THE DIFFERENCES OF DRIVING BEHAVIOR AMONG DIFFERENT DRIVER AGE GROUPS AT SIGNALIZED INTERSECTIONS

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(Received December 27, 1999)

Over the past few years the population of older drivers has substantially increased across the United States. Older drivers are a group of special interest because of their potential age-related deficiencies. It is essential to understand their driving behavior and adjust the conditions of roadway systems according to their requirements. Likewise, driving behavior of older drivers needs to be considered in order to adequately estimate capacities at intersections. In the past few years, research projects were performed by the University of South Florida to analyze the differences of driving behavior among different driver age groups. Typically, the driving behavior of older drivers was evaluated by analyzing their start-up lost time and saturation headway at signalized intersections as compared to young and mid-age driver groups. Research results were based on data collected from signalized intersections with different land-use types. These intersections are located in west and central Florida where the elderly population has been increasing rapidly in recent years. From the results it was found that the presence of older drivers significantly reduced intersection capacity at all study sites because of their higher lost times and lower saturation flow rates. Therefore, driving behavior of older drivers should be considered in designing intersections located in places with a significant older driver population. In the research, models were developed to predict start-up lost time and saturation headway values generated by older drivers. Then, the variation in capacities with an increasing percentage of older drivers in the traffic stream was modeled. Finally, adjustment factors for different percentages of older drivers were developed to adjust intersection capacity. These factors are believed to account for the presence of older drivers in the traffic stream. The adjustment factors may be used in capacity analysis and design procedures for intersections with a significant older driver population.

Key Words: Older drivers, Start-up lost time, Saturation headway, Intersection capacity, Adjustment factor

1. INTRODUCITON

The special population of the elderly has been increasing rapidly in the past few years in the United States. The population over 65 years old is projected to grow from 12.6% of the total population in 1990 to 21.1% by 2030[1]. In other words, there will be one elderly person over 65 years old among every five people, resulting in over 50 million elderly people being eligible to drive[2]. Past studies found that persons at age 65 or older relied on personal automobiles for 94 percent of their trips in rural areas and 88 percent in urban areas[3]. The increase in the elderly population and their mobility needs make them a significant proportion of traffic exposure. Past data have shown that crash rates of older drivers per capita was not high, but it was very high per vehicle mile driven or time driven[4]. Also, it was found that older drivers are involved more in multi-vehicle crashes, including crashes at intersections and crashes in urban areas. Particularly, crashes involving older drivers are overrepresented at intersections, which were found to be the most hazardous locations for older drivers because their driving tasks are more complicated at intersections[4–8]. It has been estimated that 40 percent of fatalities, 60 percent of injuries, and 55 percent of PDO (Property Damage Only) crashes occur at intersections[8, 9]. Moreover, older drivers have a higher fatality risk than other drivers once involved in a crash[4]. Data showed that older drivers were two to three times more likely to die as a result of an accident than the average road user[10]. Because of all these facts, adequate design of intersections has become one of the major concerns for transportation engineers.

One of the major reasons attributing to the high crash rate among older drivers is the decrease in their information processing capabilities and the decline in their motor skill responses due to the natural aging process. Furthermore, because of these aging related problems, older drivers were found to have a distinct driving behavior when compared to drivers of other age groups. This difference in driving behavior of the older driver population will have an impact on intersection capacities as they experience different lost times and saturation headways than the other driver age groups.

