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An analysis of Malaysia road traffic death distribution by road environment

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Abstract. Various initiatives, strategies and programmes have been taken by the Government of Malaysia to resolve issues pertaining to road traffic deaths. Nevertheless, the implementation of the programmes outlined in Malaysian Road Safety Plan 2006 needs to be enhanced in order to achieve the set targets. In this regard, it is imperative for all parties concerning road safety to determine the factors that significantly contribute to road traffic deaths. According to the Ministry of Works, Malaysia, the blackspot treatment programme (which is centred on the elimination of road hazards by engineering approaches) is successful in reducing the number of injuries due to road traffic accidents up to a certain extent. This study is focussed on analysing road traffic deaths caused by various road environment elements recorded by the police from 2000 to 2011 in order to determine their distribution, proportion and relationship with fatal accidents. The Chi-square test and Marascuilo procedure with 5% level of significance are used in this study. Based on locality, the number of road traffic deaths in rural area (66%) is significantly higher compared with that in urban areas (34%). Based on road category, the number of road traffic deaths is the highest for federal roads, whereas the highest rate of fatalities per kilometre is recorded for expressways. Based on road segment, the number of road traffic deaths is the highest for straight road segments, followed by bends. In addition, the number of road traffic deaths is the highest for Y/T junctions, followed by cross junctions. The lowest number of road traffic deaths is recorded for interchanges and roundabouts. The results show that only 11.25% of the total road traffic deaths are related to road defects. The highest proportion of deaths due to road defects (48.6%) is associated with lack of street lighting provision, whereas road shoulder edge drop-off and potholes contribute 15.4% and 11.2% of road traffic deaths, respectively.

Keywords. Road traffic deaths; fatalities rate; deaths distribution; road environment; Malaysia.

1. Background

In 2012, 6,917 people were killed due to road traffic accidents in Malaysia. This country has the highest rate of road traffic fatalities per 100,000 population among all ASEAN countries in 2007. In fact, road traffic accidents were the fifth leading cause of certified deaths in 2008 [8]. Road traffic deaths cost the nation roughly USD 2.75 billion in 2011 based on a loss of MYR 1.2 million (USD 0.4 million) per death [16]. This value is almost 1% of the country's gross domestic product (GDP).

In response to the escalating trend of road traffic deaths, particularly from 1990 to 1996 (figure 1), various initiatives, strategies and programmes have been developed and implemented by the Government of Malaysia in order to reduce the number of road traffic deaths. Most of these initiatives, strategies and programmes were carried out after the introduction of the Five-Year National Road Safety Target in 1996. These comprise:

- implementing the road safety plans and programmes in the target years;
- setting new national road safety targets;
- providing road safety education in schools;
- carrying out intensive media campaigns on road safety;
- establishing the road safety audit (RSA) unit under the Public Works Department (JKR);
- establishing the Road Safety Department (JKJR);
- establishing the Malaysian Institute of Road Safety Research (MIROS);
- establishing the Land Public Transport Commission (SPAD);
- imposing RSA from the planning stage;
- implementing blackspot treatment programmes and

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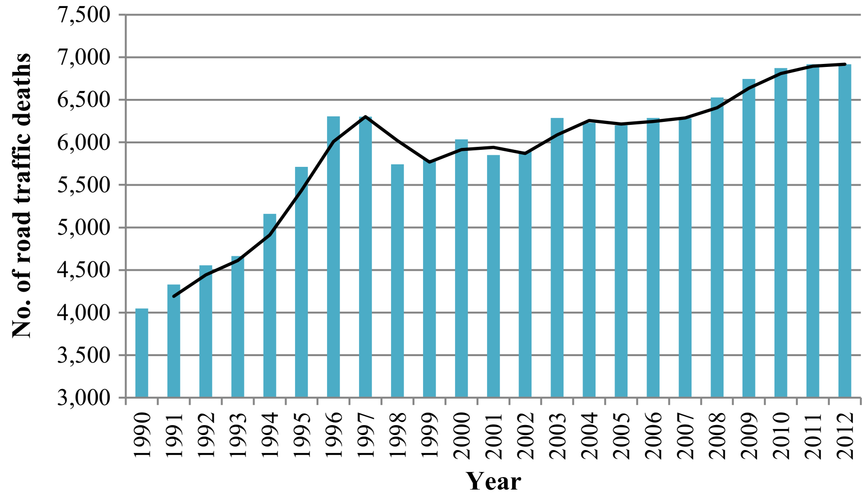

Figure 1. Number of road traffic deaths in Malaysia from 1990 to 2012. Note that the trend is superimposed in the bar chart, as indicated by the solid black line. Source: Number of road traffic deaths estimated from the Annual road accident statistics reports by the Royal Malaysian Police [20].

- implementing integrated enforcement, including the use of speeding and traffic light offence cameras.

The latest Malaysian Road Safety Plan was launched in 2006, whereby the following targets need to be achieved by the year 2010:

- 2.0 deaths per 10,000 registered vehicles,
- 10 deaths per 100,000 population and
- 10 deaths per billion vehicle-kilometre travelled.

