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Analysis of speed characteristics for rural two-lane roads: A field study from Minoufiya Governorate, Egypt

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Distribution of spot speeds

Abstract This paper presents an analysis into speed characteristics on rural two-lane highways under existing conditions. Empirical data from several study sites on intercity rural two-lane roads in Minoufiya Governorate, Egypt were used in this investigation. Three separate however relevant analyses are presented in this paper. The first analysis investigates the relationship between 85th percentile speed and headway to define a headway value corresponding to free moving vehicles. The second analysis examines the suitability of the posted speed limits on the roads under study. The third and last analysis inspects the conformity of the study sites' speed data with normal distributions. It was found that the 85th percentile speed took a constant value at headway equal to 5 s or more. Also, a significant proportion of drivers exceed the posted speed limit as well as the current speed limit may not be appropriate. Finally spot speed data follow a normal distribution.
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1. Introduction

Traffic analysts are required to be familiar with speed characteristics of a highway. Speed characteristics are important in the evaluation of traffic performance, examination of highway consistency and safety, setting appropriate traffic control devices and speed limits, and development of simulation programs, etc.

The determination of headway corresponding to free flow speed is considered a key item in highway and traffic engineering applications, and especially in defining operating/design speed and setting speed limit. Free flow conditions avoid the effect of traffic flow on vehicle speed, as only the effect of highway geometry on speed is considered. There is no single definition for headway that corresponds to free flow speeds. The first part in the analysis presented in this paper involves an investigation of speed-headway relationship in order to define free-flow condition on rural two-lane highways in Egypt.

Speed limits are used in most countries to regulate the speed of road vehicles. Speed limits are important to reduce the differences in vehicle speeds by drivers using the same road at the same time which increases safety. Studying the suitability of

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the posted speed limit for the roads under study is another aspect of this paper. This is performed by measuring the compliance of the drivers with the posted speed limits and recommending appropriate speed limits based on engineering investigations.

The speed distribution of individual vehicles has to be specified in the form of a suitable mathematical model for many traffic applications. Spot speed data on a highway generally follow the normal distribution when traffic conditions are more or less homogenous. Traffic stream in developing countries such as Egypt may consist of a small portion of slow moving vehicles, such as animal drawn, while the majorities are fast moving vehicles such as cars. The large variation in speeds between fast and slow vehicles may cause the speed distribution curve to deviate from the normal distribution. The third part of the analysis in this paper tries to address this issue by examining the agreement of the collected speed data with normal distribution.

According to the objectives of this paper, which were stated earlier, a detailed statistical analysis was carried out to examine the speed characteristics on the selected field sites as collected by the traffic counters. More specifically, the analysis was carried out for the following reasons:

- To investigate the headway value corresponding to a free flow speed condition.
- To examine the suitability of the posted speed limit and the compliance of driver with it.
- To use the speed data to examine the conformity with the normal distribution.

2. Background studies

A free moving vehicle is a vehicle that is free from interaction with other vehicles in the traffic stream; as only the effect of highway geometry on vehicle speed is considered. There is no single definition for the case of free moving vehicle. Several authors have various definitions of the case of free flow conditions. Homburger et al. [1], in the Fundamentals of Traffic Engineering, recommended 4 s as a minimum headway between the following vehicle and the vehicle traveling ahead to define free flow, although larger values are preferred if traffic conditions permit. Poe et al. [2] concluded that vehicles with headway equal to or greater than 5 s are considered to be under free flow conditions. A free-flowing vehicle was defined by Fitzpatrick et al. [3] as having 5 s headway. Lamm et al. [4] reported that the speed data is considered under flow conditions when the isolated vehicles have a time gap of at least 6 s or heading a platoon of vehicles. Lin et al. [5] concluded that for the construction and analysis of the speed versus distance curves it is necessary to have a minimum time interval between two vehicles of 8 s in order to ignore the influence due to the presence of other vehicles. Cunagin and Chang [6]; and Radwan and Kalevela [7] considered that vehicles with headways greater than 9 s would be under free flow conditions. However, one of the objectives of this research is to revalidate this definition, particularly for rural intercity two-lane roads in Egypt.

Establishment of reasonable and safe speed limits should be based on an engineering study. Incorrectly posted speed limits on streets and highways might lead to driver non-compliance and speed differential which may lead to accident occurrences, as reported by Najjar et al. [8]. In the USA, speed data were collected by FHWA at both urban and rural roads with posted speed limits ranging from 25 to 55 mph. The data were analyzed to determine the compliance with posted speed limits. Results show that mean speeds exceeded posted speed limits by 1–8 mph; 85th percentile speeds ranged from 6 to 14 mph over the posted speed limit, or 4–7 mph over the mean speed; on average 70% of motorists are exceeding the posted speed limits. The study also found that accident rates for the 25-mph zones were consistently much higher than the other zones [9]. Another study was conducted also by FHWA to review current practice for setting and enforcing speed limits on all types of roads. In setting speed limits, according to this study, decision makers attempt to establish a reasonable balance between safety and mobility for a specific highway section. Accordingly, the speed limit should inform drivers of maximum driving speeds under favorable conditions that decision makers consider reasonable and safe for a highway section [10]. This paper therefore uses the field data to investigate the suitability of the posted speed limits on the roads under study.

