing is an important factor where different railroad crossings include different train detection, message transmission and control systems. In the next section a detailed classification of railroad crossing types will be presented. Three other factors are also detrimental to the safety of railroad crossings. The first is type of land use in the vicinity of the crossing, as different land uses entail different levels of crossing volumes and different composition of crossing traffic and pedestrians. In addition, traffic legislation with regards to crossing violations and the level of

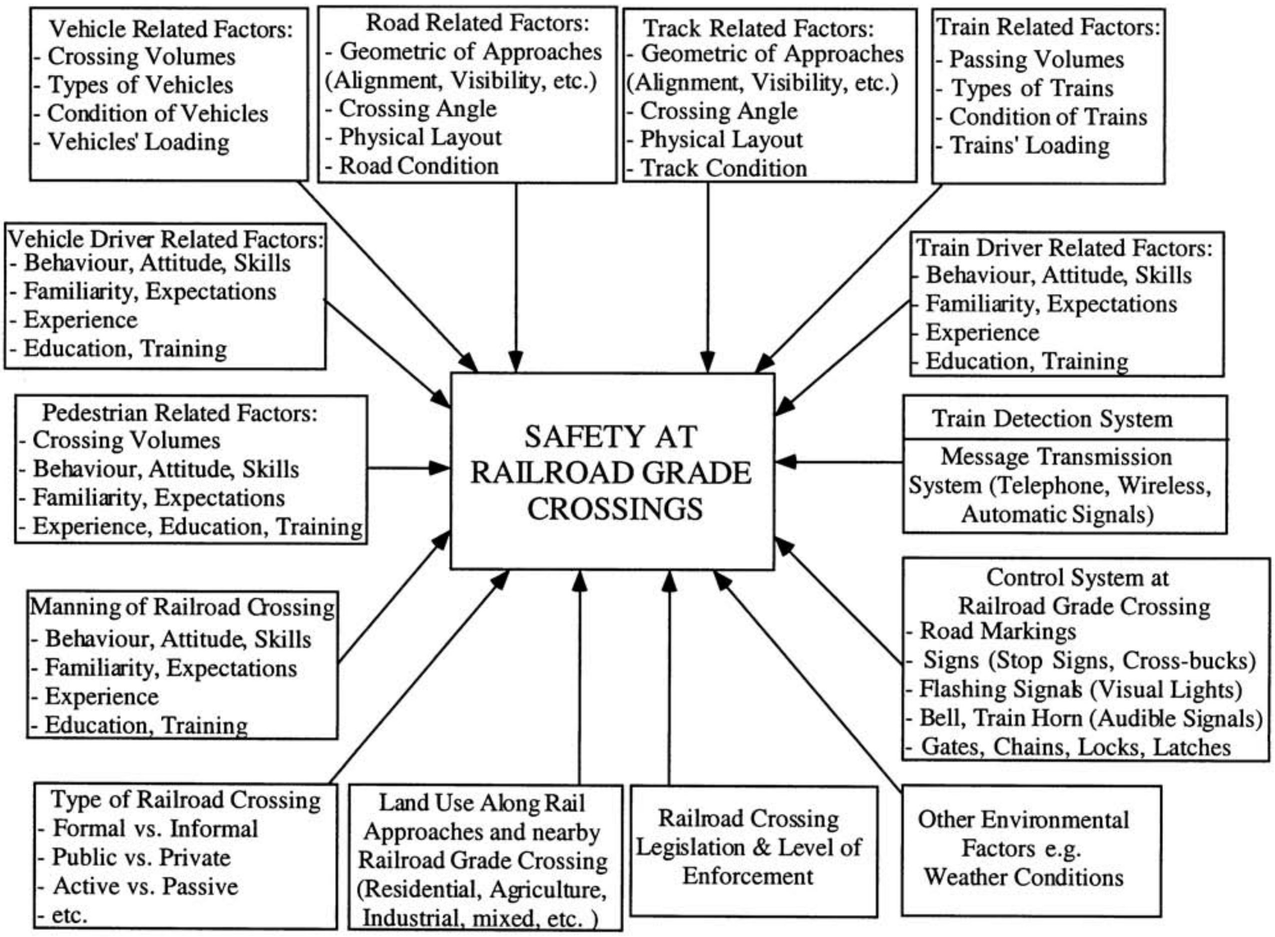

Figure 1: Conceptualization of Factors Affecting Safety at Railroad Grade Crossings

enforcement are important in providing disincentives for violators. Finally, other environmental factors including weather conditions such as fog or rain can hinder the visibility at railroad grade crossings.

4 TYPES OF RAILROAD GRADE CROSSINGS IN EGYPT

In this section, a classification of the different types of railroad grade crossings in Egypt is presented. This is depicted in figure 2. The figure shows five layers of hierarchical classifications.

The first is formal versus informal crossings. Formal crossings are those, which are officially recognized by ENR. Informal crossings are those crossings, which citizens have illegally opened by demolishing parts of track barriers. Usually this takes place in residential areas that are physically divided by the railway or in areas where residences are on one side of the rail and work locations are on the other side of the rail. These informal crossings are more common in urban areas in Egypt. A large number exists in the vicinities of Greater Cairo. ENR is exerting a lot of effort in trying to close these informal crossings or alternatively transferring these to formal ones.

The second layer of classification is to categorize formal crossings as either public or private crossings. Public crossings are constructed, operated and maintained by ENR. Private crossings are constructed, operated, and maintained by a private entity that the railtrack passes its premises. Examples include the big steel and sugar companies that own and operate railtrack for transporting their raw materials and/or products. While any public crossing is required to have warning signs and pavement markings, private crossings are not. The common cross buck is the basic warning sign required at all public crossings. Other warning signs include the round advance warning sign, and the stop or yield sign. Public crossings are further classified into active (i.e. protected) crossings versus passive (i.e. unprotected crossings). Active crossings have additional safety features. These include automatically or manually activated flashing lights or flashing lights in combination with gates.