Transportation engineers need to adjust the design and operational standards of intersections due to this significant increase in older driver population and the safety aspects related to them. The evaluation of driving behavior of older drivers would allow transportation engineers to design intersections and estimate capacities in a more adequate manner. Driving behavior of drivers at signalized intersections is represented by lost time and saturation headway. A small change of these two characteristics may result in a significant difference in capacity. The lost time is defined as the sum of clearance lost time and start-up lost time. Clearance lost time is defined as the time between the crossing of the last vehicle in phase A over the stop line and the initiation of green for phase B[11]. Saturation headway is the equal headway observed between vehicles entering an intersection in a stable-moving platoon. Start-up lost time is defined as the extra time spent by the first few vehicles in the queue to enter the intersection as compared to saturation headway[9]. In relation to capacity at an intersection, it can be calculated for a specific lane group. The lane group capacity is defined by the Highway Capacity Manual (HCM)[12] as the maximum rate of flow for the subject lane group that may pass through the intersection under prevailing traffic, roadway and signalization conditions. The lost time and saturation headway are two of the most important factors in the calculation of intersection capacity. The following shows the basic equation for capacity calculation[12]:

$$c_i = s_i \times \left(\frac{g_i}{C}\right) \qquad (1)$$

where:

- c_i = capacity of lane group i, vph;
- s_i = saturation flow rate for lane group i, vphg, $s_i = N \times (3600/h)$;
- N = number of lanes in the lane group;
- h = saturation headway;
- g_i/C = effective green ratio per lane group i, $g_i = G_i - (l_1 + l_2)$;
- G_i = the total time of green and yellow for lane group i;
- l_1 = start-up lost time, sec.;
- l_2 = clearance lost time, sec.; and
- C = cycle length, sec.

Longer reaction time of older drivers, which may cause longer start-up lost time or saturation headway at signalized intersections, may be one of the causes of driving safety and high crash involvement at intersections. Therefore, evaluation of the driving behavior differences between older drivers and other age groups is very important. Nevertheless the differences among different driver age groups, current methods to assess, design, and improve roadway intersections are based on average driving behavior and performance. The capacity analysis method based on average driving behavior may result in over-estimation of intersection capacity and level of service at locations with a significant older driver population. The intersection design based on such analysis may not provide adequate operational service as expected and may result in potential safety problems. It may be necessary to consider the driving behavior of older drivers when analyzing intersection capacity if the older driver population is significant.

In Florida, the percentage of older drivers is significantly high and is growing rapidly. This significant percentage of older drivers will impact the capacity at intersections, which may cause operational and safety problems. For this reason, it is fundamental to evaluate the influence of older drivers at intersections in Florida in order to determine existing problems. In August 1996, a research project was started to evaluate the driving behavior of older drivers at signalized intersections. This paper summarizes the results obtained from the project [9, 13]. The main purpose of the research was to investigate and evaluate the differences of driving behavior between older drivers and other driver age groups in terms of start-up lost time and saturation headway at signalized intersections. Three driver age groups (old, middle age, and young) were investigated and compared in this research. The older driver group was defined as drivers aged 65 years or older. The middle age group was defined as drivers aged between 30 and 64 years. The young driver group was defined as drivers aged less than 30 years. In the research, differences in driving behavior for left-turn and through movements among different age groups and different land-use types were observed. Start-up lost time and saturation headway for different age groups and land-use types were estimated. However, clearance lost time was not considered because the field data have shown that there were no significant differences of clearance lost time between different age groups. Right-turn movement was not considered because drivers could perform this maneuver during the red phase. The variation in capacities with different percentages of older driver population was estimated based on start-up lost time and saturation headway to evaluate the impact of older drivers on intersection capacities. Finally, older driver population adjustment factors based on different percentages of older drivers were developed to account for their presence in the traffic stream. The adjustment factor table developed in the research may be used in capacity analysis and design procedures for intersections with a significant older driver population.