The majority of the pervious studies confirmed that individual spot speed data usually display a normal distribution as reported by Islam and Seneviratne [11]; Kerman et al. [12]. Also, Leong [13] and McLean [14] who found that, for lightly trafficked two-lane roads where most vehicles are traveling freely, car speeds measured in time are approximately normally distributed with coefficient of variation ranging from about 0.11 to 0.18. Kumar and Rao [15] found that the spot speed data conform to the normal distribution.

However, in developing countries such as Egypt, speed may deviate from the normal curve as the traffic becomes heterogeneous due to the large variation in speeds of fast moving and slow moving, non-motorized, vehicles. Such variation causes the speed distribution curve to deviate from generally accepted unimodal normal distribution to a bimodal or a multimodal distribution, see Fig. 1, as reported by Dey et al. [16]. Dey et al. examined this issue using free flow speed data from India as they found that the type of distribution does not truly depend upon the percentage of slow moving vehicles in the traffic stream. They introduced a new parameter "Spread Ratio", to predict the bimodality in the speed data, as in the following equation: $SR = \frac{V_{85}-V_{50}}{V_{50}-V_{15}}$.It was found that the speed data will be represented by a unimodal curve if the spread ratio lies between 0.69 and 1.346 and tends to be bimodal as the spread ratio deviates from such range.

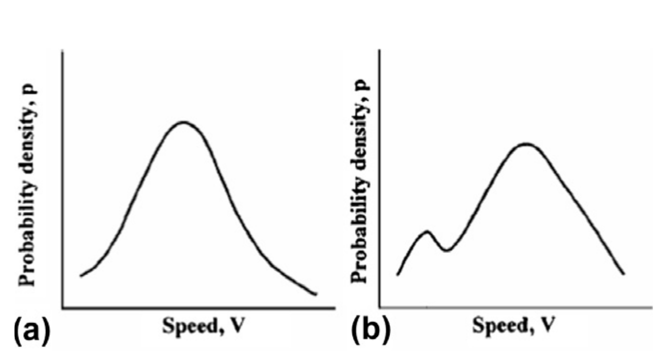

Figure 1 Probability density curves: (a) unimodal distribution; (b) bimodal distribution [16].

Table 1 Site characteristics, data collection durations, vehicular counts, percentage of heavy trucks and buses, maximum hourly volumes and directional split ratio.

Site no.	Pavement width (m)	Average shoulder width in both directions (m)	Duration of data collection (h)	Total traffic counts in both directions (vehicles)	%age of heavy trucks and buses in both directions	Maximum hourly volumes (Vph) in both directions	Maximum directional split ratio (%)
1	6.0	1.7	4	1672	4.8	425	57
2	6.5	1.0	7	2867	4.2	418	52
3	8.5	1.5	8	7234	3.3	1065	51
4	7.5	1.5	8	3484	3.0	470	52
5	7.7	1.1	8	3214	5.0	453	51
6	7.0	2.2	7	4873	3.1	781	52
7	6.4	1.1	8	2986	4.3	410	53
8	6.0	1.2	8	3213	4.0	421	51
9	6.5	1.6	8	3884	3.0	550	52
10	6.2	2.0	8	3869	1.9	560	52
11	7.2	1.5	8	3081	5.4	433	55
12	6	1.3	8	1423	4.9	200	53
13	6.8	2.4	8	4882	3.5	670	52
14	6.0	2.1	8	2582	4.2	456	52
15	7.3	1.5	9	2565	5.7	304	54
16	6.0	2.3	8	1543	3.7	215	52
17	6.1	1.0	10	940	5.2	132	53
18	6.0	1.5	9	779	5.1	106	56
19	6.0	1.4	10	931	5.0	117	53
20	6.1	1.8	8	2357	3.6	326	52

However, examining the conformity of the study sites' speed data with the normal distribution as well as examining the bimodality using the spread ratio equation is presented in the analysis section.

3. Study sites and field data

The scope of this research focuses on the intercity rural two-lane roads in Egypt. Therefore the analysis of this paper used 20 sites from two-lane roads that connect Shebin El-Kom, the capital city of Minoufiya Governorate, with the adjacent cities. It was ensured that the selection of the study sites encompasses all rural two-lane roads inside Minoufiya Governorate. All roads have a posted speed limit of 60 km/h. The chosen sites are located on straight sections with level terrain to avoid the effect of the longitudinal gradient, and far from the influence of intersections, driveways, and horizontal curves.