Passive crossings range from being a footpath or a completely opened crossing to a manually operated crossing. In order to transfer a crossing from being passive to active, a number of factors have to be examined. These include, the crossing traffic volumes, the traffic mix, the number of passing trains and the accident or violation history of the crossing.

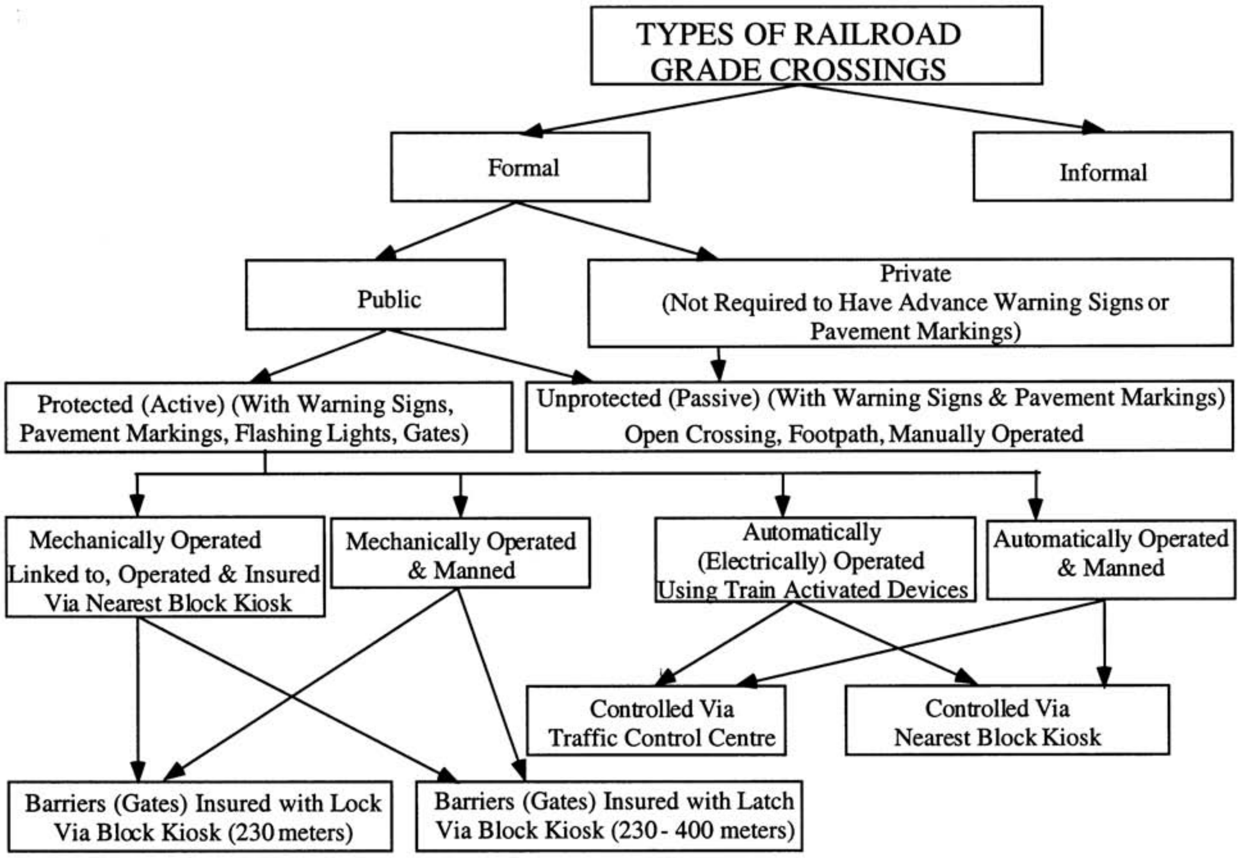

Figure 2: Classification of Railroad Grade Crossings in Egypt

In terms of operation of the flashing lights and the gates, active crossings can be classified into:

a) Mechanically operated devices, which are linked to, operated and insured via the nearest block kiosk.
b) Mechanically operated devices that are manned. Most mechanically operated public crossings in Egypt are 24 hours manned with the responsibility of ensuring gate or chain closing.
c) Automatically (electrically) operated devices. These are electrical circuits located on the rail track at predetermined distances from the crossings and activated by the passage of trains.
d) Automatically operated that is manned. Most electrically operated public crossings in Egypt are 24 hours manned with the responsibility of ensuring gate or chain closing.

5 ASSESMENT OF SAFETY FEATURES FOR SELECTED RAILROAD GRADE CROSSINGS IN GREATER CAIRO

In this section an assessment of safety conditions for four railroad grade crossings in Greater Cairo, namely Ain Shams, Sharkawia, Waborat, Bashteel is conducted. This is achieved through developing a set of features that can be used in qualitatively assessing safety at railroad grade crossings, see table 5. Reviewing table 5, an overall assessment in terms of crossing safety, could lead to conclude that Waborat is the worst of the four in relative terms. At this crossing, high volumes in terms of passing trains, crossing vehicles and pedestrians are being witnessed.