2. PROCEDURE

2.1 Selection of study sites

The land-use factor was considered in order to assess variation in driving behavior in different land-use types. Intersections with high rush-hour volumes were preferred in order to obtain saturated queues waiting for the green signal. Selected intersections should have varied elderly driver population in order to assess the impacts of an increasing older driver population on intersection capacity. Study locations should also have protected and exclusive left-turn lanes so that the difference in driving behavior of drivers maneuvering left-turn and through movements could be identified. Six intersections located in residential, shopping center, recreational, and business areas were selected as study locations. These intersections are:

- SR 192 & SR 535 (recreational area in Kissimmee, FL);
- E. Busch Blvd. & N. 40th St. (recreational area in Tampa, FL);
- SR 580 & US 19 (shopping center in Clear Water, FL)
- Water Ave. & Dale Mabry Hwy. (business area in Tampa, FL);
- Water Ave. & Sheldon Rd. (residential area in Tampa, FL); and
- Sun City Center Blvd. & N. Pebble Beach Ave. (residential area in Sun City, FL).

Only one approach per intersection was considered for the analysis. The west approach at SR 192 & SR 535 has two exclusive left-turn lanes and three through movement lanes. This is a T-shaped intersection with 12-foot lanes in width and a semi-actuated signal. The east approach on Busch Blvd. & N. 40th St. has two exclusive left-turn lanes, three through lanes, and one right-turn. This intersection is a 4-legged intersection with fully actuated signals and 12-foot lanes on all approaches. The west approach of SR 580 & US 19 has two exclusive left-turn lanes, two through lanes, and one shared lane for through and right-turn movements. It is a 4-legged intersection with a lane width of 12 feet. The traffic signal is fully actuated. The north approach of N. Dale Mabry Hwy. & Water Ave. has two exclusive left-turn lanes, three through lanes, and one right-turn lane. All lanes of the approach are 12 foot in width and have a pre-timed signal. The north approach of Sheldon Rd & Water Ave. has two exclusive left-turn lanes, two through lanes, and one right-turn lane. It is a 4-legged intersection with 12-foot lanes and signal fully actuated. The east approach of Sun City Center Blvd. & N. Pebble Beach Ave. has one exclusive left-turn lane, two through lanes, and one right-turn lane. All lanes of the approach are 12-foot wide and the signal is fully actuated.

2.2 Some considerations

Usually, large vehicles such as trucks, buses, and recreational vehicles take a longer time to react to traffic signal changes. Thus, large vehicles have longer start-up lost time and lower saturation flow rate compared with passenger vehicles. In this research, in order to focus on the subject, namely analysis of driving behavior differences among different driver age groups at signalized intersections, vehicle size was not the factor to be considered. Therefore, this research only focused on passenger cars. Traffic data of large vehicles were not included for analysis. All research conclusions were based on data from passenger cars.

There is another issue that needs to be stated in this paper. Pedestrians and two-wheeled vehicles may have significant impacts on vehicle start-up lost time, particularly in large metropolitan cities such as New York City. Vehicles have to wait until all pedestrians and two-wheeled vehicles in the crossing street clear the intersection though the signal has turned to green. Thus, the start-up lost time can be significantly extended. However, the capacity analysis procedure included in the HCM does not consider the impacts of pedestrians and two-wheeled vehicles because most cities in the USA do not have a significant population of pedestrians and two-wheeled vehicles. In this research, all the sites for traffic data collection did not have a significant population of pedestrians and two-wheeled vehicles. There was little impact of pedestrians and two-wheeled vehicles on vehicle start-up lost time. Thus, the factor of pedestrians and two-wheeled vehicles could be neglected in the project so that the topic of the research can be focused without biases by other factors.

In this research, driver age group was determined by field observations. When a vehicle approached to an intersection and stopped waiting for green light, the driver's appearance was visually observed by a field research engineer, and the driver's age group was determined according to the driver's appearance. Originally, it was planned to survey each driver to obtain the age information. However, it was found that such a survey plan would greatly affect driver's driving behavior, resulting in biased start-up lost time and saturation headway data. Later, a study was performed to evaluate the significant difference between the survey results and observation results in terms of the age group information. It was found that the difference was statistically not significant. Therefore, in this research, the observation method was adopted to determine the age group of each driver.