Roadside automatic traffic counters were used to collect the traffic and speed data used in this paper. The counters were placed approximately at the midpoint of the straight section preceding/succeeding horizontal curves or intersections. Speed and Traffic data collection were carried out in working days, during daylight hours. During all data collection periods, the weather was clear and the pavement was dry and in a good condition. Also, the chosen sites have relatively similar traffic characteristics in terms of traffic mix, congestion and potential enforcement characteristics.

Site characteristics, data collection duration, vehicular counts, percentage of heavy trucks and buses, maximum hourly volumes during the data collection durations and maximum directional split ratio at the study sites are provided in Table 1.

4. Data analysis

4.1. Definition of free flow condition

4.1.1. Relationship between 85th percentile speed and headway

The most common method used in highway and traffic engineering studies is to calculate the 85th percentile from individual free flow speed measurements and to consider this to be the operating speed. There is no single definition for headway that corresponds to free flow speeds, as explained earlier. Here, speed data at each travel direction in the survey sites were used

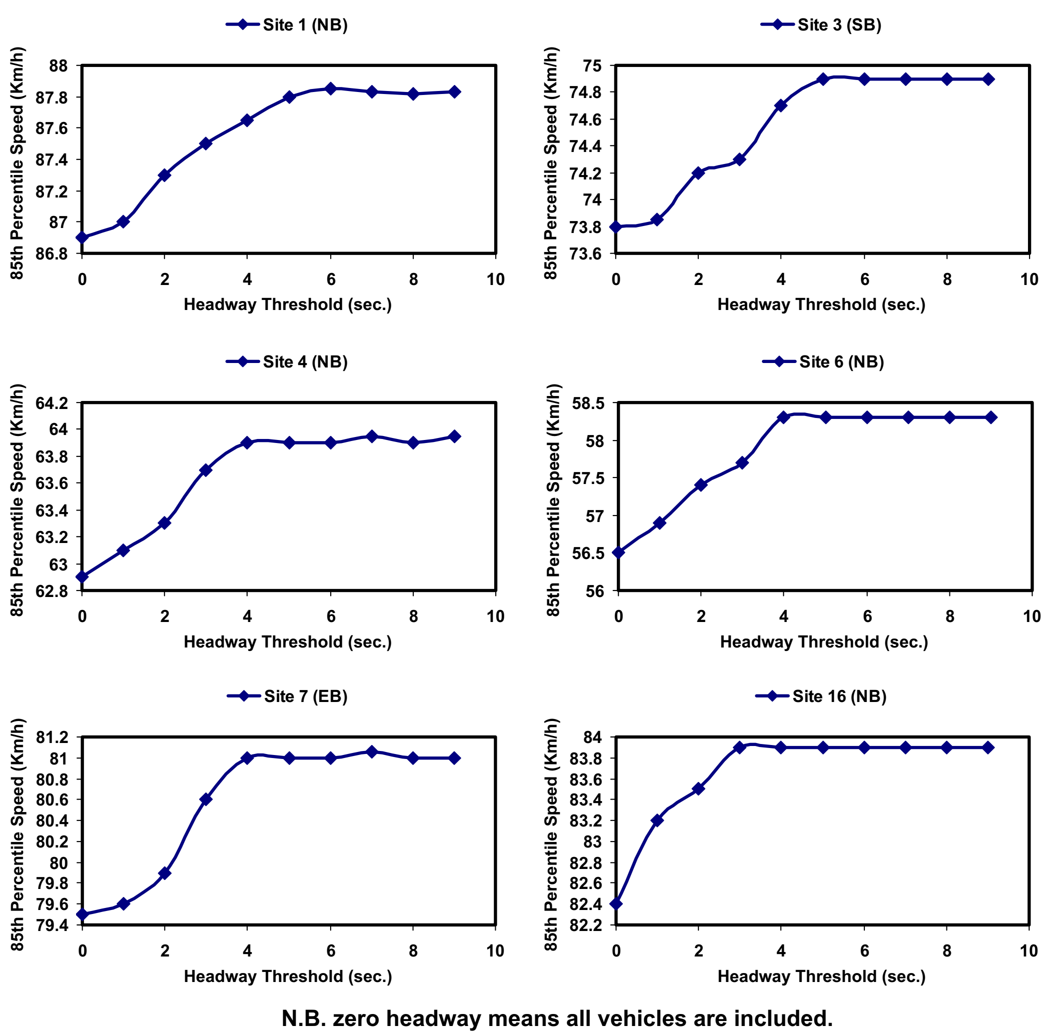

Figure 2 Relationships between 85th percentile speed and headways equal or greater than a threshold value at examples of the study sites.