In addition, volumes of vehicle and pedestrian violations at this crossing are also high. Some essential safety features are missing including physical barriers such as chains, and no ENR manning. Waborat crossing is also located in a densely populated area. The crossing traffic composition contains a significant number of animal drawn carts. In addition a number of para-transit minibuses stop at or in the vicinity of the crossing to allow passengers to board and alight. Looking at similar features for the other crossings, it can be concluded that the safety situation at Bashteel is also unfavorable. This is followed, in relative terms, by Ain Shams and then Sharkawia. The average values, over the four crossings, for hourly crossings of vehicles and pedestrians are 907 veh./hr. and 540 ped./hr. respectively. As for violations, these values are 103 veh./hr. (i.e. 11.4%) and 134 ped./hr. (i.e. 24.8%). These values demonstrate the dominance of pedestrian violations as a result of the four crossings being located in highly populated urban or semi-urban areas with low affluence and high pedestrian activities.

Table 5: Features of Four Selected Railroad Grade Crossings in Greater Cairo

Railroad Grade Crossing Features	Ain Shams	Sharkawia	Waborat	Bashteel
Governorate (*)	Cairo	Qualibia	Cairo	Giza
Line Name	Ain Shams-Suez	Cairo-Alexandria	Rail Yard	Cairo-Ittai Barood
No. of Crossings on Line	10	16	1	21
Type	Public, Active	Public, Active	Public, Active	Public, Active
Type of Control	Mechanical Via Nearest Block Kiosk	Automatic Via Traffic Control Center	Mechanical Via Nearest Block Kiosk	Automatic Via Nearest Block Kiosk
Surrounding Land Use	Residential & Commercial (High Density)	Rural	Residential (High Density)	Commercial & Residential (Medium Density)
Intersecting/Parallel Roads	Main Collector/ Distributor	Cairo-Alex. Rural Road	Collector/Distributor	Collector/Distributor
Crossing Vehicles (**) (Average Vehicles/ Hour)	High Vol. (1932 veh./hr)	Low Vol. (162 veh./hr.)	Medium Vol. (559 veh./hr.)	High Vol. (976 veh./hr.)
Crossing Vehicles (**) (Standard Deviation)	414 veh./hr.	28 veh./hr.	158 veh./hr.	272 veh./hr.
Crossing Pedestrians (**) (Average Ped./Hour)	Medium Vol. (590 ped./hr.)	Low Vol. (194 ped./hr.)	High Vol. (913 ped./hr.)	Medium Vol. (463 ped./hr.)
Crossing Pedestrians (**) (Standard Deviation)	220 ped./hr.	83 ped./hr.	413 ped./hr.	165 ped./hr.
Passing Trains	Medium volumes	High Volumes	High Volumes	Medium Volumes
Number of Railtracks	3	4	3	2
Railtrack Level	Second Class	First Class	Second Class	Second Class
Train Speeds	Low	Very High	Low	Low
Pavement markings	No	Yes	No	No
Warning signs	Yes (cross bucks/stop signs)	Yes (cross bucks/stop signs)	Yes (cross bucks/stop signs)	Yes (cross bucks/stop signs)
Warning Bell	Yes	Yes	Yes	Yes
Warning Flashing Signals	Yes	Yes	Yes	Yes
Barriers (Gates or Chains)	No	Yes, Chains	No	Yes, Chains
ENR Manned	No	Yes	No	Yes
Traffic Police Manned	No	Yes	Yes	No
Violating Vehicles (%) (Average Vehicles/ Hour)	Yes (9.5%) (183 veh./hr.)	Yes (14.1%) (23 veh./hr.)	Yes (16.8%) (94 veh./hr.)	Yes (10.2%) (100 veh./hr.)
Violating Vehicles (%) (Standard Deviation)	116 veh./hr.	12 veh./hr.	44 veh./hr.	35 veh./hr.
Violating Pedestrians (Average Pedestrians/ Hour)	Yes (17.5%) (103 ped./hr.)	Yes (37.9%) (74 ped./hr.)	Yes (27.3%) (249 ped./hr.)	Yes (23.6%) (109 ped./hr.)
Violating Pedestrians (Standard Deviation)	59 ped./hr.	34 ped./hr.	152 ped./hr.	71 ped./hr.
Emergency Features (***)		Danger Capsules		Danger Capsules
Slow Moving Vehicles	Few	No	Yes	Yes

(*) Greater Cairo region is composed of Cairo governorate and parts of Giza and Qualibia governorates
(**) Based on data collected in February 2000 within EASRT study. Maximum (Minimum) Observed Values = Mean (Average) + (–) Standard Deviation
(***) ENR manning personnel has danger capsules that can be used in case of emergency (such as vehicle stranded). The personnel would run towards the approaching train and put the capsule on the track. Once the train passes the capsule, a big explosion sounding is heard and the train driver is warned of a danger ahead.

6 DEVELOPMENT OF SAFETY PROXY MODELS FOR RAILROAD GRADE CROSSINGS IN GREATER CAIRO

The third objective of this research is to develop probabilistic and statistical models that relate safety at railroad grade crossings to exposure parameters such as vehicle and pedestrian flows. In this context, safety can be represented by the number of accidents or by the potentiality of accident occurrence as a result of vehicle and/or pedestrian crossing violations. Other studies used similar assumption where violations were considered because of the relatively low frequency of accidents at crossings, see Fitzpatrick et al., 1999. Several types of violations may occur such as drivers not slowing down when approaching grade crossings, not looking and being fully alert and attentive, trying to beat the train, not stopping for signs and signals, driving around a lowered cross gate arm or over a low level chain. In this research, a violation is defined as the non stoppage and the continuation of crossing of a vehicle or pedestrian from the moment the flashing lights signal and/or the bells sound to the moment the physical barriers (chains) are in place and/or the train passes.

