GPS Vehicle Tracking at Urban Areas

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Abstract

The main objectives of this research were to utilize vehicle tracking technique of GPS to measure and analyze operating speed, travel time, and delay time for urban arterials and to develop operating speed models to estimate speed profile based on roadway environments. Statistical regressions were carried out to establish useful models to estimate operating speed at segments and horizontal curves, and acceleration and deceleration distances from mentioned variables. Results of this investigation indicated that: 1) On-street parking, section width, corridor function, number of median opening, number of horizontal curves, length of corridor, number of access points, and number of humps were found to be the most significant contributors to operating speed while the significant variables of horizontal curve model were entering speed, deflection angle, posted speed limit, and combination of horizontal curve and vertical curve; 2) Minimum length of study corridor can be determined after analyzing and understanding vehicle acceleration and deceleration characteristics from vehicle tracking of GPS that related with final speeds or approach speeds, and posted speed limits.

Key Words: Vehicle Tracking; GPS; Operating Speed; Travel Time; Urban Arterials.

1. Introduction

In general, traffic management strongly depends on the availability of accurate estimates and predictions of traffic condition. Travel speed data collection is an integral component of traffic engineering studies where traffic characteristics are much varies throughout the daytime. Travel speed and delay data can be derived from travel time data by using a reference desired/acceptable travel time or speed.

Global Positioning System (GPS) should have a role in data collection. GPS receivers can record location and speed automatically at regular sampling periods. As a result, large amounts of reliable travel time and speed data can be collected and processed.

Traffic congestion is a critical problem in urban areas. Congestion usually results in time delays, increased fuel consumption, pollution, stress, health hazards, and added vehicle wear. Throughout the past several decades, traffic engineers, planners, researchers, and transportation agencies have expended much effort trying to understand how urban arterials systems operate. Thus, GPS vehicle tracking technique was suggested to derive travel speed, travel time, and delay at constant interval along the arterials.

The practice of the design speed concept demonstrates that current design approaches do not always result in a consistent roadway design. Several studies (McLean [1], Garber [2[, Krammes [3], and Fitzpatrick [4]) have found the disparity between operating speeds and design speeds. To explain the disparity, many researchers have analyzed the limitations in the selection and application process of the design speed. In several studies, researchers have proposed a new performance-based design approach with the incorporation of operating speed to overcome the limitations of the design speed concept.

Operating speed depends on a variety of variables not only operational factors but also variables related to geometrical and land use characteristics which may be the main cause of congestion, so this research will focus on the relevance of these variables to travel time and delay. Under this procedure, the geometric parameters of the roadways are selected based on their influences on the desired operating speeds.

The objectives of this research were to utilize GPS to measure travel time, operating speed, and delay time for each segment of the arterials in urban areas. Moreover, developing operating speed models to estimate and analyze operating speeds of urban arterials using continuous speed profile based on roadway environments, including alignment, cross-section characteristics, roadside features, and adjacent land uses.

2. Literature Review

Recent research has demonstrated the feasibility of using GPS technology for automating the travel time data collection, reduction, and reporting when using a probe vehicle (Quiroga and Bullock [5] and Quiroga [6]). The new automated procedures provide consistency, automation, better levels of resolution, and better accuracy in measuring travel time and speed than traditional techniques. The average speeds of the vehicles when monitored over a period of time would help identify the potential congestion regions. The average speed of vehicles is more widely applicable as a measure of effectiveness (MOE) for freeways rather than for arterials. This is because large variations in vehicles speed on arterials occur due to interruptions in the traffic flow through intersections, accesses, merges and other driver behavior parameters. Consequently, average speeds can be used as a standard for measuring arterial effectiveness not by individual points but along an entire corridor. However, this means that manual corridor travel studies or GPS vehicles are necessary to identify this parameter on arterials, Martin [7].

The Highway Capacity Manual (HCM, 2000) indicates that the speed of vehicles on urban streets is influenced by street environment, interaction among vehicles, and traffic control. The HCM further defines the street environment as the geometric characteristics of the facility, the character of roadside activity, and adjacent land use. The interaction among vehicles is due to traffic density, the proportion of trucks and buses, and turning movements. Traffic control refers to induced delays to the traffic stream such as the addition of signals and signs. Most often several paths connect an origin and a destination, and the rationale for selecting a given path might be based on route attributes or personal characteristics of the traveler. These factors in path choice are summarized in Table 1, indicating that path choice is a very complex process, Jan, et al. [8].

Physical road and roadside characteristics directly impact the operating speed a driver selects. In general, past research has included the following eight "geometric" categories that strongly influence operating speed:

1. Horizontal curvature,
2. Vertical grade (and length of grade),
3. Available sight distance,
4. Number of lanes,
5. Surface type and condition,
6. Number of access points (intersections/driveways),
7. Lateral clearance, and
8. Land use type and density.