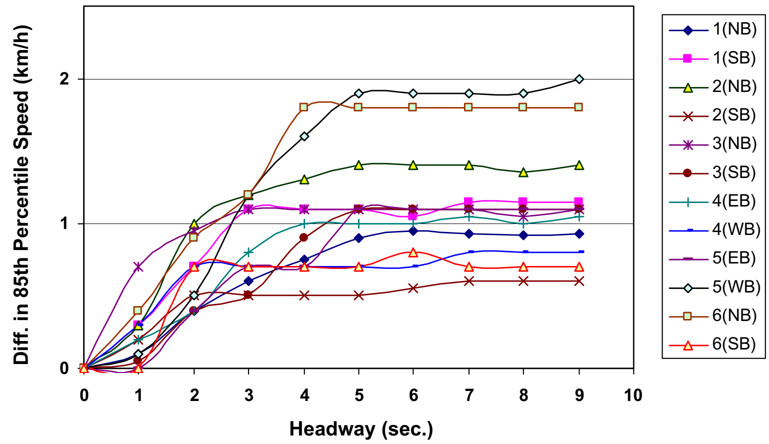

Figure 3 Relationships between difference in 85th percentile speed and headway at each direction of travel in the first six survey sites.

to investigate the car-following interaction based on the relationship between the 85th percentile speed and time headway. The aim of the analysis is to identify the headway value where vehicles can be considered under "free" flow condition in the traffic stream, i.e. vehicle speed is independent from the vehicle ahead on the same lane.

The 85th percentile speed of vehicles traveling at or beyond a given headway value is plotted for each direction (i.e. northbound, eastbound) for each study site. Examples of these plots are presented in Fig. 2, the other sites showed similar patterns. In this Figure, the 85th percentile speed increases as time headway value increases, until headway value reaches a value beyond which the 85th percentile speed becomes relatively constant. This indicates that vehicles with short time headways travel at speeds lower than their desired speeds as they being impeded by vehicles moving ahead. As the value of time headway increases, the proportion of those vehicles continues to decrease referring to a decrease in car following interaction and an increase in the freedom to select desired speed. As time headway value exceeds a certain threshold, the proportion of interacting vehicles diminishes and therefore vehicles are considered free-moving in the traffic stream. A careful examination of the plots in Fig. 2 reveals that this headway threshold is in the proximity of 5 s.

To include several plots in one figure, speed data at the first six survey sites (12 directions) were used to plot the lines in Fig. 3. Each line, in this figure, represents one direction (i.e. northbound, eastbound) in each site. The points on each line show the difference between the 85th percentile speed of all vehicles (all headways) and the 85th percentile Speed of vehicles with headway greater than or equal to a particular value. Thus, when the headway equals zero, all vehicles are included, so this difference is equal to zero. Fig. 3 shows that the difference in 85th percentile speeds for the vast majority of the observations does not increase as headway increases above about 5 s. This could indicate that free flow speeds can be defined for time headway between successive vehicles equal to 5 s or more.

4.1.2. Headway frequency

Fig. 4 shows the aggregate frequency distribution of different headway observations at the two direction of travel for the first six survey sites, as the remaining sites showed similar patterns. As shown in Fig. 4, on average, more than 60% of observations at all sites had headway values of 5 s or more. This trend was valid also during the peak hours, as in Fig. 5 (for only one site from 1:00 pm to 3:00 pm).

Therefore, it is fair to assume that the majority of vehicles traveling on rural two-lane roads are traveling near or at their desired speeds as the traffic is usually in un-congested sate. In other words, on such roads traffic levels are generally low and road geometry characteristics play a significant role in their

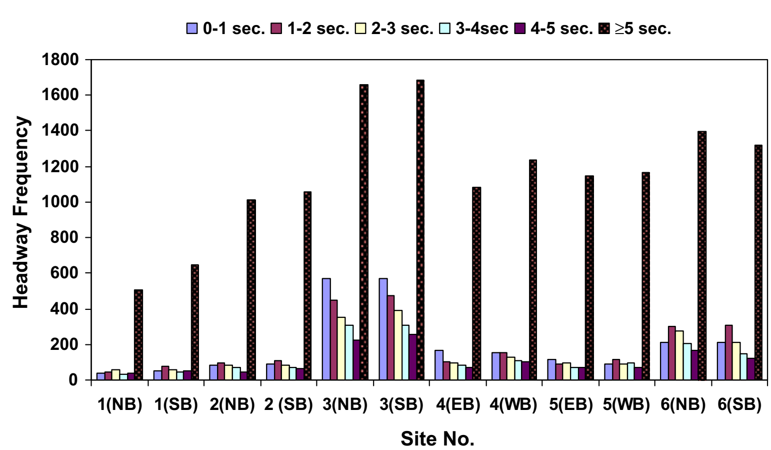

Figure 4 Frequency distribution of headway per direction of travel in the first six survey sites.

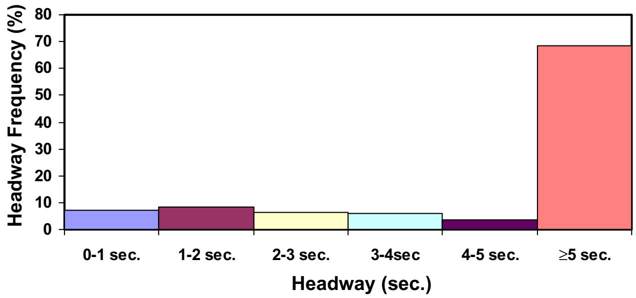

Figure 5 Frequency distribution of headway at one site during peak hour.