6.1 Probabilistic Safety Models

Accidents occurring at railroad grade intersections are an outcome of a collision between a train and a vehicle(s) or a collision between a train and a pedestrian(s). In figure 3, a Venn diagram demonstrates that accidents are the result of the intersection of passing trains and crossing vehicles (pedestrians). Furthermore, the diagram illustrates that accidents could occur either as a result of violating crossing vehicles (pedestrians) or as a result of other factors. The diagram shows that not all violating vehicles (pedestrians) are involved in accidents. However, it helps in demonstrating that the probability of being involved in an accident is higher for violating drivers (pedestrians). In this context, the relationship of accidents being a function of exposure multiplied by propensity can be applied. This relationship can take the following form.

$$\text{Accidents} = \text{Exposure} * \text{Propensity} \quad (1)$$

Where:

Exposure is the number of opportunities an accident of a certain type can occur in a given location within a given period of time. Two measures of exposures are identified in the Venn diagram. The first is a function of the flow of Passing Trains

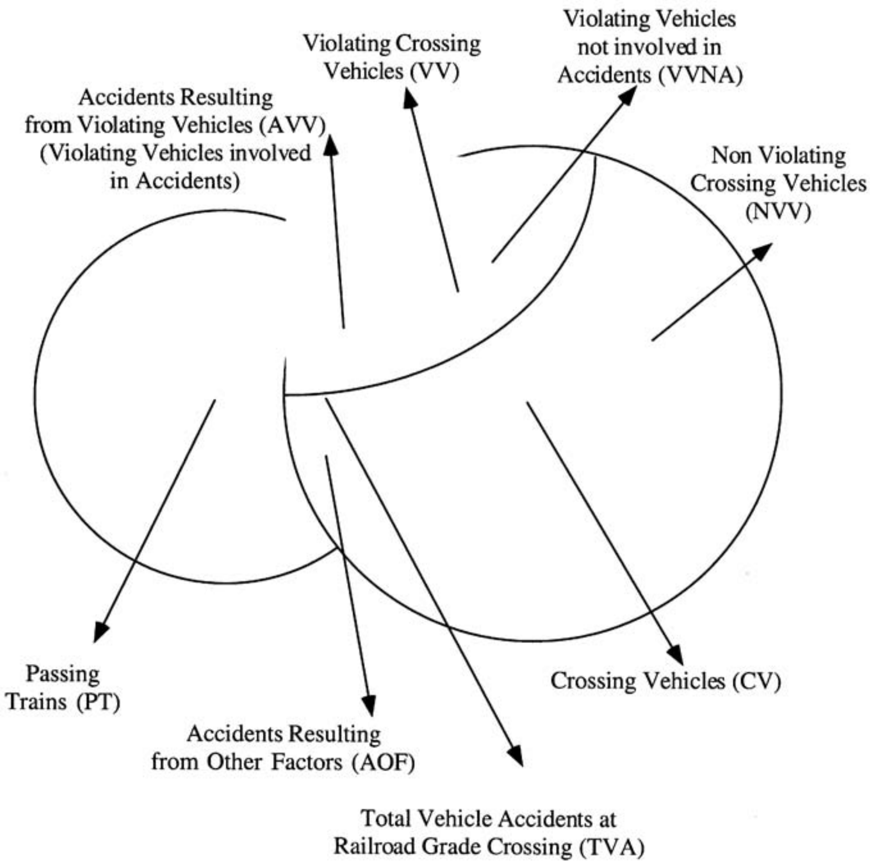

Figure 3: Venn Diagram Displaying Probabilities of Vehicle Violations and Accidents at Railroad Grade Crossings

(PT) and the flow of Crossing Vehicles (CV) (or crossing pedestrians). The second is a function of the flow of PT and the flow of Violating crossing Vehicles (VV) (or violating crossing pedestrians). The literature of accidents at road intersections contains several functional forms that take account of conflicting flows.

Some researchers used the sum of entering flows as a measure of exposure to intersection accidents, see Schaechterle et al., 1970 and Smith, 1970. Other researchers proposed the product of entering flows as a measure of exposure to accidents at road intersections. The most famous functional form was proposed by Tanner, 1953 as follows:

$A = C\,(V_1^{a}\,V_2^{b})$, where A is the number of accidents, V_1 and V_2 are the conflicting entering flows, C, a & b are calibration coefficients. In many studies, values of a & b were approximately 0.5, which suggests that the change in number of accidents is proportional to the change in flows, see Leong, 1973.

In this research, exposure to railroad crossing accidents is expressed as a function of the product of train and vehicle conflicting flows.

Propensity can be defined as the conditional probability that an accident occurs given the opportunity for occurring. Propensity can be expressed as an accident rate i.e. accidents per PT multiplied by CV, or accidents resulting from violating vehicles per PT multiplied by VV.

Using the Venn diagram and applying the above relationships, the following two equations, for the computation of Total Vehicle Accidents (TVA) and Accidents resulting from Violating Vehicles (AVV) at the crossing, can be deduced:

$$TVA = C(PT^{a}*CV^{b}) * [TVA/C(PT^{a}*CV^{b})] \quad (2)$$

$$AVV = C(PT^{a}*VV^{b}) * [AVV/C(PT^{a}*VV^{b})] \quad (3)$$

Additionally, using the Venn diagram and applying the rules of conditional probability, see Freund, 1971, the following probability models can be deduced.