Table 1: Factors Affecting Path Choice

Traveler	Age, sex, life cycle, income level, education, household structure, race, profession, length of residence, number of drivers in family, number of cars in family, etc.	
Route	Road	Travel time, travel cost, speed limits, waiting time. Type of road, width, length, number of lanes, angularity, intersection, bridges, slopes, etc.
	Traffic	Traffic density, congestion, number of turns, stop signs and traffic lights, travel speed, parking, probability of accident, reliability and variability in travel time, etc.
	Environment	Aesthetics, land use along route, scenery, easy pick-up/drop-off, etc.
Trip	Trip purpose, time budget, time of the trip, mode use, number of travelers	
Circumstances	Weather conditions, day/night, accident en-route, route and traffic information, etc.	

(Krammes [10], Harwood [11], and Fitzpatrick [12]) have suggested the incorporation of operating speed model with a feedback loop into the design speed concept. Under this approach, the geometric elements of roadways are selected based on their influences on the desired operating speeds. Generally, this method predicts the operating speed along the alignments, checks the design consistency, and if necessary, adjusts the design features until the predicted operating speeds are consistent with the design speeds.

Levinson [13] found that flow has a small impact on link speed, each 1000 vehicles per lane per hour reduces speed by 4 - 8 kph. Longer links have higher speeds, indicating that they more closely approximate free-flow conditions. Wiley and Keyser [14] found that traffic flow-rate (vph) was not sensitive enough to consistently identify the occurrence of congestion.

Fitzpatrick *et al.* [4] found that the most important factors in selecting a design speed value were functional classification and speed limit. Once the design speed is selected, the AASHTO design policy presents minimum design values for geometric elements to incorporate safety factors. Designers can choose geometric characteristic above minimum values based on the terrain and economic constraints.

Al-Masaeid [15] investigated the consistency of horizontal alignment characteristics on rural highway for different vehicle classes. Operating speeds for 22 rural roads were collected. The speed of passenger cars, light trucks, and trucks was measured on tangent and horizontal curves. In the analysis, the speed reduction between tangent and curve or successive curves was considered the inconsistency indicator. It was found that the degree of curve, length of vertical curve, gradient, and pavement condition had a significant effect on consistency of simple horizontal curves.

Poe and Mason [16] used a mixed-model statistical approach to analyze the influence of geometric, roadside, driver, and traffic control features on drivers' operating speeds. They considered the following variables during model development:

- Geometric measures (e.g., curve radius, grade, sight distance),
- Cross-section (e.g., lane width, road configuration),
- Roadside (e.g., access density, land use, roadside lateral obstructions),
- Traffic control devices (e.g., speed limit, pavement marking), and
- Driver / vehicle (e.g., gender, age, number of passengers, vehicle type).

The following model was developed:

$$V_{85}^{1} = 49.59 + 0.5 * DC - 0.35 * G + 0.74 * W - 0.74 * HR \tag{1}$$

$$V_{85}^{2} = 51.13 - 0.1 * DC - 0.24 * G - 0.01 * W - 0.57 * HR \tag{2}$$

$$V_{85}^{3} = 48.82 - 0.14 * DC - 0.75 * G - 0.12 * W - 0.12 * HR \tag{3}$$

$$V_{85}^{4} = 43.41 - 0.11 * DC - 0.12 * G + 1.07 * W + 0.3 * HR \tag{4}$$

Where,

V851 = 85th percentile speed (km/h) at 150 ft before the beginning of curve (PC160),
V852 = 85th percentile speed (km/h) at the beginning of curve (PC),
V853 = 85th percentile speed (km/h) at the middle of curve (MC),
V854 = 85th percentile speed (km/h) at the end of curve (PT),
DC = degree of curvature (degrees per 30m),

G = grade (%),
W = lane width (m), and
HR = hazard rating (0 to 4).

3. Data Collection

Three types of data were collected in this study:

1. Vehicle travel time and its speed: Vehicle tracking technique using GPS was used to collect travel time and operating speed data.
2. Road environment features: cross section characteristics, features along segments like humps, and land use were included.
3. Traffic characteristics: Hourly traffic volume, pedestrian volume, and parking occupancy rate were investigated.

3.1 GPS Vehicle Tracking Technique

A GPS receiver coupled with a portable computer was used to record the test vehicles position and speed at time intervals as frequent as every second. Minimum sample sizes or number of travel time runs can be calculated using Equation (5) by substituting with c.v. = 9, e = 10% and 95% confidence level, the sample size was 6 runs. At our research work, the arterial streets of Irbid City, Jordan including circular and radial roads that offer mobility and accessibility throughout the city were included.

$$Smplesize, n = \left(\frac{z \times c.v.}{e} \right)^2 \qquad (5)$$

Two people were used to collect vehicle tracking data equipped with GPS unit. One as driver and the second operates the GPS unit.