However, it should be noted that these targets were not achieved until the end of the target year. The data on road traffic deaths in Malaysia from 2005 to 2011 are shown in table 1 and it can be seen that the rate of road traffic deaths is 3.4 per 10,000 registered vehicles and 24.3 per 100,000 population in 2010. These values are indeed higher than the set targets. Even though the rate of fatalities per 10,000 registered vehicles decreases from 4.2 in 2005 to 3.2 in 2011, the implementation of the programmes outlined in the Malaysian Road Safety Plan may need further improvement. In addition, it is important for all parties concerned with road safety to determine the factors that significantly contribute to road traffic deaths. For example, the Public Works Department at the Ministry of Works, Malaysia, found that the implementation of the blackspot treatment programme from 2004 to 2007 reduced the number of traffic accidents at the rehabilitative locations by a significant margin. This programme is centred on the elimination of blackspot accidents by means of engineering approaches. On average, 98.81% out of 755 blackspot locations do not have any fatal accidents following the implementation of the blackspot treatment programme, which indicates that this programme is indeed effective [3]. This also indicates that the road environment has a significant contribution to the number of fatal accidents in Malaysia. For this reason, it is crucial to prioritise improving the road environment in Malaysia since this will lead to a significant reduction of road traffic deaths.

Table 1. Data on road traffic deaths in Malaysia from 2005 to 2011.

Year	Road traffic deaths	Registered vehicles (10,000)	Population (100,000)	Rate of road traffic fatalities per 10,000 vehicles	Rate of road traffic fatalities per 100,000 population
2005	6,200	1,481.64	264.77	4.2	23.4
2006	6,287	1,579.07	268.32	4.0	23.4
2007	6,282	1,681.39	271.86	3.7	23.1
2008	6,527	1,797.19	275.41	3.6	23.7
2009	6,745	1,901.68	278.95	3.5	24.2
2010	6,872	2,018.86	283.34	3.4	24.3
2011	6,877	2,135.93	289.64	3.2	23.7

Source: The rates of road traffic fatalities were estimated from the data published by the Royal Malaysian Police, Department of Statistics [7] and Road Transport Department, Ministry of Transport Malaysia [17].

A number of studies have been carried out over the years to investigate the contribution of various road environment elements towards road traffic accidents. According to Jones *et al* [15], the percentage of roads classified as minor, the percentage of roads throughout urban areas and the average curvature of roads are among the statistically significant explanatory variables that contribute towards road traffic accidents. In addition, researchers have also discovered that road environment factors constitute 30% of crashes.

Based on the literature, road environment seems to have a substantial contribution towards road traffic accidents [1, 2]. According to the World Health Organization (WHO) [24], the lack of attention to road safety when planning new road networks and designing roads, defects in existing roads and lack of remedial action at high-risk crash sites are the risk factors for crashes. Hence, this study is focussed on investigating the road environment elements that have a significant contribution on road traffic deaths in Malaysia. The findings of this study can be used to identify the road elements that have a significant effect on road traffic deaths, and this will help the relevant authorities to plan and design safer roads in order to reduce road traffic accidents. The findings of this study will be useful to all parties concerned with road safety.

2. Materials and methods

2.1 *Data*

The number of road traffic deaths from 2000 to 2011 is the primary data used in this study. These data are taken from the Annual road accident statistics reports issued by the Royal Malaysian Police (PDRM). The accuracy of the data is considered high since they are obtained from a credible resource. In fact, the number of road traffic deaths in Malaysia estimated by WHO [25] is similar to the statistics given in the Annual road accident statistics reports. A standardised form named POL.27 has been used by the police since the early 1990s to collect data related to road traffic accidents at accident scenes. The details of the accident are filled out in this form. The form is then dispatched to the traffic branch police headquarters and the data are keyed into the data entry system for analysis and archival purposes. The data consist of the time and type of accident, the number and type of vehicles involved in the accident, road environment and reports on injuries of the vehicle occupants, as well as the location of the accident. These data are filtered and only the number of deaths due to road environment elements is analysed in order to observe the trend and determine the proportion of road traffic deaths caused by the various road elements. The number of road traffic deaths is determined based on locality (i.e., rural and urban areas), road category (i.e., federal roads, state roads and municipal roads, as well as expressways), road segment (i.e., straight roads, road bends, Y/T junctions, cross junctions, roundabouts, interchanges and staggered junctions) and road defect (i.e., no/insufficient street lighting, low/high road shoulder edge drop-offs, potholes, slippery roads, dusty roads, roads without guardrails, low/high manholes, roads with loose gravel, narrow bridges and defective traffic lights).

Other data are also used to determine the relationship between road traffic deaths and other factors. These include population data taken from annual reports published by the Department of Statistics, Office of the Prime Minister of Malaysia. The number of registered vehicles is available from the reports published by the Road Transport Department, Ministry of Transport, Malaysia. Information on the length of various roads is obtained from reports published by the Highway Planning Unit, Ministry of Works, Malaysia.

The data used in this study are focussed on a 12-year period (from 2000 to 2011) since this is the period when most of the major road safety initiatives and programmes were launched in Malaysia. One of these initiatives is the Malaysian Road Safety Plan, whereby the aim of this Plan is to reduce the number of road traffic deaths. In addition, there is only a slight difference in the number of road traffic deaths from one year to another within this period and therefore, it can be expected that the trend of road traffic deaths is similar. In addition, both the RSA and blackspot treatment programme (each with the aim of improving road environment by means of engineering approaches) are emphasised in this period. JKR published the guidelines for RSA in 1997 and then imposed the RSA for both new and upgrading road projects.