$$P(TVA \backslash CV)\ 0= P(TVA \cap CV)/P(CV) \quad (4)$$

$$P(AVV \backslash VV) = P(AVV \cap VV)/P(VV) \quad (5)$$

$$P(TVA \backslash CV) = P(AVV/VV) + P(AOF_V) \quad (6)$$

Where AOF_V = Accidents, resulting from Other Factors, for Vehicles

$$P(AOF_V) = P(TVA \backslash CV) - P(AVV \backslash VV) = P(TVA \cap CV)/P(CV) - P(AVV \cap VV)/P(VV) \quad (7)$$

$$P(TVA) = \text{Total Number of Vehicle Accidents at Crossing/No. of Crossing Vehicles} \quad (8)$$

$$P(AVV) = \text{Accidents Resulting from Violating Vehicles/No. of Violating Vehicles} \quad (9)$$

$$P(VV) = \text{No. of Violating Vehicles/No. of Crossing Vehicles} \quad (10)$$

$$P(CV) = \text{No. of Crossing Vehicles at a given Railroad Crossing/Total No. of Crossing Vehicles at 3 Neighbouring Railroad Crossings Including the Given Crossing in the Middle} \quad (11)$$

Similar models can be deduced for pedestrians' accidents. Hence the probability of the total number of accidents at the railroad grade crossing can be expressed as follows:

$$P(TA) = P(TVA \backslash CV) + P(AOFV) + P(TPA \backslash CP) + P(AOF_P) \quad (12)$$

Where:

TA = Total Number of Accidents
TPA = Total Number of Pedestrian Accidents
CP = Crossing Pedestrians
AOF_P = Accidents, resulting from Other Factors, for Pedestrians

6.2 Development of Prediction Models for Vehicle and Pedestrian Violations at Railroad Grade Crossings in Greater Cairo

In the course of conducting the traffic safety assessment for the four selected railroad grade crossings in Greater Cairo, 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.

In an effort to research safety at railroad grade crossings, the Egyptian Academy of Scientific Research and Technology (EASRT) is currently financing a study looking at the relationship between accidents and traffic volumes at main road intersections and railroad grade crossings in Greater Cairo, see EASRT, 2000. In the course of this study, a program of data collection was conducted for six main railroad grade crossings in Greater Cairo. The ESART program of traffic data collection covered four types of traffic flow data.

a) Traffic flow by the hour of the survey
b) Violating traffic flow by the hour of the survey
c) Pedestrian flow by the hour of the survey
d) Violating pedestrian flow by the hour of the survey

Basically data was collected during the month of February 2000 over a week period and in some days over 24 or 16 or 12 hours duration. For details of these traffic surveys, see EASRT, 2000. As a result of unavailability of specific accident data at the selected railroad grade crossings, this paper suggests that numbers of violating vehicles and pedestrians be used as proxy for the potentiality of accidents occurrence. To serve this purpose, data collected within the ESART study was compiled and thoroughly examined and cleaned.

Cleaned data for four crossings is used in the calibration of safety models for the railroad grade crossings in Greater Cairo. These are meant to assist in:

a) predicting expected number of vehicle and pedestrian violations at railroad crossings in Greater Cairo,
b) providing forecasts to be used as proxies to perceive expected future safety levels at railroad grade crossings in Greater Cairo,
c) providing data on expected violation levels in case of lack or discontinuity of data collection programs,
d) devising, evaluating and monitoring safety initiatives, policies, measures, actions and programs that are meant to reduce the extent of crossing violations and hence of accidents.

Hourly data of traffic and violations, for the considered crossings, are utilized in the calibration of these predictive models. The developed models are based on an a-priori assumption that the number of hourly violations is a function of exposure measures taken here as hourly crossing flows. Five functional forms were utilized, namely the linear, power, logarithmic, exponential and quadratic polynomial, see table 6. To establish the goodness of fit and statistical significance of the calibrated models two statistics were computed, namely the R^2 and the F-statistic. The table shows all of the calibrated models. Those models producing the highest correlation values as well as significant F statistics are shaded.

A total of 60 statistical models were calibrated. These represent 25 models, using five different functional forms, expressing the relationship of vehicle violations to crossing vehicles for the 4 selected railroad grade crossings and a combination of the four. The other 25 models represent the relationship between pedestrian violations and crossing pedestrians for the 4 selected railroad grade crossings and a combination of the four. In an effort to produce two different vehicle violation models for two ranges of flows of crossing vehicles, another 10 models were calibrated.

As shown in table 6, not all models were significant. In cases where polynomial functions gave marginally better calibration results, the next significant functional form was advocated. This is meant to avoid the loss of an extra degree of freedom when using the quadratic polynomial function. In this context, the power function was the most dominant function, where 4 out of seven significant models followed this function. The other three significant models followed the linear function.

For Ain Shams and Bashteel railroad crossings, the calibrated models were judged to be statistically weak either as a result of very low R^2 (less than 0.4) or insignificant F values. Several conclusions can be deduced from these models:

a) The dispersion of data for Ain Shams and Bashteel railroad crossings is very high. Both crossings are physically characterized by wide two directional approaches. This allows a significant number of crossings (more than 900 vehicles/hour) as well as of violations to occur.
b) Data for both Sharakawia and Waborat railroad crossings produced good calibration results. Both crossings are physically characterized by narrow crossing width. This allows relatively low numbers of crossings (less than 900 vehicles/hour) and violations to occur.
c) For Sharakawia, both vehicle and pedestrian violation models followed the linear form.
d) For Waborat, both vehicle and pedestrian violation models followed the power form.
e) Models calibrated for pedestrian violations are statistically stronger than models calibrated for vehicle violations.
f) A statistically significant model was calibrated for vehicle violations occurring at crossing volumes below 900 vehicle/hour using data for the four considered railroad crossings. However, it was not possible to calibrate a statistically acceptable model for vehicle violations occurring at crossing volumes above 900 vehicle/hour using data for the four considered railroad crossings.