3.2 Geometry and Land use Characteristics

Also the following Roadway characteristics and land use data were collected for segments of arterials using tape and field survey:

- Land use type (commercial, residential, industrial, and university).
- Roadway class (arterial or secondary).
- Function (radial or circular).
- Number of lanes.
- Type of section (Divided or one way).
- Number of humps.
- Number of median opening.
- Number of road crossing.

- Number of access points.
- Number of schools.
- Length of segment (m).
- Segment width (m).
- Median width (m).
- Posted speed limit (km/hr).

A new scheme was developed to extract the horizontal curves characteristics from digital images. The grade of entire segment was extracted from one-second GPS point data by subtract the altitude of each point from the following point along the segment. Then, the difference in elevation divided by the length of segment will be the grade of segment.

3.3 Operational Factors Data

Traffic volumes were recorded in April 2006 based on manual traffic counts for the chosen 107 segments. Traffic counts were conducted at the middle of the block of the two directions of the road at 15-minutes interval. Traffic volumes at 39 intersections were also collected.

Pedestrian volumes were also counted during spring time from April through May, 2006. The counts of pedestrian volume were performed for 40 meter segment lengths at the middle of the block where pedestrian crossed the arterial, Whereas, intersection pedestrian volume counts were performed for 20 meter from intersection of each leg. Parking occupancy at certain time was measured for the two direction of segment.

Since the speed data were collected at one-second interval, an acceleration and deceleration rates for one second were calculated using Equation 6 and 7.

$$a_n = (v_n - v_{n-1})/3.6(t_n - t_{n-1}) \qquad 0 < i < n \qquad (6)$$

$$d_n = (v_n - v_{n-1})/3.6(t_n - t_{n-1}) \qquad 0 < i < n \qquad (7)$$

Where,

a_n = estimated acceleration rate at the nth second (m/s^2),
d_n = estimated absolute deceleration rate at the nth second (m/s^2), and
v_n = speed at the nth second (km/hr)

4. Models Development

4.1 Approach

SPSS-software package was used to develop the math model, based on multiple and stepwise linear regression analysis to generate models of operating speed at tangent and horizontal curves, acceleration distance for existing several land use, road environment features, and traffic characteristics.

The speed profile was generated for each trip by plotting operating speed versus distance along each of the study segments. Then, the average acceleration and deceleration data of each trip was removed based on the acceleration and deceleration distances, if the site is delimited by two traffic controls. Only daytime trips during off- peak time period were used to increase the likelihood of sampling free-flow speeds.

Speed limit was highly correlated with operating speeds because drivers tend to drive at higher speeds on roads with higher speed limits. Therefore, speed limit was not used as an independent variable.

4.2 Operating Speed Models for Segment

The predicting dependent variable was operating speed. Independent variables in the model included: Land use, Road environment features, and Traffic characteristics. Table 2 shows description of the independent variables for operating speed models. The developed model for operating speed was:

$$\begin{aligned} V_{Operating} &= 17.364 - 6.078X_1 + 2.905X_2 - 3.514X_3 - 1.72X_4 \\ &- 3.859X_5 + 0.01X_6 - 0.821X_7 + 7.794X_8 - 1.538X_9 \end{aligned} \qquad R^2{}_{Adj} = 0.72 \qquad (8)$$

Where,

$V_{operating}$ = Operating speed at segment (km/h),

X_1 = On-Street parking density-indicator.
(0% = 0, Low = 1, mid = 2, High =3, Very high = 4)

X_2 = Width of section of segment (m).

X_3 = Function of Segment-indicator (Ring road = 1, Arterial = 2).

X_4 = Number of median opening at segment.

X_5 = Number of Horizontal curves at segment.

X_6 = Length of segment between controlled intersection (m).

X_7 = Number of access points at segment.

X_8 = Type of section-indicator (1= One way, 2 = Divided)

X_9 = Number of humps at segment.