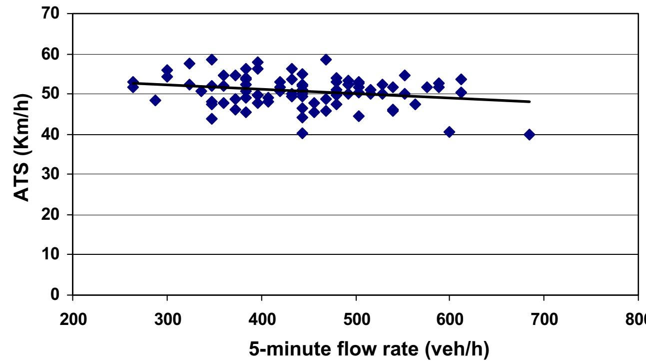

Figure 6 Relation between average travel speed (ATS) and 5 min. flow rate at one of the study sites.

operational performance and speed characteristics. Fig. 6 shows an example of the relation between average travel speed (ATS) and 5 min. flow rate at one of the study sites. From this figure it is clear that the variation of ATS with traffic volume is very low.

4.2. Driver compliance with speed limit

The analysis carried out in this section was based on speeds under free flow conditions for the 20 study sites; assuming headways equal to or more than 5 s. Also, the free flow speeds in both directions of travel were merged to a single distribution. All the study sites are subjected to 60 km/h speed limit (SPL), which is the national speed limit for intercity rural two-lane roads in Egypt. Table 2 shows the standard deviation of free flow speeds, the 50th percentile speed (median speed), the 85th percentile speed (operating speed), the absolute difference between speed limit and operating speed, the total percentage of drivers exceeding the speed limit at each site as well as the percentages of drivers exceeding the speed limit by 1–10, 10–20, or more than 20 km/h.

Several things are apparent on looking at the information presented in Table 2. Such things could include:

- The 85th percentile speed, in all sites, is almost higher than the 50th percentile speed by one standard deviation. This is comparable to that found in other studies [17] and could be compatible with a normal distribution.
- The 85th percentile speeds vary widely from site to site with a maximum of 88.60 km/h and a minimum of 51.1 km/h, even though the speed limit is constant and equals to 60 m/h in all sites.
- The drivers exceeding the speed limit at the study sites vary broadly from about 75%, as in site No. 1, to about 4%, as in site No. 15. On average the share of vehicles exceeding the speed limit is about 40%. Also, the percentages of drivers exceeding the speed limit by 1–10, 10–20, or more than 20 km/h are differed from site to site.

Based on the above points and Table 2, the results show the changes in 85th percentile speed among the study sites despite that they are in the same class (i.e. rural two-lane two-way). Previous studies [18,19] indicate that the length of straight section/tangent is the most important variable affecting a driver's choice of speed. It was also found that the curvature of the horizontal curves at each end of the straight section has an effect on the operating speed at such straight section. The local characteristics of straight section such as pavement width or shoulder width may not have significant impact on drivers' choice of speed at straight sections. This may explain also the variance in the observed speed data between the survey sites in terms of individuals exceeding the SPL regardless of the local geometry characteristics (i.e. pavement width or shoulder width). However development of the relationships between operating speed (85th percentile speed) and straight section characteristics is beyond the objective of this paper.

Moreover, the speed limit of 60 Km/h may not be the appropriate one in the majority of the study sites. Many speed studies have indicated that sensible and cautious drivers will most likely drive at the speed dictated by the roadway and traffic conditions rather than depending on posted speed limits. However, in order to consider roadway and traffic characteristics in selecting the most comfortable, safe and efficient speed limit, actual engineering field speed studies should be carried out. Normally, the 85th percentile speed should be selected as a primary factor in determining the posted speed limit [8].

Hashim [19] found that the absolute difference between speed limit and the 85th percentile speed/design speed plays a significant role in the case of killed or seriously injured accidents (KSI). His study proved that as this difference increases the KSI accident frequency increases. This would agree with the hypothesis that many drivers prefer to travel constantly near the speed limit. However the highway alignment may enable drivers to exceed the speed limit substantially, as in Table 2. Alternatively the alignment forces the drivers to drive well below the speed limit especially in the case of poor alignment (e.g. sharp curves), interrupting the homogeneity of drivers' speeds. Either of these could lead to severe accidents. This confirms that speed limits should usually be set near the 85th percentile speed. Similar conclusion was reported before by Milton and Mannering [20], since the 85th percentile speed is virtually equal to the design speed according to many design standards.