Table 6: Models for Predicting Vehicles' and Pedestrians' Violations at Railroad Grade Crossings in Greater Cairo

Rail-Road Crossing	Models Relating Violating Crossing Vehicles (VV) to Crossing Vehicles (CV)				
	Linear	Logarithmic	Quadratic	Power	Exponential
Ain Shams	Y=0.0641X+59.1224	Y=116.389LnX–694.47	$Y=-5E-05X^2+0.2632X-115.83$	$Y=0.1881X^{0.8886}$	$Y=60.3549e^{0.0005X}$
55 Observations	R^2=0.052, F=2.93, Insig.	R^2=0.065, F=3.71, Insig.	R^2=0.077, F=2.16, Insig.	R^2=0.138, F=8.51, Sig.	R^2=0.107, F=6.35, Sig.
Sharkawia	Y=0.3367X–31.732	Y=52.891LnX–245.519	$Y=0.00205X^2-0.3497X+23.98$	$Y=0.0001X^{2.3478}$	$Y=1.868e^{0.14566X}$
47 Observations	R^2=0.581, F=62.46, Sig.	R^2=0.548, F=54.48, Sig.	R^2=0.611, F=34.59, Sig.	R^2=0.53, F=49.83, Sig.	R^2=0.529, F=50.67, Sig.
Waborat	Y=0.1891X–11.911	Y=81.9183LnX–420.34	$Y=-2E-05X^2+0.2151X-18.235$	$Y=0.0448X^{1.1957}$	$Y=18.7923e^{0.0026X}$
64 Observations	R^2=0.449, F=50.44, Sig.	R^2=0.408, F=42.8, Sig.	R^2=0.449, F=24.85, Sig.	R^2=0.486, F=58.5, Sig.	R^2=0.481, F=57.6, Sig.
Bashteel	Y=0.0711X+30.4569	Y=57.4085LnX–292.81	$Y=3.4E-05X^2+0.0097X-56.16$	$Y=1.3132X^{0.6241}$	$Y=44.7628e^{0.0008X}$
12 Observations	R^2=0.305, F=4.38, Insig.	R^2=0.288, F=4.05, Insig.	R^2=0.311, F=2.03, Insig.	R^2=0.29, F=4.10, Insig.	R^2=0.296, F=4.2, Insig.
Four Crossings	Y=0.08202X+28.659	Y=65.708LnX–316.64	$Y=-3.4E-05X^2+0.165X+1.437$	$Y=0.315X^{0.84313}$	$Y=29.897e^{0.0009X}$
178 Observations	R^2=0.455, F=146.8, Sig.	R^2=0.483, F=164.2, Sig.	R^2=0.486, F=82.71, Sig.	R^2=0.719, F=449, Sig.	R^2=0.514, F=186, Sig.
0<CV/hr.<900	Y=0.1725X–5.348	Y=60.611LnX–287	$Y=-4.13E-05X^2+0.209X-10.95$	$Y=0.0479X^{1.183}$	$Y=12.44e^{0.003215X}$
	R^2=0.707, F=277.7, Sig.	R^2=0.687, F=251.9, Sig.	R^2=0.708, F=138.53, Sig.	R^2=0.775, F=395, Sig.	R^2=0.727, F=306, Sig.
CV/hr.>900	Y=0.0724X+41.1	Y=134.6LnX–833.46	$Y=-6.57E-05X^2+0.315X-170.8$	$Y=0.2217X^{0.867065}$	$Y=62.09e^{0.000466X}$
	R^2=0.08, F=5.162, Insig.	R^2=0.09, F=6.18, Insig.	R^2=0.11, F=3.59, Insig.	R^2=0.14, F=9.87, Insig.	R^2=0.12, F=8.14, Insig.
Rail-Road Crossing	**Models Relating Violating Crossing Pedestrians (VP) to Crossing Pedestrians (CP)**				
	Linear	Logarithmic	Quadratic	Power	Exponential
Ain Shams	Y=0.1138X+35.8312	Y=72.8498LnX–357.1	$Y=-0.0002X^2+0.3359X-33.08$	$Y=0.5082X^{0.817}$	$Y=42.1527e^{0.0013X}$
40 Observations	R^2=0.18, F=8.36, Sig.	R^2=0.204, F=9.74, Insig.	R^2=0.222, F=5.28, Sig.	R^2=0.275, F=14.4, Sig.	R^2=0.236, F=11.7, Sig.
Sharkawia	Y=0.3512X+5.4006	Y=57.4172LnX–223.47	$Y=0.0004X^2+0.1866X+20.48$	$Y=0.9833X^{0.8146}$	$Y=26.892e^{0.0047X}$
16 Observations	R^2=0.715, F=35.16, Sig.	R^2=0.618, F=22.68, Sig.	R^2=0.724, F=17.06, Sig.	R^2=0.68, F=29.93, Sig.	R^2=0.691, F=31.3, Sig.
Waborat	Y=0.2418X+28.5587	Y=198.852LnX–1083.3	$Y=-0.0002X^2+0.6651X-146.5$	$Y=0.1141X^{1.1136}$	$Y=64.3132e^{0.0012X}$
57 Observations	R^2=0.435, F=42.4, Sig.	R^2=0.456, F=46.19, Sig.	R^2=0.502, F=27.24, Sig.	R^2=0.584, F=77.2, Sig.	R^2=0.464, F=47.66, Sig.
Bashteel	Y=0.2X+16.7256	Y=100.982LnX–504.94	$Y=-0.0005X^2+0.6767X-95.87$	$Y=0.616X^{0.8238}$	$Y=44.9293e^{0.0016X}$
14 Observations	R^2=0.22, F=3.39, Insig.	R^2=0.236, F=3.72, Insig.	R^2=0.249, F=1.82, Insig.	R^2=0.217, F=3.3, Insig.	R^2=0.184, F=2.71, Insig.
Four Crossings	Y=0.2459X+0.6162	Y=134.189LnX–682.34	$Y=-4E-05X^2+0.313X-20.615$	$Y=0.5284X^{0.8629}$	$Y=46.95e^{0.0014X}$
127 Observations	R^2=0.534, F=143, Sig.	R^2=0.442, F=99.06, Sig.	R^2=0.537, F=71.89, Sig.	R^2=0.534, F=143, Sig.	R^2=0.534, F=143, Sig.