Table 2: Description of Independent Variables of Operating Speed Models

	Variables	Symbol	***Description***
Road Environment Features	Lane Number	No_Lane	Number of lane in Segment
	Section Type. Indicator	Type_secti	Type of Segment Condition
			1: Undivided
			2: Divided
	Hump Number	No_of_Hump	Number of Humps along Segment
	Opening Number	No_of_Open	Number of Median Opening along Segment
	Road crossing Number	No_Roadcro	Number of Road crossing at Median Opening
	Access Number	No_access	Number of Access Roads along Segment
	Length	Length	Length of Segment (m)
	No of H.C	No_HC	Number of Horizontal Curve along Segment
	Section Width	Sec_Width	Segment Width in Its Direction (m)
	Median Width	Med_Width	Median Width of Segment
	Grade	G	Percent of Grade from Start Point to Ending Point (%)
Operational Characteristics	Parking Rate. Indicator	Parkrate8	Percent of On-Street Parking Space along Segment
			1: 0% of on-street parking is occupied
			2: Low on-street parking is occupied
			3: Mid on-street parking is occupied
			4: High on-street parking is occupied
	Traffic Volume	Vol	Traffic Volume of Mid-Block in Segment (Veh/h)
	Pedestrian Volume	Ped	Pedestrian Crossing Volume of (50m) section
			at Mid-Block in Segment (Veh/h)
Land use	Land use Indicator	Land use	1: Residential; 2: Commercial
			3: University; 4: Industrial
Others	Function. Indicator	Function	Segment Function in Roadway Network
			1: Ring road
			2: Arterial
	Speed Limit	Speed limit	Posted Speed Limit (km/h)

On-street parking occupancy rate, width of segment, and functional classification were the most significant variables affecting on operating speed.

Existence of on-street parking was associated with lower operating speeds. On-street parking indicated potential hazards due to possible vehicle door opening, parking maneuvers, and presence of pedestrians as well as made a street looks narrower. The ring road segments had higher operating speed than arterial segments because of ring road segments had a speed limit higher than arterial segments that encourage drivers to increase their speeds. Number of median opening in segments had a significant effect on driver's speeds. In fact drivers would be cautious at opening due to expected traffic conflicts at these openings.

Drivers tend to select higher operating speeds at roads of longer length of segments and travel at higher speeds when there was less number of access points, because of an unexpected entry of low speed vehicles.

4.3 Operating Speed Models for Horizontal Curves

Predicted dependent variable was the driver speed (operating speed) at urban horizontal curves. Independent variables in the model development included horizontal curve characteristics, land use, and road environment features. Table 3 shows the description of independent variables.

Final operating speed model of urban horizontal curves is shown in equation (9):

$$V_h = -5.306 + 0.787V_e - 0.12D + 0.256V_l - 0.561G \quad R^2{}_{Adj} = 0.97 \qquad (9)$$

Where,

V_h = Operating speed at urban horizontal curve (km/h),
V_e = Entering speed at the beginning of horizontal curve (km/h),
D = Deflection angle of horizontal curve in degrees,
V_ℓ= Posted speed limit at segment (km/h), and
G = Combination of horizontal curve and vertical curve

The model indicates that entering speed at the point of curvature of a horizontal curve (P.C.) has the most significant influence on driver's speed in urban horizontal curves. This finding is logical due to change of curvature from maximum radius at tangent to definite value at the curve and sudden lower curvature. Drivers tend to travel at higher speeds on horizontal curve having lower degree of curvature, to be consistent with operating speed of segments. Higher posted speed limit encourages drivers to steer vehicles with higher operating speed at urban horizontal curves. Moreover, the presence of gradient at horizontal curves influenced the driver's speed. Driver's speeds were reduced due to the presence of horizontal curves, decrease of sight, and potential deceleration caused by grade.

Table 3: Description of Independent Variables for horizontal curves model

	Variables	***Description***
Horizontal Curve Characteristics	Radius	Radius of curvature (m)
	Deflection Angle	Deflection angle of curve in degrees
	Degree of Curvature	Degree of curvature in degrees
	Curve Length	Length of curve (m)
Road Environment Features	Lane Number	Number of lane in Segment
	Section Type. Indicator	Type of Segment Condition
		1: Undivided
		2: Divided
	Section Width	Segment Width in Its Direction (m)
	Grade	Percent of Grade from Start Point to Ending Point (%)
Land use	Land use Indicator	1: Residential
		2: Commercial
		3: University
		4: Industrial
Others	Function. Indicator	Segment Function in Roadway Network
		1: Ring road
		2: Arterial
	Entering Speed	Vehicle speed at B.C (km/h)
	Speed Limit	Posted Speed Limit (km/h)

4.4 Acceleration Distances Model Development

Equation (10) shows the developed model of acceleration distance.

$$D_a = -44.72 + 4.28V_f - 0.885V_i - 0.0318HV + 22.208 \times Landuse1.Indicator + 16.57 ParkingRate1.Indicator \qquad R^2 = 0.61 \qquad (10)$$

Where,

D_a = Acceleration Distance Required to achieve Final Speed (m),

V_f = Final Speed at Acceleration Stopped (km/h),

V_i = Initial Speed at Beginning of Acceleration (km/h),

HV = Hourly Traffic Volume (Veh/h),

Land use-indicator is as follow:

- if residential, Land use-indicator = 1
- if commercial, university, and industrial, Landuse1.indicator = 0