2.2 *Statistical analysis*

The number of road traffic deaths per road element recorded by the police, as well as other data as mentioned previously, is analysed in order to determine the distribution, proportion and relationship with other factors that have been identified by the police as the contributors of fatal road traffic accidents. The distribution of deaths based on each road element will indicate whether the number of deaths is in any way related to the road element or the number of deaths is obtained merely by chance. Two types of statistical analysis are carried out in order to fulfil the objective of this study. Firstly, the Chi-square test with 5% level of significance is used to determine the statistical significance of the road elements associated with road traffic deaths. Secondly, multiple comparisons are made using the Marascuilo procedure with 5% level of significance. This procedure enables one to compare all possible pairs of proportions and it is used to determine whether the difference in the number of road traffic deaths between any two road elements is significant.

The Marascuilo procedure is described in detail in NIST/SEMATECH [18] and only a brief description is given here. The first step involves computing the differences $p_i - p_j$, (noting that $i \neq j$) among all $k(k-1)/2$ pairs of proportions, based on the assumption that there are samples of size n_i ($i = 1, 2, 3, \ldots, k$) from k populations. The test statistics are the absolute values of these differences.

The second step involves choosing a level of significance and computing the corresponding critical values for the Marascuilo procedure using the following equation:

$$r_{ij} = \sqrt{\chi^2_{1-\alpha,k-1}}\sqrt{\frac{p_i(1-p_i)}{n_i} + \frac{p_j(1-p_j)}{n_j}} \quad (1)$$

where χ^2 denotes the Chi-square value. The final step involves comparing each $k(k-1)/2$ test statistic against its corresponding critical r_{ij} value. It shall be noted here that the pairs having a test statistic that is higher than the critical value ($\alpha = 5\%$) are said to be significant.

3. Results and discussion

3.1 *Road traffic deaths based on locality*

Based on the population and housing census data, the proportion of population in urban areas has increased from 62% to 71% from year 2000 to 2010 [9]. This clearly indicates that the population is significantly higher in urban areas compared with rural areas. However, interestingly, the number of road traffic deaths is significantly higher in rural areas compared with urban areas, as shown in figure 2 and table 2. The roads in rural areas contributed to 66% of road traffic deaths from 2000 to 2011, whereas the remaining 34% was contributed by the roads in urban areas. However, it is apparent from the results that there is a significant decrease in the number of road traffic deaths in rural areas in 2003, with a percentage of 12%.

The results here are indeed consistent with the results of previous studies, whereby the number of road traffic deaths is more pronounced in rural areas compared with urban areas [4, 21, 22]. However, Elvik *et al* [11] observed a different trend altogether and their results showed that the rate of road traffic accidents in urban areas is 2–10 times higher than that for rural areas. The higher number of road traffic deaths in urban areas may be attributed to the decrease in the probability of survival of the vehicle occupants as a result of severe injuries. In general, the probability of fatalities and severe injuries increases with older age, non-use of seat belts, vehicle damage, high vehicular speeds and early morning crashes. According to Travis *et al* [22], motorists with severe injuries are more likely to die in rural areas after controlling for person-specific and event-specific factors. Rakauskas *et al* [21] offered a plausible explanation for this, which involves road design, proximity of emergency medical services and human factors. The results of their study indicated that rural drivers were engaged in riskier behaviour (e.g., not buckling their seat belts) because they had lower perceptions on the risks associated with such behaviour. Rural drivers perceived that the utility of government-sponsored traffic safety interventions is low, unlike urban drivers. These factors are also relevant to the road traffic scenario in Malaysia, since, for instance, in 2011, the total fatalities in rural areas was 4,034, whereas it was 2,315 on roads in urban areas. However, there are no comprehensive studies to date that have explored the factors that lead to higher road traffic deaths in rural areas in Malaysia compared with urban areas.

It can be seen from table 2 that the Chi-square value (χ^2) is 298.61, which is higher than the critical χ^2 value with 11 degrees of freedom at 5% confidence interval ($\chi^2_{11,0.05} = 19.68$). This indicates that there is a significant difference in the number of road traffic deaths between rural and urban areas. In other words, the number of road traffic deaths based on the locality of the road network is statistically significant, and therefore it is not merely due to chance. The results obtained from the Marascuilo procedure also indicate that there is a significant difference in the

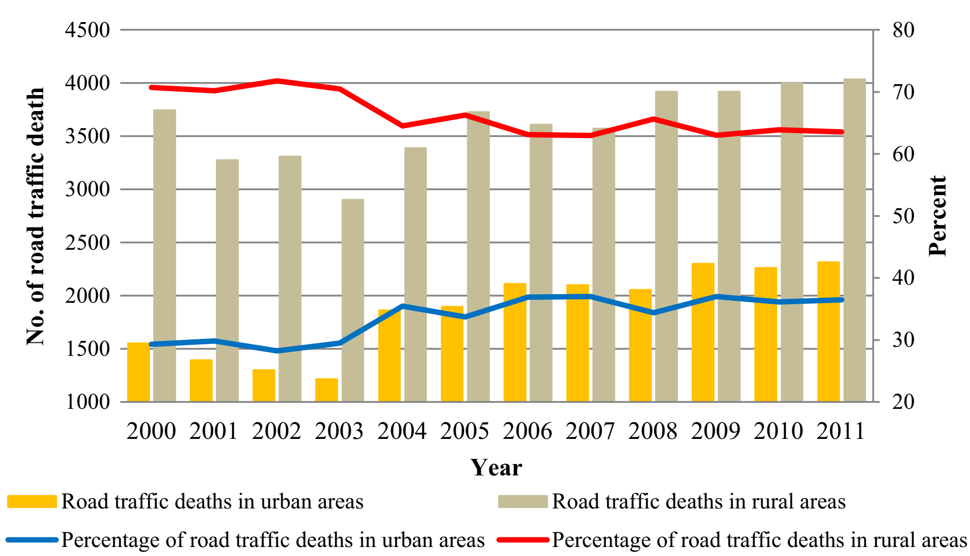

Figure 2. Number and percentage of road traffic deaths in urban and rural areas from 2000 to 2011.