2.3 Data collection

The data collection process involved two parts. In the first part, parameters such as driver's age, time of initiation of green signal, and time at which vehicles cross the stop line were recorded. Start-up lost time and saturation headway for each of the driver age groups and land-use types were calculated based on these parameters. The second part consisted of manual data collection of signal timings, geometric features of intersections, and peak-hour volumes. In the data collection procedure, drivers were first categorized under three different age groups based on field survey. The people doing the data collection were trained and supervised by the person in charge of the study in order to minimize survey errors. Because conventional data collection methods were time consuming, data for this research were collected using a laptop computer with a software program developed by Dai[9]. The program automatically records the time of initiation of green signal, vehicular position in queue, time of vehicles crossing the stop line, and time headway of vehicles as soon as the user presses the appropriate keys. Data were collected on weekends at recreational and shopping areas and on weekdays at residential and business areas. It was ensured that the pavement was dry and normal weather conditions prevailed during the entire data collection period. Headway data were collected when the rear wheels of the vehicles crossed the stop-line. Eighteen hours of data were recorded for each movement at each intersection in order to cover rush and non-rush hours and to have sufficient data points. Approximately 10% of the data were not effectively used, as saturated queues were not obtained during these periods. The data considered were when saturated queues waiting for the signal were observed.

2.4 Data analysis

This analysis was based on two important measures: the saturation headway and start-up lost time. First, the start-up lost time and saturation headway were computed for each driver age group, land-use type, and through and left-turn movements with real time traffic data obtained in the field. Then, differences in driving behavior among different age groups, different land-use types, and between left-turn and through movements were analyzed. The statistical significance of these differences was tested by the one-way ANOVA tail test. Linear models were used to develop statistical relationships between the start-up lost time and older driver population, and between the saturation headway and older drivers. Capacities were then calculated using the Highway Capacity Software (HCS)[14], based on predicted values of the start-up lost time and saturation flow rate. The variation in capacities with different percentages of older drivers in the traffic stream was determined to find the impact of older drivers' driving behavior on intersection capacity. Finally, older drivers' adjustment factors were developed for different percentages of older drivers to account for their impact on the capacity of the intersection.

3. ANALYSIS

3.1 Estimation of start-up lost time and saturation headway

In HCM, saturation headway is calculated by averaging the discharge headway of the 5th queued vehicle to the last queued vehicle. It implies that the stable queue starts from the 5th queued vehicle. Saturation headway is calculated by the following equation:

$$h = \frac{\sum_{i=1}^{m}\sum_{j=5}^{n_i} h_{ij}}{\sum_{i=1}^{m}(n_i - 4)} \qquad (2)$$

where:

h = saturation headway, sec.;
h_{ij} = discharge headway of j^{th} queued vehicle in the i^{th} cycle, sec.;
n_i = vehicle position in the i^{th} cycle, $n_i > 4$; and
m = total number of cycles during an observation period.

The headway data collected in the field were first categorized into three groups: older drivers, middle-aged drivers, and young drivers. The headways for each of the driver age group were then averaged based on the queue position. Average values of the headway associated with different driver age groups and vehicle positions in the queue were used to generate headway curves for different age groups. The values of saturation headway were obtained based on the definitions presented in Eq. (2). Figures 1 and 2 show the headway curves for through and left turn movements, respectively, based on data collected from all intersections. As indicated in Figures 1 and 2, average headway differences between different driver age groups did exist for the first several vehicles in queue for through and left turn movements. This difference decreased