ParkingRate1.indicator is as follow

- if there is low on-street parking, Parking Rate-indicator = 1
- if there is mid on-street parking, Parking Rate-indicator = 0
- if there is high on-street parking, Parking Rate-indicator = 0

Driver's acceleration distance depended on traffic volume density at the beginning of segment. In fact, acceleration distance decreases when traffic volume increased. That was due to driver feeling to release rapidly from surrounding vehicles. While, the adjacent land use of segments had significant influence on driver's acceleration distance. The model indicated that segments in industrial or university with more vehicles and pedestrian activities needed more acceleration distance. Drivers tend to be more cautious around intersections where there were more pedestrian activities. Thus, so they require more acceleration distance. Percent of on-street parking had significant influence on driver's acceleration distance. The model indicated that drivers needed more distance to achieve the desired speed in arterial segments that had high percentage of on-street parking. Thus drivers may feel more curious on safety resulting in increasing the acceleration distances.

4.5 Deceleration Model Development

The developed model of deceleration distance is shown in equation (11) where the selected variables were significant at the 95% level.

$$\begin{aligned} D_d &= 45.864 + 0.675 V_a + 0.016 \times Length - \\ & 2.33 \times G + 6.607 \times Landuse1.Indicator - \\ & 9.813 ParkingRate1.Indicator \end{aligned} \qquad R^2 = 0.27 \qquad (11)$$

Where,

D_d = Deceleration Distance Required to stop or yield (m),

V_a = Approach Speed before Deceleration begins (km/h),

Length = Length of segment (m),

G = Grade of entire Segment (%),

Land use-indicator is as follow:

- if residential, Land use-indicator = 1
- if commercial, university, and industrial, Landuse1.indicator = 0

Parking Rate-indicator is as follow

- if there is low on-street parking, Parking Rate-indicator = 1
- if there is mid on-street parking, Parking Rate-indicator = 0

- if there is high on-street parking, Parking Rate-indicator = 0

This was a demonstration that the deceleration model was not reliable. Thus, it is an indication of missing variables that should be included in the model.

5. Analysis and Discussion

5.1 Vehicle Acceleration and Deceleration Characteristics Analysis

The group-level means for average acceleration rates; i.e. acceleration time and distance for each final speed group shown in Table 4 was computed. One important application of this finding is the estimation of driver's acceleration when knowing the final speed values.

Table 4: Average Acceleration Rate, Time and Distance According Final Speeds

Final speed	80-90	70-80	60-70	50-60	40-50
Average Acc. Time	18.5	16.7	15.9	14.0	13.1
Average Acc. rates	0.961	0.771	0.696	0.728	0.611
Average Acc. Distance	274	234	193	140	104
Average Initial Speed	24	31	26	21	17
85% Acc. Distance	334.3	295.05	239.6	190.65	149.35
Number of trip	12	18	45	70	52

Using the acceleration profile data that was extracted using GPS at every second, average acceleration rates at one-second interval for all trips for each final speed group were computed for the first 15 seconds prior to stop.

These rates were weighted by sample size at each second. Figure 1 shows the acceleration speed profiles with different final speeds ranging from 40 to 90 km/hr. This Figure indicated that drivers normally tended to apply higher acceleration rates at the beginning and then decreased acceleration rates with the increase of their speeds. Final speed group of (80-90) km/hr had a higher acceleration rate at the beginning more than other groups.