Table 2. Chi-square values and the number of road traffic deaths based on locality, road category and road segment from 2000 to 2011.

	Year													Proportion
	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	Total	(%)
Locality														
Rural areas	3,745	3,274	3,310	2,901	3,387	3,727	3,609	3,572	3,920	3,918	3,999	4,034	43,396	66.0
Urban areas	1,552	1,392	1,301	1,214	1,861	1,896	2,110	2,100	2,054	2,300	2,261	2,315	22,356	34.0
$\chi^2 = 298.61$ and $\chi^2_{11,0.05} = 19.68$														
Road category														
Federal roads	2,089	1,957	2,007	1,950	2,028	2,009	2,248	2,245	2,297	2,505	2,459	2,449	26,243	38.9
State roads	1,365	1,273	1,246	1,325	1,339	1,657	1,362	1,440	1,480	1,620	1,548	1,616	17,271	25.6
Municipal roads	918	926	964	1,136	1,198	1,106	1,201	1,117	1,207	1,130	1,148	1,121	13,172	19.5
Expressways	408	376	421	489	491	473	522	533	602	550	662	724	6,251	9.3
Others	452	456	313	328	243	378	386	337	388	413	443	439	4,576	6.8
$\chi^2 = 355.97$ and $\chi^2_{44,0.05} = 60.48$														
Road segment														
Straight roads	3,522	3,240	3,244	3,690	*	3,774	3,450	3,791	4,014	4,450	3,767	4,216	41,158	65.7
Road bends	988	953	863	894	*	950	930	1,053	1,065	936	1,050	1,119	10,801	17.2
Y/T junctions	530	525	541	576	*	581	537	593	613	567	777	623	6463	10.3
Cross junctions	218	226	218	215	*	248	676	198	242	212	318	349	3120	5.0
Staggered junctions	124	72	45	36	*	26	25	12	10	10	113	8	481	0.8
Roundabouts	27	31	15	23	*	19	77	16	14	32	125	22	401	0.6
Interchanges	9	8	12	12	*	25	24	9	16	11	110	12	248	0.4

$\chi^2 = 1859.94$ and $\chi^2_{60,0.05} = 79.08$. * Not available.

Table 3. Results of the Marascuilo procedure for road traffic deaths based on locality and road category.

Contrast	Value	Critical value	Significant
|p(Urban areas)–p(Rural areas)|	0.320	0.005	Yes
|p(Federal roads)–p(State roads)|	0.133	0.008	Yes
|p(Federal roads)–p(Municipal roads)|	0.194	0.007	Yes
|p(Federal roads)–p(Expressways)|	0.296	0.007	Yes
|p(Federal roads)–p(Others)|	0.321	0.007	Yes
|p(State roads)–p(Municipal roads)|	0.061	0.007	Yes
|p(State roads)–p(Expressways)|	0.163	0.006	Yes
|p(State roads)–p(Others)|	0.188	0.006	Yes
|p(Municipal roads)–p(Expressways)|	0.103	0.006	Yes
|p(Municipal roads)–p(Others)|	0.127	0.006	Yes
|p(Expressways)–p(Others)|	0.025	0.005	Yes

number of road traffic deaths between rural and urban areas, as shown in table 3. The higher number of road traffic deaths in rural areas (66%) is indeed a strong basis for road safety authorities to prioritise design and development of road safety features in rural areas.

3.2 *Road traffic deaths based on road category*

In general, the roads in Malaysia can be categorised into expressways, federal roads, state roads and municipal roads. The total length of the roads was around 127,517 km in 2011 [13], and the total length of the roads increased significantly after 2008 (particularly in 2009), as shown in figure 3 and table 2. State roads and municipal roads constitute a large percentage of the total road length, with a value of 84.9%. However, it is evident from the results that the highest number of road traffic deaths occurs on federal roads, followed by state roads and municipal roads.

The estimated rate of road traffic fatalities per kilometre in 2011 is shown in table 4. It can be seen that the highest rate of road traffic fatalities per kilometre occurs on expressways, followed by federal roads. The rate of road traffic fatalities per kilometre is the lowest for state and municipal roads. It should be noted here that the rate of road traffic fatalities per vehicle-kilometre travelled may be a more realistic measure compared with the number of deaths based on road category. However, there are no detailed studies that provide recent data on the vehicle-kilometre travelled in Malaysia to date.

High vehicular speeds may be the reason why the highest rate of road traffic fatalities occur on expressways, followed by federal roads and state roads. In general, the allowable speed limit for expressways is 110 kph, whereas the allowable speed limit is 90 kph for federal roads and state