Based on the above dissection, the posted speed limit of 60 km/h could only be appropriate for sites 5, 6, 11, 13, 14, 15, 18 and 20. Fig. 7, as an example, shows the cumulative frequency distribution curves for sites 1 and 6. From this Figure, it is obvious that the two cumulative distributions are completely different; i.e. the difference between operating speeds

Table 2 Analysis of driver compliance with speed limit.

Site	Standard deviation (km/h)	V_{50} – Median speed (km/h)	V_{85} – Operating speed (km/h)	Abs. diff. bet. SPL and V_{85}	% exceeding SPL	% (1–10) km/h over SPL	% (10–20) km/h over SPL	% > 20 km/h over SPL
1	16.92	71.6	88.6	28.6	75.5	24.2	23.0	28.3
2	18.79	67.4	86.4	26.4	64.1	21.6	19.6	22.9
3	15.35	60.1	75.2	15.2	48.0	25.0	15.6	7.4
4	15.46	55.3	71	11	34.9	19.7	10.4	4.8
5	13.61	52.9	65.5	5.5	28.9	20.4	5.9	2.6
6	10.06	45.6	55.1	4.9	5.7	5.2	0.5	0.0
7	17.3	67.3	83.2	23.2	67.4	24.1	22.8	20.5
8	16.59	57.2	74.2	14.2	43.6	21.3	13.8	8.5
9	14.15	57.6	70.9	10.9	43.1	26.2	12.2	4.7
10	14.22	54	67.3	7.3	33.5	22.5	8.3	2.7
11	13.14	46.1	59.1	0.9	14.7	11.2	2.7	0.8
12	15.06	56.5	71.3	11.3	42.1	24.5	13.4	4.2
13	11.79	45.4	57.6	2.4	11.3	8.8	2	0.5
14	13.21	49.7	61.9	1.9	19.3	13.8	4	1.5
15	10.63	40.3	51.1	8.9	3.7	2.9	0.7	0.1
16	18.32	62.3	79.6	19.6	55.3	20.9	19.5	14.9
17	16.24	58.3	73.8	13.8	46.9	23.5	16	7.4
18	12.99	51.1	63.4	3.4	24.2	19.2	4	1
19	15.93	57.2	72.4	12.4	42.7	23.3	13.7	5.7
20	12.46	50.4	63	3	21.2	15.4	4.5	1.3

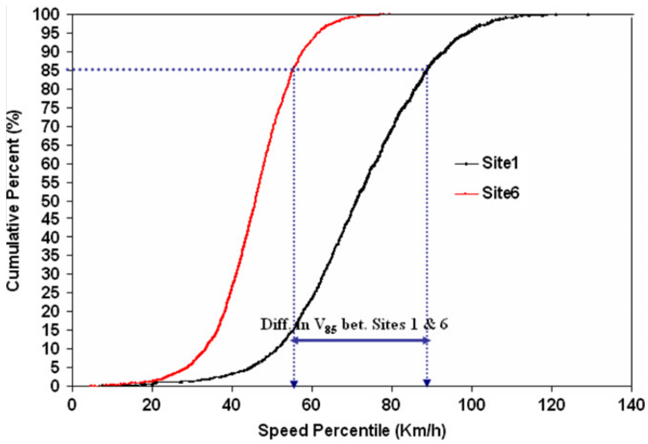

Figure 7 Speed cumulative frequency distribution curves for sites 1 and 6.

(V_{85}) is very large. Therefore, using the same speed limit (60 Km/h) for both sites may not be completely correct.

The correct way to solve this situation is the establishment of speed zoning of reasonable and safe speed limits on roadways based on an engineering study. A speed zone is a section of highway where a speed limit different from the statutory speed limit has been established [21]. The purpose of speed zoning is to establish a speed limit that is reasonable and safe for a given section of a roadway. Speed for zoning should be based on the principle of setting speed limits as near as practicable to the speed at or below which 85% of drivers are traveling. When the speed limit is below the 85th percentile, a few drivers will obey the posted speed. Most, however, will drive at a speed comfortable to them, probably more than the posted speed limit. Due to the speed differential, an increase in accidents may result. Unfortunately, accident data to investigate the association between the variance of 85th percentile speed and accident rates are not available, in this study.

Care should be exercised in interpreting the higher speed limits in some sites. Raising the speed limit, without engineering study, may associated with an increase in accident frequency, but this research points to that it is the differences between the 85th percentile and speed limit that is more likely to cause an increase speed differential and consequently in accident frequency.

4.3. Examining speed distributions

In this section of analysis the free flow speed data (headway $\geqslant 5$ s.) from each direction were considered independently, creating a speed distribution for each direction of travel per site. The Kolmogorov–Smirnov one-sample test (1-sample K–S test) was used to ascertain whether these speed distributions have been drawn from a normal population. The Kolmogorov–Smirnov one-sample test for normality is based on the maximum difference between the sample cumulative distribution and the hypothesized cumulative distribution. This goodness-of-fit test tests whether the observations could reasonably have come from the specified distribution (i.e. normal distribution in this case). If the "D" statistic, the most extreme absolute difference, is significant, then the hypothesis that the distribution is normal should be rejected. The test was applied for speed data at each direction of travel and the results are presented in Table 3. From this table, the P-value, listed here as Asymp. sig. (2-tailed), is greater than 0.05 ($P > 0.05$) in the vast majority of the cases. Then there is no evidence against the null hypothesis that the speed samples have been drawn from a normal distribution. In other words, the speed data are normally distributed.