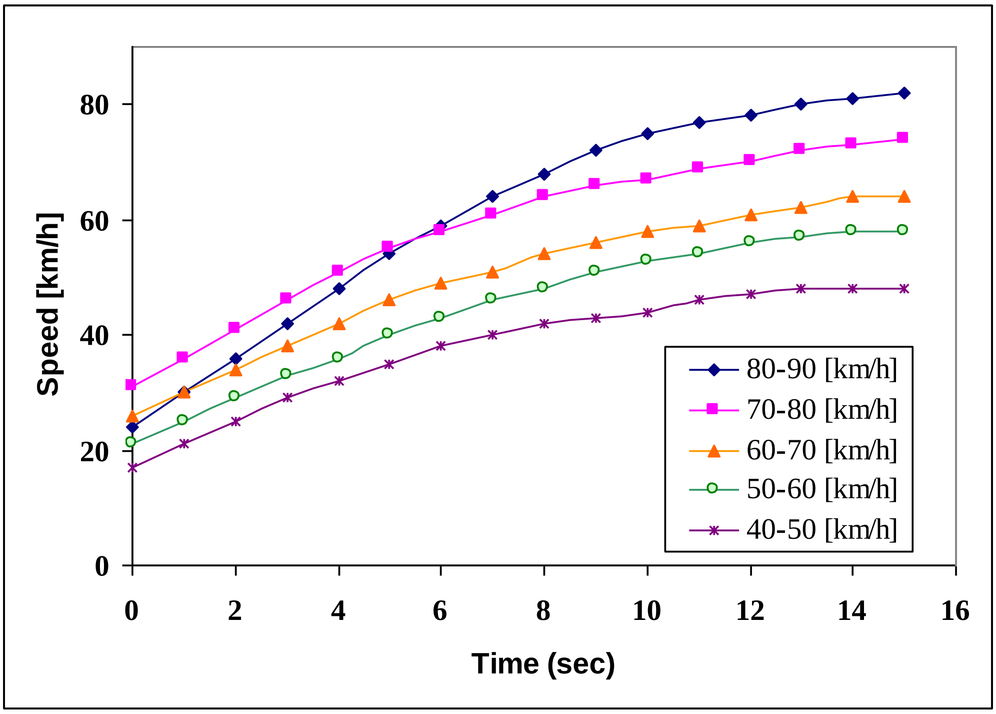

Figure 1 Acceleration Speed Profile with Different Final Speeds.

Table 5 shows the average deceleration rate, time, and distance on roads with different approach speeds. Approach speed had a significant influence on drivers’ deceleration behavior. Drivers with higher approach speed normally decelerated over longer time and distance.

Using the second-by-second GPS speed and time measurements, deceleration profile and average deceleration rates for one-second during the final 8 seconds prior stop were plotted. Figure 2 demonstrates the last 8 seconds observations in a plot of speed versus time. The higher initial deceleration rates were associated with higher approach speeds. However, this relationship was not applicable to the last three seconds prior to stop. It was observed that during the final two seconds, all drivers decelerated at similar rates regardless of their approach speeds.

Table 5: Average Deceleration Rate, Time and Distance According Approach Speeds

Approach Speed	80-90	70-80	60-70	50-60	40-50
Average Dec. Time	7.8	6.9	6.8	6.0	5.1
Average Deceleration	-2.009	-2.050	-1.919	-1.881	-1.981
Average Dec. Distance	128	98	82	60	47
Average Final Speed	33	27	23	21	15
Average 85% Dec. Distance	168.8	116.55	103	84.9	77.55
Number of trip	9	22	51	55	124

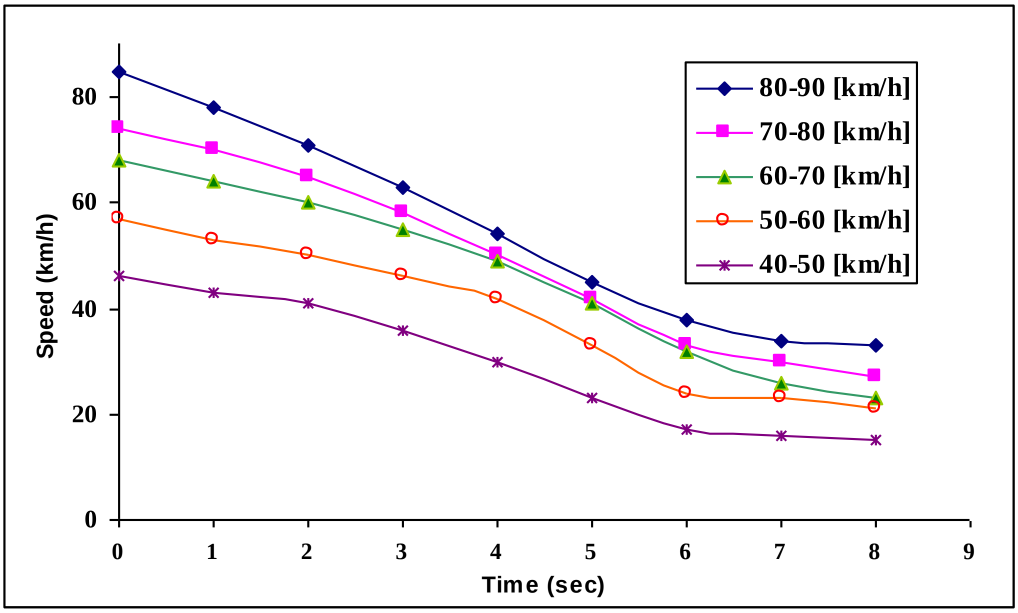

Figure 2 Deceleration Speeds Profiles with Different Approach Speeds

5.2 Minimum Segment Length

The driver's acceleration and deceleration behaviors on urban streets that was evaluated in the previous sections could be used as a guidance to determine the minimum length of the segments to be studied between two intersections with traffic control devices. The minimum length of segment should be at least equal to the length of acceleration zone plus the length of deceleration zone in order to make drivers able to accelerate to the desired speeds under free-flow conditions. Because the acceleration and deceleration approach speeds are unknown, output of average values of this research work could be used to estimate the minimum length of segments required at any selected speed limit.