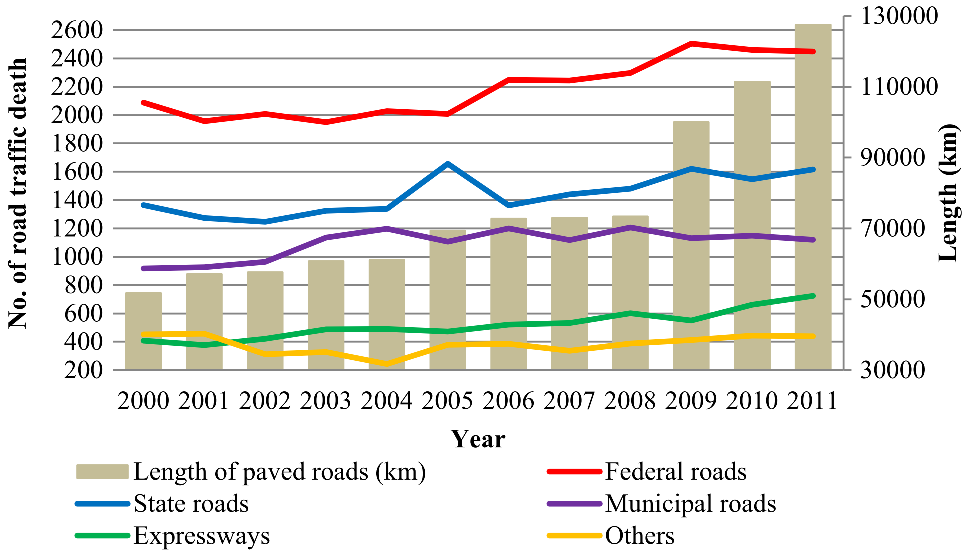

Figure 3. Number of road traffic deaths based on road category and length of paved roads from 2000 to 2011.

Table 4. Rate of road traffic fatalities per kilometre in 2011.

Road category	No. of deaths in 2011	Length of roads (km)	Rate of road traffic fatalities per kilometre
Federal roads	2,449	19,216.24	0.13
State and municipal roads	2,737	108,300.72	0.03
Expressways	724	1,630.00	0.44

roads. Relatively low speed limits are imposed for municipal roads as well as designated areas such as school and residential areas. Even though other researchers were unable to determine whether higher vehicular speeds will definitely increase the number of road traffic accidents, they agreed that higher vehicular speeds will certainly increase the severity of accidents. The impact of higher speed limits on the severity of accidents has been investigated in several studies [23, 26].

Based on the results shown in table 2, the Chi-square value (χ^2) is 355.97, which is higher than the critical χ^2 value with 44 degrees of freedom at 5% level of confidence

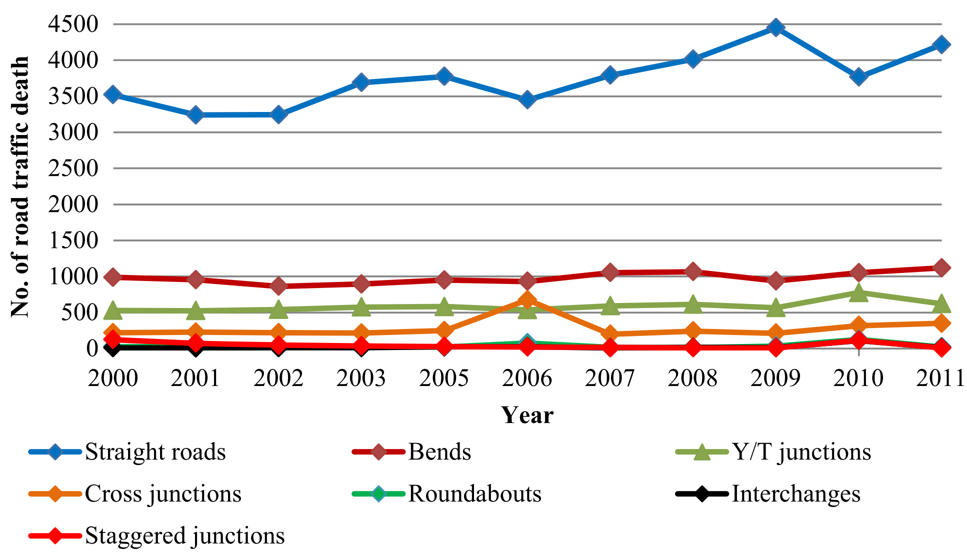

Figure 4. Number of road traffic deaths based on road segments from 2000 to 2011.

($\chi^2_{44,0.05} = 60.48$). This indicates that there is a significant difference in the number of road traffic deaths based on road category. The results obtained from the Marascuilo procedure also indicate that there is a significant difference in the number of road traffic deaths between all pairs of road categories, as shown in table 3. The highest rate of road traffic fatalities per kilometre occurs on expressways, whereas the highest proportion of road traffic deaths occurs on federal roads, with a value of 38.9%. These findings highlight the importance for road safety authorities to increase safety features and implement countermeasures to reduce road traffic deaths on expressways and federal roads. The installation of traffic enforcement cameras such as speed cameras at blackspot locations (particularly along expressways and federal roads) may be a viable solution to reduce road traffic deaths due to speeding and this initiative should be continued.

3.3 *Road traffic deaths based on road segment*

It is generally expected that road bends can lead to vehicle crashes–however, a recent study in the UK has shown that areas that are mainly made up of curved roads had lower crash rates than those with straight roads [15]. In Malaysia, most of the road traffic deaths from 2000 to 2011 occurred on straight segments, followed by bends, as shown in figure 4 and table 2. This may due to the fact that the length of straight roads is significantly higher than road bends, and therefore it is very likely that more accidents will occur along straight roads. This finding indicates that the road safety authorities in Malaysia should take note that many existing straight roads are still not safe for road users. However, it is highlighted here that the road accident data are not available for year 2004 in the statistic report.