F test serves to test how well the regression model fits the data.
H_0 = There is no relationship between X and Y and that $R^2 = 0$ 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

7 A PROPOSED SAFETY ACTION PLAN

This research advocates the development of an action plan to improve the safety at railroad grade crossings in Egypt. This is guided by the research conclusions as well as by the American experience documented in USDOT, 1994a, 1995 & 1997. In the next subsections, a number of measures are identified, categorised and recommended as potential components of a proposed action plan for improving safety at railroad crossings in Egypt.

Organizational

Pro-active safety management is becoming increasingly popular as a means of preventing accidents and near accidents. In a study of an Australian public rail authority, organization-related problems (including training, communication, operating equipment, maintenance, staff attitude, supervision, working conditions, rules/procedures, staffing, management, housekeeping, equipment design, organisational policies) were identified as latent causes for failures, see Edkins and Pollock, 1996. Such problems are ingredients for unfavourable working environment, hence unsafe and faulty act that could possibly lead to the occurrence of incidents and/or accidents. In this context, this paper recommends the funding of research studies that would examine these factors within ENR and recommend on directions for improvements.

Education, Training & Mass Media

a) Educational and training materials emphasising safe behaviour at railroad grade crossings should be developed.
b) Drivers must be educated to stop within at least 4.5 meters from the nearest railtrack, to consider crossbucks as yield signs and to stop whenever signals are activated.
c) Train crews should be trained to always observe the following rules when approaching grade crossings:

   Ring the bell, and blow the whistle

   Keep the headlights on bright

   Proceed at speeds consistent with instructions for railroad grade crossings.

d) Reasons underlying crossing violations should be thoroughly investigated. These include poor perception of risk, overconfidence, previous hindsight, and inadequate information. Education, training and mass media campaigns should be tackling these.
e) Mass media campaigns targeting violators by demonstrating the disastrous consequences of violations should be developed. A recent study by Witte and Donohue, 2000, provided good examples of such mass media campaigns using real footage of train crashes or interviews with those involved or those left behind when loved ones died in crashes. Once accidents occur at a railroad grade crossing, the propensity of fatalities and serious injuries are extremely high in comparison to other types of accidents.
f) Other important messages include avoiding being stranded at the railtrack and if stranded leaving your vehicle immediately with all other passengers.

Train Related

a) Investigate the potentiality for improvement of train visibility especially at night times. Several types of lights are available including ditch lights, strobe lights and oscillating lights. Mounting retroreflective material on the sides of trains was investigated by Conti et al., 1999. Using such material, vehicle's headlights will illuminate the reflectors and make the train more conspicuous
b) Invest more in applying the Automatic Driver Control (ADC) System. This system forces trains to adhere to pre-specified speeds at certain locations such as railroad grade crossings.
c) Train drivers to be closely monitored so as to ensure their use of whistle bans or horns when approaching grade crossings. Horns to be located in a position that is most advantageous for broadcasting toward the direction of travel. The sound levels resulting from inside of the car and the surrounding environment can be very high that it negates the sound levels produced by train warning horns. Train horns should be able to produce sound levels of at least 110 dBA.

Evaluation

a) Conduct feasibility studies to look at the potentialities of either complete closure of some railroad grade crossings (in case lightly used) or in case heavily used looking for alternatives in terms of construction of overpasses or underpasses. Such studies should assess potential benefits and costs resulting from closure of crossings or construction of grade separations. Several factors should be considered in such assessments including crossing volumes, violations, accidents, neighbouring crossing traffic, etc. see USDOT, 1994b for the US experience with this issue. In this context, the obtained models for predicting the number of violations at railroads in Greater Cairo can be used in assessing safety disbenefits resulting from continuing to keep those crossings with high violations opened.

b) Develop continuous safety management programme at railroad grade crossings. Such program would include standardised accident and violation reporting system, data management and analysis, proposal of remedial measures, pre and post evaluation of efficiency and effectiveness of such measures and finally monitoring and feedback.

Engineering and Maintenance

a) The physical layout of crossings should be improved, by removing any sight obstructions, repainting road markings for approaching road arms, and reducing approaching curves, etc.
b) Construct median barriers for the two approaching roads so as to prevent violators from going around the gates or obstructing flows of the other direction.
c) Invest in using more wireless communication between control centres, train crews and manning crew at rail grade crossings.
d) Invest more in adding flashing signals and gates (or chains) to all passive crossings, transferring these to active crossings. Gates and chains are particularly important as several studies have demonstrated the potentialities of reducing violations as a result of gate introduction. In the Netherlands, it was reported that 820 flashers-only crossings account for 60% of train vehicle collisions, while 750 crossings protected with half barrier gates account for 30% despite higher traffic values, see Tenkink and Van der Horst, 1990. Another relatively recent study in the USA reported that the addition of gates significantly reduced the percentage of drivers crossing in front of trains from 67% to 38%, see Meeker and Weber, 1997.
e) Improve visibility and conspicuity of the cross buck through continuous maintenance and optimum selection of location. Visibility can be affected by such things as trees, vegetation, buildings, earth embankments, and rail cars.
f) Develop or adapt international standards for the design of road approaches to the crossing. Design issues include horizontal and vertical curves, sight distances and signal systems. For a review of available US standards, see Heathington and Hensley, 1999. In the US, several guidelines for the design of grade crossing are utilized. These include.