Figure 3 depicts a second degree polynomial relationship between the minimum segment length and posted speed limit. The output of this Figure could be also used for the purpose of finding the minimum segment length from the posted speed value.

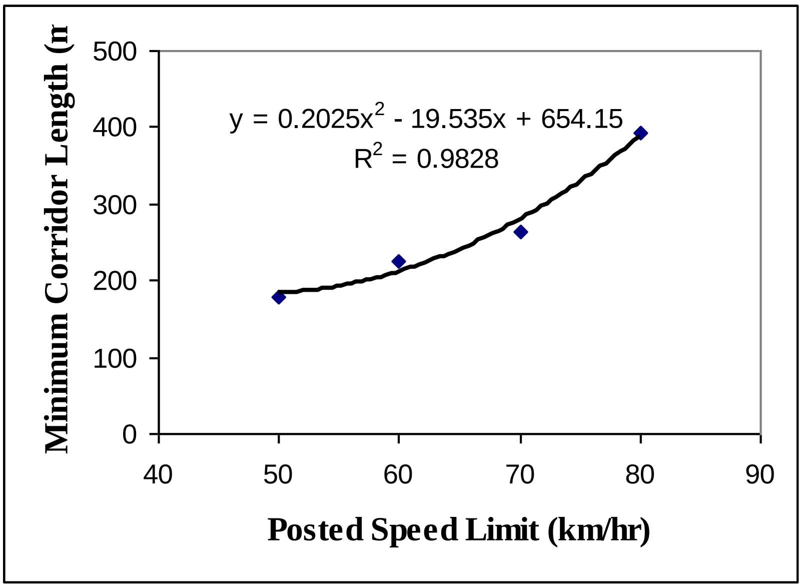

Figure 3: Minimum Segment Length with Different Speed Limits.

5.3 Influence of Humps Existence on Travel time and Speed Profile

The influence of humps existence on travel time, driver's speed, and speed profile was investigated. These traffic characteristics were studied continuously when vehicle arrived and departed the hump location.

Figure 4 demonstrates the speed profile observation in a plot of vehicle's speed versus distance for the different speed limits. Higher initial deceleration rates were associated with higher approach speeds. However, it can be seen that recovery distance to reach the original speed were increased as speed limit increased. Drivers normally decreased their speeds before the humps, reaching the lowest speed at the hump, then acceleration of speed started gradually to reach recover speed value.

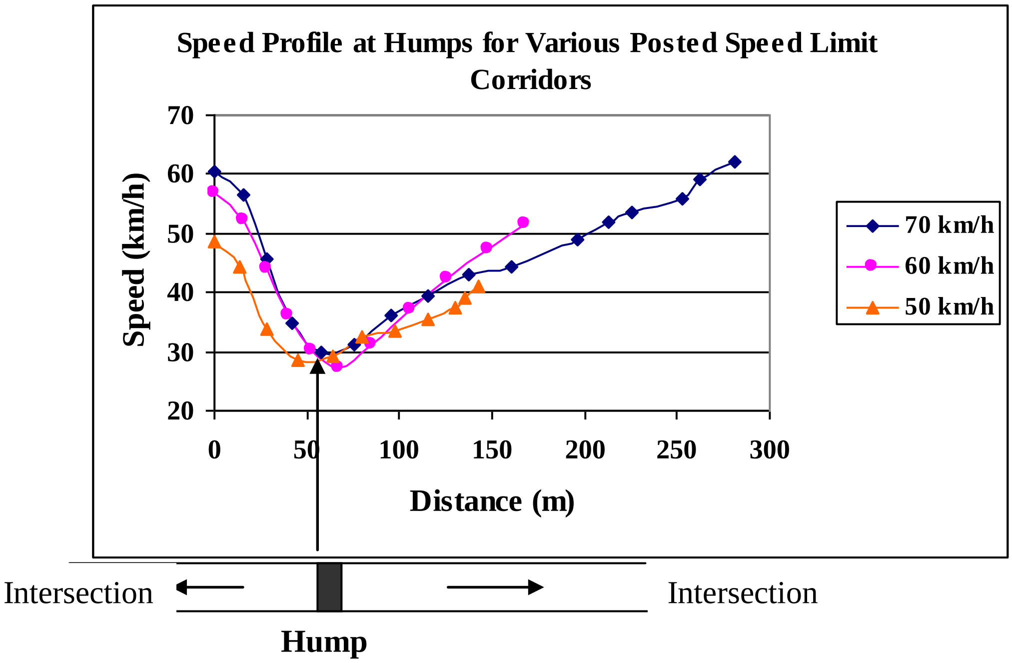

Figure 4 Speed Profile at Hump Zone with Different Speed Limits.