It can be seen from figure 4 and table 2 that the highest number of road traffic deaths occurs at Y/T junctions, followed by cross junctions, regardless of the proportion of each type of junction. The number of road traffic deaths is the lowest at interchanges and roundabouts. The relatively high number of accidents at Y/T junctions may be due to the skewness angle of the junctions, which restricts visibility of the motorists. According to Elvik *et al* [11], skewed junctions seem to be associated with a higher number of accidents compared with junctions in which the angle between the roads is 90°. Skewed junctions are also found to be the most problematic for older drivers. In general, accidents that occur at junctions with 90° angles are less severe compared with skewed junctions. Nevertheless, the results indicate that the highest number of road traffic deaths occurs at Y/T junctions compared with cross junctions, which is contradictory to the findings of several studies. For instance, Yannis *et al* [27] discovered that 47% of the fatal accidents in year 2006 occurred at crossroads whereas 22% occurred at T or Y intersections.

Previous studies have also shown that the number of road traffic accidents is lower at grade-separated junctions and roundabouts [11, 19]. According to O'Cinneide and Troutbeck [19], T-junctions are safer than staggered junctions, but staggered junctions are safer than cross junctions. However, their finding contradicts the current road scenario in Malaysia since the results of this study indicate that staggered junctions are safer than Y/T junctions. It should be noted that the numbers of accidents that occur at Y and T junctions are combined in the police reports and therefore, comparison cannot be made with regard to the number of

Table 5. Results of the Marascuilo procedure for road traffic deaths based on road segment.

Contrast	Value	Critical value	Significant
|*p*(Straight roads)–*p*(Road bends)|	0.484	0.009	Yes
|*p*(Straight roads)–*p*(Y/T junctions)|	0.554	0.008	Yes
|*p*(Straight roads)–*p*(Cross junctions)|	0.607	0.007	Yes
|*p*(Straight roads)–*p*(Roundabouts)|	0.650	0.007	Yes
|*p*(Straight roads)–*p*(Interchanges)|	0.653	0.007	Yes
|*p*(Straight roads)–*p*(Staggered junctions)|	0.649	0.007	Yes
|*p*(Road bends)–*p*(Y/T junctions)|	0.069	0.007	Yes
|*p*(Road bends)–*p*(Cross junctions)|	0.123	0.006	Yes
|*p*(Road bends)–*p*(Roundabouts)|	0.166	0.005	Yes
|*p*(Road bends)–*p*(Interchanges)|	0.168	0.005	Yes
|*p*(Road bends)–*p*(Staggered junctions)|	0.165	0.005	Yes
|*p*(Y/T junctions)–*p*(Cross junctions)|	0.053	0.005	Yes
|*p*(Y/T junctions)–*p*(Roundabouts)|	0.097	0.004	Yes
|*p*(Y/T junctions)–*p*(Interchanges)|	0.099	0.004	Yes
|*p*(Y/T junctions)–*p*(Staggered junctions)|	0.095	0.004	Yes
|*p*(Cross junctions)–*p*(Roundabouts)|	0.043	0.003	Yes
|*p*(Cross junctions)–*p*(Interchanges)|	0.046	0.003	Yes
|*p*(Cross junctions)–*p*(Staggered junctions)|	0.042	0.003	Yes
|*p*(Roundabouts)–*p*(Interchanges)|	0.002	0.001	Yes
|*p*(Roundabouts)–*p*(Staggered junctions)|	0.001	0.002	No
|*p*(Interchanges)–*p*(Staggered junctions)|	0.004	0.002	Yes

Table 6. Chi-square values and the number of road traffic deaths based on road defect from 2000 to 2011.

	Year													
Road defect	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	Total	Proportion (%)
No/insufficient street lighting	120	120	173	194	297	334	333	365	370	429	420	480	3,635	48.6
Low/high road shoulder edge drop-offs	94	142	82	65	76	83	102	100	114	103	107	87	1,155	15.4
Potholes	49	69	35	54	83	73	68	78	92	65	76	98	840	11.2
Slippery roads	50	46	26	36	40	40	64	57	50	46	54	77	586	7.8
Dusty roads	14	25	12	17	21	22	24	34	22	22	44	46	303	4.0
No guardrails	6	14	17	12	24	17	25	34	30	43	29	30	281	3.8
Low/high manholes	18	21	16	17	20	20	15	18	15	34	28	51	273	3.6
Loose gravel	17	15	12	10	7	12	12	14	19	16	24	26	184	2.5
Narrow bridges	16	14	11	9	8	12	10	15	7	14	21	10	147	2.0
Defective traffic lights	6	4	4	2	5	9	3	7	8	7	13	4	72	1.0
Narrow railway crossings	0	0	1	0	5	1	1	0	0	0	0	2	10	0.1

$\chi^2 = 410.35$ and $\chi^2_{110,0.05} = 135.48$.

road traffic deaths resulting from accidents at staggered and T junctions in this study.

It can be seen from table 2 that the Chi-square value (χ^2) is 1,859.94, which is higher than the critical χ^2 value with 60 degrees of freedom at 5% level of confidence ($\chi^2_{60,0.05} = 79.08$). This indicates that there is a significant difference in the number of deaths based on road segment. However, the results of the Marascuilo procedure shown in table 5 indicate that there is a significant difference in the number of deaths for most pairs of road segments, with the exception of the following pair: |*p*(Roundabouts)–*p*(Staggered junctions)|. Based on the results, it is not necessary for road safety authorities to change the road segments from staggered junctions to roundabouts or *vice versa* in order to reduce road traffic deaths. Even if such a change is implemented, it is expected that this change will not reduce the number of road traffic deaths substantially.