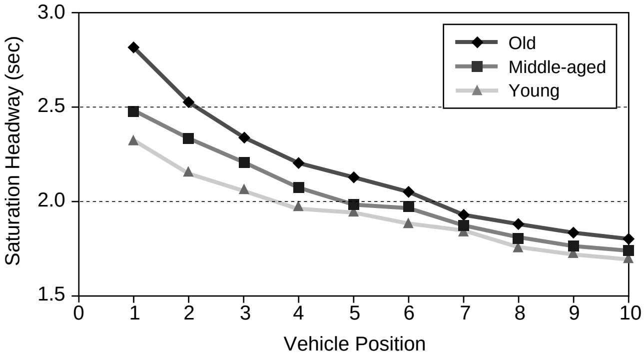

Fig. 1 Headway comparison for through movement

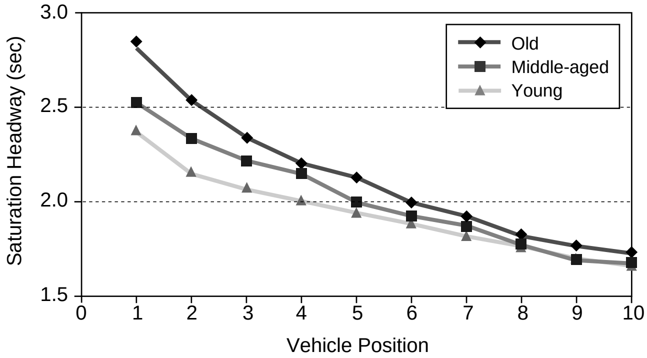

Fig. 2 Headway comparison for left-turn movement

with the increase in queue position and eventually stabilized at a relatively constant value. This variation in the average headway between different age groups reflect the reaction time of the first several drivers responding to the signal change. The reaction time of older drivers when present in the first few positions of the queue was much higher than that of the other drivers. This particular driving characteristic is a primary indicator of their age-related physi-

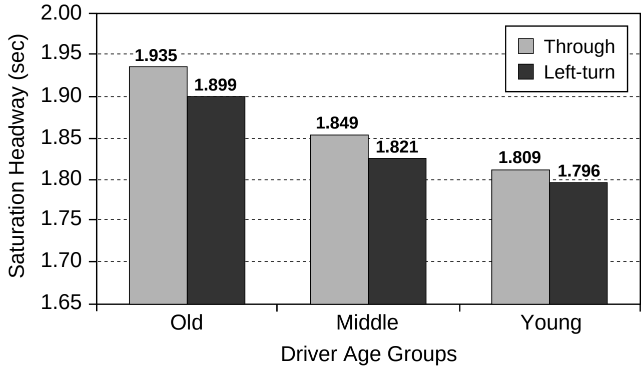

Fig. 3 Saturation headway comparison among driver age groups

cal deficiencies. It may also indicate that older drivers are not as aggressive as other age groups when waiting for the traffic signal. In fact, older drivers are sometimes overcareful in driving.

Table 1 presents the values of the start-up lost time and saturation headway for through and left turn movements for different driver age groups at each of the study sites. Figure 3 shows the differences in the saturation headway between different age groups and turning movements based on data collected from all sites. It can be seen that older drivers had longer saturation headway compared with other driver age groups. Young drivers usually take less saturation headway.

Start-up lost time is measured as the cumulative extra time taken by the first n vehicles to pass the stop-line. The HCM specifies that saturation headway should be estimated based on the headway of all the queued vehicles except the first four vehicles (or n = 4). This approach implies that the first four vehicles incur most, if not all, of the start-up lost time. Thus, the start-up lost time is calculated by the HCM procedure as:

$$t_{sl} = t_4 - 4 \times h \qquad (3)$$

Table 1 Summary of saturation headway and start-up lost time (in sec.)