Additionally, the spread ratio parameter (SR) that is introduced by Dey et al. [16] is used in this section and presented in Table 3. The SR is defined as: $\mathrm{SR} = \frac{V_{85}-V_{50}}{V_{50}-V_{15}}$ where: V_{15}, V_{50}, and V_{85} are 15th, 50th, and 85th speeds, respectively. The calculated SR values ranged from 0.84 to 1.15 which means that the speed data will be represented by a unimodal curve as SR values lie between 0.69 and 1.346, according to Dey et al. findings [16].

These results may have a great impact on many traffic studies as a correct description of speed distribution will be extremely useful in congestion and traffic simulation studies, geometric design of roads and many others.

5. Summary of findings and recommendations

The current paper presented analyses which addressed three different aspects of speed characteristics on rural two-lane highways. The most important findings of this paper are:

1. Empirical observations showed that the 85th percentile speed takes a constant value at headway equal to 5 s or more. This indicates that free flow speeds can be defined for time headway between successive vehicles equal to 5 s or more. Also, the results showed that the majority of vehicles traveling on rural two-lane roads are traveling near or at their desired speeds as more than 60% have headway values of 5 s or more.
2. The percentage of drivers exceeding the speed limit varies widely from site to site. On average the share of drivers exceeding the speed limit is about 40%. Therefore the speed limit of 60 Km/h may not be appropriate for the majority of the study sites. The 85th percentile speed should be selected as a primary factor in determining the posted speed limit for any homogenous roadway zone. The purpose of a speed zoning is to establish a speed limit that is reasonable and safe for a given zone of a roadway. Such zoning speed limit could be different from the statutory speed limit.
3. The Kolmogorov–Smirnov one-sample test (1-sample K–S test) was used to determine whether the speed distributions at the study sites have been drawn from a normal population. The analysis confirmed that the speed data are normally distributed. Additionally the spread ratios (SR) show that the speed data will be represented by a unimodal curve.

Finally, Future research should be conducted to extend all aspects of this research using comprehensive field data from various regions and Governorates in Egypt not only for rural two-lane highways but also for rural multilane highways.

Table 3 1-sample K–S test and speed ratio at different sites.

Site	Dir	1-sample K–S test		Speed ratio (SR) analysis			
		D	Asymp. sig. (2-tailed)	V_{15}	V_{50}	V_{85}	SR
1	NB	0.026	0.883	53.6	70.2	87.8	1.06
	SB	0.027	0.747	56.2	71.3	88.6	1.15
2	NB	0.019	0.849	46.4	64.1	82.4	1.03
	SB	0.023	0.739	50.4	70.6	88.9	0.91
3	NB	0.029	0.133	37.4	52.2	64.1	0.89
	SB	0.024	0.320	38.9	53.6	68.0	1.09
4	EB	0.023	0.626	42.8	60.1	75.6	0.90
	WB	0.022	0.562	43.6	59.8	74.9	0.93
5	EB	0.039	0.068	36.7	51.5	63.9	0.84
	WB	0.020	0.743	41.1	60.5	76.7	0.84
6	NB	0.028	0.230	37.1	47.5	58.3	1.04
	SB	0.028	0.270	35.6	43.9	52.3	1.01
7	EB	0.041	0.077	47.2	65.5	81.0	0.85
	WB	0.034	0.196	49.3	68.1	84.5	0.87
8	NB	0.027	0.505	40.0	55.8	72.0	1.03
	SB	0.033	0.175	41.8	59.8	76.0	0.90
9	EB	0.021	0.719	41.8	57.2	70.9	0.89
	WB	0.038	0.052	42.8	57.2	70.9	0.95
10	EB	0.021	0.747	38.9	52.9	65.5	0.90
	WB	0.034	0.100	39.6	55.1	68.8	0.88
11	NB	0.027	0.427	49.3	71.3	90.4	0.87
	SB	0.039	0.074	49.0	67.3	82.8	0.85
12	EB	0.040	0.294	31.0	41.4	50.8	0.90
	WB	0.048	0.164	38.9	53.3	65.9	0.88
13	NB	0.041	0.014	35.6	44.3	52.2	0.91
	SB	0.030	0.165	41.1	51.8	62.6	1.01
14	EB	0.023	0.721	36.0	48.6	60.1	0.91
	WB	0.034	0.336	37.4	50.8	63.7	0.96
15	NB	0.021	0.788	29.5	39.2	48.2	0.93
	SB	0.044	0.061	29.2	41.4	54.7	1.09
16	NB	0.036	0.398	40.7	64.4	83.9	0.82
	SB	0.055	0.048	43.6	60.8	75.6	0.86
17	EB	0.063	0.100	37.4	54.4	66.6	0.72
	WB	0.066	0.050	44.3	64.4	79.6	0.76
18	NB	0.045	0.548	40.3	54.7	67.0	0.85
	SB	0.052	0.286	38.2	50.0	60.8	0.92
19	EB	0.065	0.069	41.8	60.5	74.5	0.75
	WB	0.035	0.673	42.5	57.6	70.6	0.86
20	EB	0.033	0.299	36.7	49.3	60.1	0.86
	WB	0.024	0.739	39.6	52.6	65.2	0.97