3.4 *Road traffic deaths based on road defect*

There are 11 types of road defects that have been identified by the police, as given in their annual road traffic accident reports. On average, only 11.25% of the total number of road traffic deaths is related to these road defects whereas the remaining 88.75% is because of other reasons. The Chi-square values and the number of road traffic deaths based on road defect from 2000 to 2011 are shown in table 6. It can be seen that 48.6% of road traffic deaths is due to lack of street lighting provision. Low or high road shoulder edge drop-offs account for 15.4% of the road traffic deaths, whereas potholes account for 11.2% of road traffic deaths. Other road defects contribute only less than 10% of road traffic deaths. However, it is worth noting that defective traffic lights at junctions do not contribute significantly to road traffic deaths since a relatively low number of deaths is recorded for this defect.

Several researchers have also observed a link between road traffic accidents and poor street lighting provision. Elvik *et al* [11] found that adequate street lighting reduces fatal accidents by 60%, but it reduces road traffic injuries and vehicle damage by only 15%. The reduction of fatal accidents was found to be statistically significant. Isebrands *et al* [14] discovered that the rate of night time crashes decreases by 37% upon installation of street lights and the result is statistically significant. However, the contribution of road shoulder defects towards road traffic accidents is rather inconsistent based on the findings of previous studies. Some researchers found that wider road shoulders have a positive impact on road traffic accidents whereas others found that wider road shoulders result in a higher number of road traffic accidents as well as increases the severity of crashes [6, 10]. Road shoulder edge drop-offs, however, are believed to be one of the causes of road traffic accidents since the motorists will lose control of their vehicles. The effect of pavement edge drop-offs on road traffic accidents has been studied by Glennon [12]. More importantly, low or high road shoulder drop-offs have been identified by the police as the second leading cause of road traffic deaths in Malaysia.

Based on the feedback obtained from 122 respondents [5], 46% of the respondents claimed that accidents occurred because they wanted to swerve from potholes and uneven road surfaces in order to prevent damage to their vehicles. It can be seen from table 6 that the Chi-square value (χ^2) is 410.35, which is higher than the critical χ^2 value with 110 degrees of freedom and 5% level of confidence ($\chi^2_{110,0.05} = 135.48$). This indicates that there is a significant difference in the number of deaths based on road defects. However, the results obtained from the Marascuilo procedure (table 7) show that the difference in the number of deaths between the following pairs of road defects is not significant, i.e., |*p*(Dusty roads)–*p*(No guardrails)|, |*p*(Dusty

Table 7. Results of the Marascuilo procedure for road traffic deaths based on road defect.

Contrast	Value	Critical value	Significant
|*p*(No/insufficient street lights)–*p*(Road shoulder edge drop-offs)|	0.331	0.030	Yes
|*p*(No/insufficient street lights)–*p*(Potholes)|	0.373	0.029	Yes
|*p*(No/insufficient street lights)–*p*(Slippery roads)|	0.407	0.028	Yes
|*p*(No/insufficient street lights)–*p*(Dusty roads)|	0.445	0.027	Yes
|*p*(No/insufficient street lights)–*p*(No guardrails)|	0.448	0.026	Yes
|*p*(No/insufficient street lights)–*p*(Manholes)|	0.449	0.026	Yes
|*p*(No/insufficient street lights)–*p*(Loose gravel)|	0.461	0.026	Yes
|*p*(No/insufficient street lights)–*p*(Narrow bridges)|	0.466	0.026	Yes
|*p*(No/insufficient street lights)–*p*(Defective traffic lights)|	0.476	0.025	Yes
|*p*(No/insufficient street lights)–*p*(Narrow railway crossings)|	0.484	0.025	Yes
|*p*(Road shoulder edge drop-offs)–*p*(Potholes)|	0.042	0.024	Yes
|*p*(Road shoulder edge drop-offs)–*p*(Slippery roads)|	0.076	0.022	Yes
|*p*(Road shoulder edge drop-offs)–*p*(Dusty roads)|	0.114	0.020	Yes
|*p*(Road shoulders)–*p*(No guardrails)|	0.117	0.020	Yes
|*p*(Road shoulders)–*p*(Manholes)|	0.118	0.020	Yes
|*p*(Road shoulders)–*p*(Loose gravel)|	0.130	0.019	Yes
|*p*(Road shoulders)–*p*(Narrow bridges)|	0.135	0.019	Yes
|*p*(Road shoulder edge drop-offs)–*p*(Defective traffic lights)|	0.145	0.019	Yes
|*p*(Road shoulder edge drop-offs)–*p*(Narrow railway crossings)|	0.153	0.018	Yes
|*p*(Potholes)–*p*(Slippery roads)|	0.034	0.020	Yes
|*p*(Potholes)–*p*(Dusty roads)|	0.072	0.018	Yes
|*p*(Potholes)–*p*(No guardrails)|	0.075	0.018	Yes
|*p*(Potholes)–*p*(Manholes)|	0.076	0.018	Yes
|*p*(Potholes)–*p*(Loose gravel)|	0.088	0.017	Yes
|*p*(Potholes)–*p*(Narrow bridges)|	0.093	0.017	Yes
|*p*(Potholes)–*p*(Defective traffic lights)|	0.103	0.016	Yes
|*p*(Potholes)–*p*(Narrow railway crossings)|	0.111	0.016	Yes
|*p*(Slippery roads)–*p*(Dusty roads)|	0.038	0.016	Yes
|*p*(Slippery roads)–*p*(No guardrails)|	0.041	0.016	Yes
|*p*(Slippery roads)–*p*(Manholes)|	0.042	0.016	Yes
|*p*(Slippery roads)–*p*(Loose gravel)|	0.054	0.015	Yes