Name of Intersection	Driver Age Groups											
	Saturation Headway (sec.)						Start-up Lost Time (sec.)					
	Old		Middle		Young		Old		Middle		Young	
	Thru	Left	Thru	Left	Thru	Left	Thru	Left	Thru	Left	Thru	Left
Sun City Center Blvd & Pebble Beach Av.	1.972	1.986	1.944	1.898	1.873	1.904	1.895	1.990	1.307	1.469	1.247	1.223
Waters Ave. & Sheldon Rd.	1.950	1.755	1.72	1.718	1.719	1.672	1.857	2.232	1.534	1.786	1.179	1.296
Busch Blvd. & N. 40th St.	1.904	1.862	1.872	1.791	1.838	1.796	2.249	2.337	1.798	1.808	1.254	1.399
SR192 & SR535	2.081	2.074	1.908	1.911	1.87	1.847	2.406	2.969	2.315	2.820	1.505	1.887
SR580 & US19	1.840	1.887	1.788	1.806	1.777	1.779	2.255	2.475	1.474	1.844	1.357	1.733
Dale Mabry Hwy. & Waters Av.	1.863	1.828	1.861	1.804	1.778	1.777	2.181	2.307	1.739	1.999	1.207	1.356

where:

t_{sl} = start-up lost time (sec.);

t_4 = total time for the first four vehicles to enter the intersection (sec.); and

h = saturation headway (sec.)

According to the above equation, in order to calculate the start-up lost time, the total time for the first four vehicles to enter the intersection was first computed for each driver age group and movement. This value was obtained by measuring the time from initiation of the green signal to the time taken by the 4th vehicle to enter the intersection. The start-up lost time for each driver age group and lane movement was then calculated by using Eq. (3) based on data collected from all sites. Table 1 also presents the start-up lost time values for left-turn and through movements. Figure 4 shows the differences in the start-up lost time between different age groups. As seen in Figure 4, older drivers also had longer start-up lost time compared with other driver age groups. Young drivers had less start-up lost time compared with older and middle age groups.

3.2 One-way ANOVA test

Based on the results presented previously, older drivers took longer time to enter intersections compared with other age groups. The one-way ANOVA procedure was used to verify the statistical significance of these differences. This test involves testing of a null hypothesis in which the means of dependent variables are assumed to be equal. The criterion for accepting or rejecting this hypothesis is dependent upon the F and $F_{Critical}$ values. The $F_{Critical}$ values are based on the values of level of significance or the confidence levels assumed while performing the test. If the value of F is greater than $F_{Critical}$ then the null hypothesis will not be accepted. The test was conducted at the 95% confidence level with the following null hypotheses:

H_{01}: Drivers' age does not have an impact on start-up lost time and saturation headway; and

H_{02}: Land-use does not have an impact on start-up lost time and saturation headway.

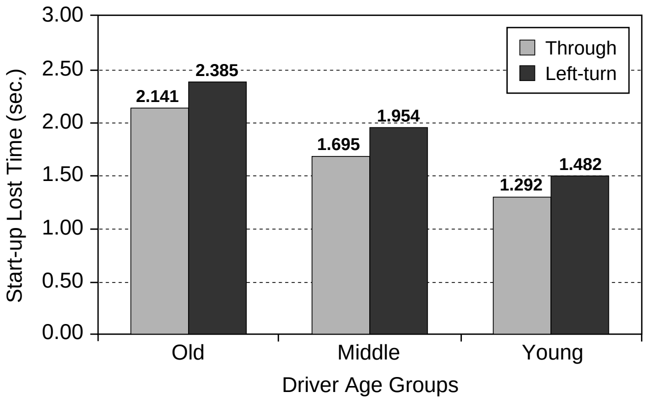

Fig. 4 Start-up lost time comparison among driver age groups

Table 2 presents the results of the one-way ANOVA test. Statistically, the following findings can be concluded:

- Driver's age has significant impact on start-up lost time in both lane movements;
- Driver's age has significant impact on saturation headway in through movement but not in left-turn movement;
- Land-use does not have a significant impact on start-up lost time in both lane movements; and
- Land-use has a significant impact on saturation headway in left-turn lane movement but not in through movement.

These conclusions were found to be compatible with the estimated values of start-up lost time and saturation headway. These results are discussed in detail in the following sub-section.