Railroad-Highway Grade Crossing Handbook by Federal Highway Administration (FHWA)

Manual for Railway Engineering by American Railway Engineering and Maintenance of Way Association (AREMA)

Railroad-Highway Grade Crossing Handbook by FHWA

A Policy on Geometric Design of Highways and Streets by the American Association of State Highway and Transportation Officials (AASHTO)

Manual on Uniform Traffic Control Devices by FHWA

Regulations and Enforcement

a) Regulations of other countries should be reviewed with the purpose of updating the existing regulations. For a thorough review of regulations on matters affecting rail highway crossings in the USA, see USDOT, 1983.
b) Police officers should be given more authority to inflict on spot penalties on violators. What is needed is to instigate a feeling among drivers in general and particularly among violators of the seriousness of the enforcement of traffic laws.
c) Automated enforcement equipment using mounted video cameras can be used at crossings to record violations, identify the license plate and owner of vehicle.
d) Inflicting heavy fines and penalties on violators and requesting driver retraining for violators.

Intelligent Transport Systems (ITS)

- ITS sensing and communication technologies offer a range of choices for remote sensing and the advanced detection of approaching trains at high speeds, for activation of grade crossing and warning systems, and for simultaneous communication with highway vehicles approaching grade crossings.
- ITS advances in collision avoidance offer a range of products suitable for the advanced detection of incidental barriers to the rail right of way at grade crossings and for the automatic initiation of control measures to warn, avoid, or minimize collisions.

It has to be noted that such ITS measures are to be considered over a long term transport plan that would assess the potentiality of including ITS applications in the various fields of the transport sector in Egypt.

8 SUMMARY AND CONCLUSIONS

In achieving the main research objectives, several conclusions were reached. For nine years of the period spanning from 82/83 to 93/94, derailment accidents involving freight trains proved to be the most frequently occurring accidents. During 94/95 the situation changed, where the frequency of accidents involving train collisions with other vehicles reached its highest values in relative terms i.e. 172 accidents with a percentage contribution of 54%. The frequencies of accidents involving freight trains are the highest for most of the years of the analysis.

An overall decrease in the number of train accidents was noted with a significant reduction of around 51% over the 10-year period spanning from 84/85 to 94/95. The frequency of fatalities also showed a significant reduction of almost 89% over the 10 years period 84/85 to 94/95. Fatalities per million train-kilometer dropped from 1.27 to 0.23 with a percentage decrease of 82%. Similarly, reductions of 45% in accidents per million train-kilometer and 36% in casualties per million train-kilometer were noted. On the other hand a slight increase of 3% in injuries per million train kilometer was identified.

As for severity indicators, the analysis showed that fatalities per accidents and fatalities per casualties reduced by 67% and 72% respectively. On the other hand, injuries per accident rose from 0.16 to 0.31 (i.e. an increase of 89%), while injuries per casualties rose from 0.55 to 0.87 (i.e. an increase of 60%). Comparing road and rail safety in Egypt showed that the rate of occurrence of an accident per million train-kilometer is 1.9 times higher than the rate of an accident per million vehicle-kilometer. On the other hand the situation is reversed when it comes to the rate of an injury per million train-kilometer being 0.23 times lower than the rate of an injury per million vehicle-kilometer. The same applies for the rate of a fatality per million train-kilometer. being 0.76 times lower than the rate of a fatality per million vehicle-kilometer.

Waborat railroad grade crossing was judged, in relative terms, to be the worst crossing in terms of safety features, passing and crossing volumes and violations. The safety situation at Bashteel is also unfavorable. This is followed, in relative terms, by Ain Shams and then Sharkawia.

The average values, over the four crossings, for hourly crossings of vehicles and pedestrians are 907 veh./hr. and 540 ped./hr. respectively. As for violations, these are 103 veh./hr. (i.e. 11.4%) and 134 ped./hr. i.e. 24.8%). These values demonstrate the dominance of pedestrian violations.

The research developed probabilistic and statistical models that related crossing safety represented by the potentiality of accident occurrence at railroad crossings to traffic volume parameters such as vehicle and pedestrian flows. As a result of lack of specific accident data at the selected railroad grade crossings, a proxy of the potentiality of accidents occurrence was expressed in terms of the numbers of violating vehicles and/or pedestrians.

A Venn diagram was used to demonstrate that accidents are the result of the intersection of passing trains and crossing vehicles (pedestrians). Furthermore, the diagram illustrated that accidents could occur either as a result of violating crossing vehicles (pedestrians) or as a result of other factors. Additionally, the Venn diagram was used in combination with the rules of conditional probability to deduce a set of explanatory probability models.

Hourly data of traffic and violations for the considered crossings, was utilized in the calibration of a set of statistical predictive models. The developed models are based on an a-priori assumption that the number of hourly violations is a function of exposure measures taken here as hourly crossing flows. Five functional forms were utilized, namely the linear, power, logarithmic, exponential and quadratic polynomial. In this context, 7 models proved significant of which four was based on using the power function and the other 3 followed the linear form. Finally, the paper concluded by a package of proposed countermeasures that is thought to improve the traffic safety conditions at railroad grade crossings in Egypt.

ACKNOWLEDGEMENT

Data used for the calibration of the statistical models proposed in this paper was obtained from a current study entitled: Relationship between Accidents and Traffic Volumes at Main Road Intersections as well as at Rail Road Grade Crossings in Greater Cairo. This study is conducted for the Egyptian Academy of Scientific Research and Technology by Transport and Traffic Research Unit-Faculty of Engineering-Ain Shams University.

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