Table 7. continued

Contrast	Value	Critical value	Significant
|*p*(Slippery roads)–*p*(Narrow bridges)|	0.059	0.015	Yes
|*p*(Slippery roads)–*p*(Defective traffic lights)|	0.069	0.014	Yes
|*p*(Slippery roads)–*p*(Narrow railway crossings)|	0.077	0.013	Yes
|*p*(Dusty roads)–*p*(No guardrails)|	0.003	0.014	No
|*p*(Dusty roads)–*p*(Manholes)|	0.004	0.013	No
|*p*(Dusty roads)–*p*(Loose gravel)|	0.016	0.012	Yes
|*p*(Dusty roads)–*p*(Narrow bridges)|	0.021	0.012	Yes
|*p*(Dusty roads)–*p*(Defective traffic lights)|	0.031	0.011	Yes
|*p*(Dusty roads)–*p*(Narrow railway crossings)|	0.039	0.010	Yes
|*p*(No guardrails)–*p*(Manholes)|	0.001	0.013	No
|*p*(No guardrails)–*p*(Loose gravel)|	0.013	0.012	Yes
|*p*(No guardrails)–*p*(Narrow bridges)|	0.018	0.012	Yes
|*p*(No guardrails)–*p*(Defective traffic lights)|	0.028	0.011	Yes
|*p*(No guardrails)–*p*(Narrow railway crossings)|	0.036	0.010	Yes
|*p*(Manholes)–*p*(Loose gravel)|	0.012	0.012	No
|*p*(Manholes)–*p*(Narrow bridges)|	0.017	0.012	Yes
|*p*(Manholes)–*p*(Defective traffic lights)|	0.027	0.010	Yes
|*p*(Manholes)–*p*(Narrow railway crossings)|	0.035	0.009	Yes
|*p*(Loose gravel)–*p*(Narrow bridges)|	0.005	0.010	No
|*p*(Loose gravel)–*p*(Defective traffic lights)|	0.015	0.009	Yes
|*p*(Loose gravel)–*p*(Narrow railway crossing)|	0.023	0.008	Yes
|*p*(Narrow bridges)–*p*(Defective traffic lights)|	0.010	0.008	Yes
|*p*(Narrow bridges)–*p*(Narrow railway crossings)|	0.018	0.007	Yes
|*p*(Defective traffic lights)–*p*(Narrow railway crossings)|	0.008	0.005	Yes

roads)–*p*(Manholes)|, |*p*(No guardrails)–*p*(Manholes)|, |*p*(Manholes)–*p*(Loose gravel)| and |*p*(Loose gravel)–*p*(Narrow bridges)|. This indicates that these roads defects do not have a significant impact on road traffic deaths.

4. Conclusions and directions for future research

The following conclusions can be drawn based on the findings of this study:

- The number of population is significantly higher in urban areas compared with rural areas. In contrast, the number of road traffic deaths in rural areas (66%) is significantly higher compared with that in urban areas (34%). This trend may be due to the road design, proximity of emergency medical services and non-use of seat belts as well as high vehicular speeds in rural areas.
- State roads and municipal roads make up the largest percentage of the total road length, with a value of 84.9%. However, it is interesting to note that the highest number of road traffic deaths occurs on federal roads. The highest rate of road traffic deaths per kilometre occurs on expressways. High vehicular speeds may be the main reason why the highest rate of fatalities occurs on expressways, followed by federal roads and state roads. Thus, the installation of traffic enforcement cameras such as speed cameras at blackspot locations (particularly expressways and federal roads) may be a viable solution to reduce the number of road traffic deaths due to speeding.
- The results show that most of the road traffic deaths within a 12-year period (from 2000 to 2011) occurred on straight roads, followed by road bends. However, the highest number of road traffic deaths occurs at Y/T junctions, followed by cross junctions, regardless of the proportion of each type of junction. The lowest number of road traffic deaths occurs at interchanges and roundabouts. Interestingly, staggered junctions are found to be safer compared with Y/T junctions. The relatively high number of accidents at Y/T junctions may be attributed to the skewness angle of the junctions, which restricts the visibility of motorists.
- The results of the statistical tests show that the difference in the number of road traffic deaths between roundabouts and staggered junctions is not significant. Hence, it is not necessary for road safety authorities to change road segments from staggered junctions to roundabouts and *vice versa* in order to reduce the number of road traffic deaths. The results indicate that such a change will not reduce road traffic deaths by a significant margin.
- Only 11.25% of the total number of deaths is related to road defects. The highest proportion of deaths (48.6%) is due to lack of street lighting provision. Road shoulder edge drop-offs and potholes account, respectively, for 15.4% and 11.2% of the total number of deaths by road defects. Other road defects contribute only less than 10% of the total number of deaths. It is worth noting that defective traffic lights at junctions are not a significant contributor of road traffic deaths.
- The Chi-square test results show that there is a significant difference in the proportion of deaths based on locality, road category, road segment and road defect. Further comparison is made using the Marascuilo procedure and it is found that the difference in the proportion of deaths for some pairs of road elements is not significant, i.e., $|p(\text{Roundabouts})-p(\text{Staggered junctions})|$, $|p(\text{Dusty roads})-p(\text{No guardrails})|$, $|p(\text{Dusty roads})-p(\text{Manholes})|$, $|p(\text{No guardrails})-p(\text{Manholes})|$, $|p(\text{Manholes})-p(\text{Loose gravel})|$ and $|p(\text{Loose gravel})-p(\text{Narrow bridges})|$.

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