References

[1] Homburger WS, Hall JW, Loutzenheiser RC, Reilly WR. Fundamentals of traffic engineering. Institute of transportation studies. Berkeley: University of California; 1996.

[2] Poe CM, Tarris JP, Mason Jr JM. Relationship of operating speed to roadway geometric design speed, PTI 9606. FHWA-RD-96-024, FHWA. McLean (VA): US Department of Transportation; 1996.

[3] Fitzpatrick K, Miaou S, Brewer M, Carlson P, Wooldridge MD. Exploration of the relationships between operating speed and roadway features. In: Proc. of 82nd annual meeting of transportation research board. Washington (DC); 2003.

[4] Lamm R, Chouriri EM, Mailaender T. Comparison of operating speeds on dry and wet Pavements of two-lane rural highways. Transportation Research Record, Transportation Research Board, 1280. Washington (DC): National Research Council; 1990, p. 199–207.

[5] Lin F, Su C, Huang H. Uniform criteria for level-of-service analysis of freeways. J Transport Eng, ASCE 1996;122(2):123–30.

[6] Cunagin WD, Chang EP. Effects of trucks on freeway vehicle headways under off-peak flow conditions. Transportation research record, transportation research board, vol. 869. Washington (DC): National Research Council; 1982, p. 54–9.

[7] Radwan AE, Kalevela S. Investigation of the effect of change in vehicular characteristics on highway capacity and level of service. Transportation research record, transportation research board, vol. 1005. Washington (DC): National Research Council; 1985, p. 65–71.

[8] Najjar Y, Stokes R, Russell E. Setting speed limits on Kansas two-lane highway: Neuronet approach. Transportation research record, transportation research board, vol. 1708. Washington (DC): National Research Council; 2000, p. 20–27.

[9] Harkey DL, Robertson HD, Davis SE. Assessment of current speed zoning criteria, Transportation Research Record, Transportation research board, vol. 1281. Washington (DC): National Research Council; 1990, p. 40–51.

[10] Federal Highway Administration, Managing speed: Review of current practice for setting and enforcing speed limits. TRB Special Report 254, FHWA. US Department of Transportation; 1998.

[11] Islam MN, Seneviratne PN. Evaluation of design consistency of two-lane rural highways. ITE J 1994;64(2):28–31.
[12] Kerman JA, McDonald M, Mintsis GA. Do vehicles slow down in bends? A study into road curvature. In: Proc. of driver behaviour and design, PTRC. 10th Summer annual meeting, seminar K; 1982. p. 57–67.
[13] Leong HJW. The distribution and trend of free speeds on two-lane two-way rural highways in New South Wales. In: Proc. of 4th Australian Road research board conf., part 1. Australian Road Research Board, Vermont South, Victoria, Australia; 1968. p. 791–808.
[14] McLean JR. Observed speed distributions and rural road traffic operations. In: Proc. of 9th Australian road research board conf., part 5, Australian Road Research Board, Vermont South, Victoria, Australia; 1978. p. 235–44.
[15] Kumar VM, Rao SK. Headway and speed studies on two-lane highways. Indian Highways 1998;26(5):23–36.
[16] Dey PP, Chandra S, Gangopadhaya S. Speed distribution curves under mixed traffic conditions. J Transport Eng, ASCE 2006;132(6):475–81.
[17] Taylor MC, Baruya A, Kennedy JV. Relationship between speed and accidents on rural single-carriageway roads. TRL 511. Crowthorne: Transport and Road Research Laboratory; 2002.
[18] Polus A, Fitzpatrick K, Fambro D. Predicting operating speeds on tangent sections of two-lane rural highways. Transportation research record. Transportation research board, vol. 1737. Washington (DC): National Research Council; 2000, p. 50–7.
[19] Hashim IH. Exploring the relationship between safety and the consistency of geometry and speed on rural single carriageway. In: Proc. of 38th UTSG annual meeting. Dublin, Ireland: Trinity College Dublin; 2006.
[20] Milton J, Mannering F. The relationship among highway geometrics, traffic-related elements and motor-vehicle accident frequencies. Transportation 1998;25:395–413.
[21] Institute of Transportation Engineers (ITE). Speed zone guidelines: a proposed recommended practice. RP-024, ITE, Washington (DC); 1993.

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