Figure 5 investigates the speed change profile at hump location zone for different posted speed limit segments. The peak deceleration occurred at the middle of deceleration zone prior hump location and the deceleration rate increased with increasing the speed limit of segment. From Figure 6.9, the required distance prior hump location for safety signs installation and the required humps spacing could be found.

Table 6 shows the computed delay values caused by hump occurrence. The distance where driver response and delay associated to hump existence could also be found. It can be seen that total delay and response distance increased when approach speed increased.

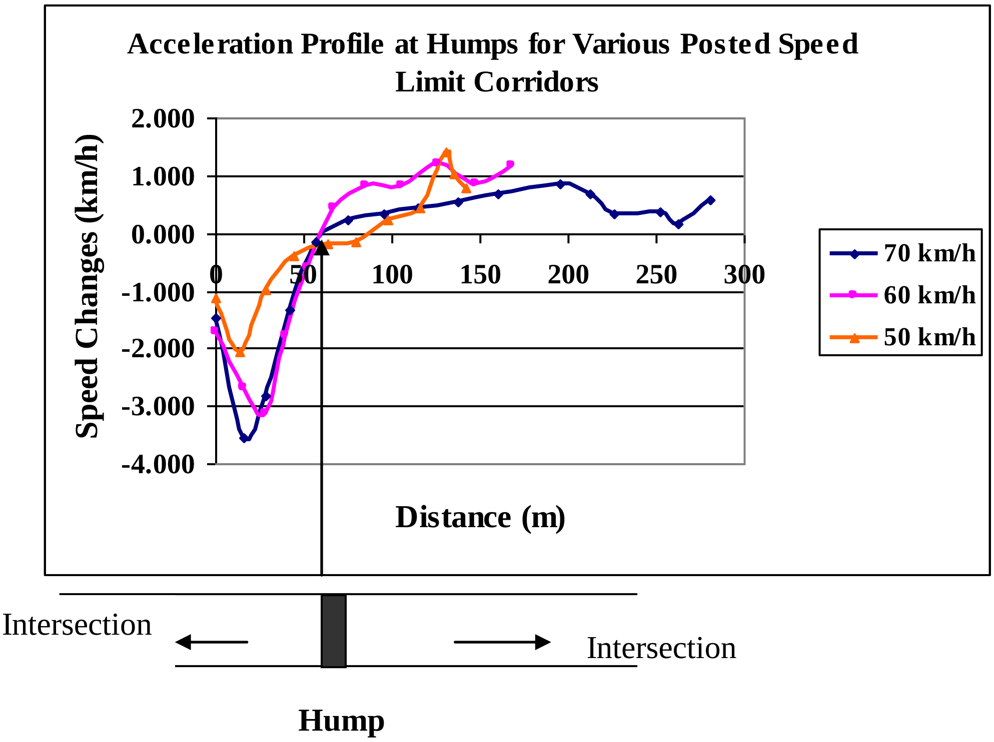

Figure 5 Speed Changes Profile at Hump Zone with Different Speed Limits.

Table 6: Responding Distance and associated delay According to approach speeds

Approach Speed	80-70	70-60	60-50	50-40
Total Distance (m)	456	242	188	125
Total Delay (sec)	11	6.3	5.5	4.4

6. Conclusions and Recommendations

Up to our knowledge, this research work is the first large scale comprehensive travel time study on urban streets with the in-vehicle GPS technology. A methodology has been developed to study travel time characteristics and operating speed on urban streets with the GPS based vehicle activity data, including summarizing GPS trips, selecting study sites, and analyzing speed profiles.

The models were developed include design features such as road environment features, operation characteristics, cross-section features, alignment characteristics, and adjacent land use. The results can help roadway designers and planners to better understand expected operating speeds and, as a result, design and evaluate proposed urban roadways accordingly. The linear multiple regression model was found to be the most significant model to predict the relationship between operating speed and other variables related to road environment, traffic condition, and horizontal alignment. However, the significant variables of horizontal curve model were entering speed at the beginning of horizontal curve, deflection angle, posted speed limit at segment (km/h), and combination of horizontal curve and vertical curve.

GPS tracking data collection can be useful to estimate the speed profile changes due to existence of road environment features like humps. Thus, Precaution signing can be determined from speed profile analysis at hump zone and maximum hump spacing was evaluated to maintain driver's speeds lower than posted speed limits.

The following areas may deserve further study:

1. Operating speed models have been developed for both tangents and horizontal curves with very promising results. But it is still recommended to select more study segments for further analysis and modeling, especially for horizontal curves.
2. Further studies are needed using peak operating speed data to investigate geometrical and operational variables.
3. Other variables should be investigated to study driver's speed behavior such as vehicle and driver characteristics not only road environment feature and operational variables.

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