3.3 Assessment based on study results

The differences in driving behavior among different age groups in selected study sites were evaluated on the basis of estimated values of the start-up lost time, saturation headway, and ANOVA test results. As indicated by the results, the recorded start-up lost time increased

Table 2 Results of one-way ANOVA test

Null Hypothesis	F		$F_{Critical}$		H_0 Acceptance	
	Left	Through	Left	Through	Left	Through
Impact of Drivers' age on Start-up Lost Time	7.405	15.177	3.682	3.682	Rejected	Rejected
Impact of Drivers' age on Saturation Headway	2.056	4.123	3.682	3.682	Accepted	Rejected
Impact of Land-use on Start-up Lost Time	2.016	0.916	3.106	3.106	Accepted	Accepted
Impact of Land-use on Saturation Headway	5.670	2.074	3.106	3.106	Rejected	Accepted

with the increase in age in all study sites for left-turn and through movements. Such results reflected the inability of older drivers to accelerate their vehicles promptly after initiation of a green signal, especially when they were at the first several positions of the queue.

Similar to start-up lost time, saturation headway values increased with the increase in age for both movements. But differences in the saturation headway for different driver age groups were found to be considerably smaller for left-turn movement compared with those for through movement. Older drivers in all locations presented higher saturation headway than other drivers for both movements, which could be attributed to an effort by older drivers to be more careful while driving by maintaining a safe distance between their vehicles and preceding vehicles.

When comparing saturation headways between left-turn and through movements, it was found that left-turn traffic had lower saturation headway than through traffic, which could be attributed to more aggressive drivers due to the less green timing for left-turning traffic.

The factor of land-use has a significant impact on the saturation headway for left-turn movement but not for saturation headway for through movement and start-up lost time. At the intersection of SR192 & SR535, a recreational area, very high start-up lost time and saturation headway were obtained. Compared with residential, shopping, and business areas, the recreational site was a special characteristic. This site is located in the city of Kissimmee, where there are several major tourist attractions such as Disney World, Sea World, and Universal Studios. This intersection has a high percentage of tourist drivers in the traffic stream, whose major travel task is for recreational activities. Therefore, the driving characteristics of tourists may be significantly different from the drivers in residential, shopping, and business areas. These tourist drivers may have higher start-up lost time and saturation headway compared with other driver types since their travel purpose is for recreation.

4. INTERSECTION CAPACITY REDUCTION AND ADJUSTMENT FACTORS

Since older drivers generate longer start-up lost time and saturation headway, the intersection capacity may be reduced when a significantly older driver population exists in the traffic stream. This capacity reduction may affect the safety and operational performance of the intersection. In the study, intersection capacity was analyzed to examine the differences between older drivers and other drivers. Based on capacity evaluation results, older driver adjustment factors were developed to adjust the capacity estimation.

4.1 Models for start-up lost time and saturation headway

The results presented previously indicated a variation in the start-up lost time and saturation headway with different percentages of older driver population. As start-up lost time and saturation headway are considered to be the most important parameters that affect intersection capacities, these parameters were modeled as the functions of the percentage of older drivers in the traffic stream in order to find the impact of older drivers on intersection capacities. In order to develop the models for the start-up lost time and saturation headway, the changes of these parameters with different percentages of older drivers were analyzed at each study site. For this purpose, the 18-hour data collected for each movement at each intersection were divided into four different time slots with equal time duration. Percentages of older drivers in each time slot were first calculated. The start-up lost time and saturation headway for each time slot were then estimated for both lane movements. Table 3 presents an example of the summary for the percentage of older drivers in each time slot and the corresponding values of the start-up lost

Table 3 Details of older drivers at Sun City Center Blvd. & Pebble Beach Ave.

Time Slots	Percentage of Older Drivers (%)		Saturation Headway (sec.)		Start-up Lost Time (sec.)	
	Through	Left	Through	Left	Through	Left
1	38.46	46.80	1.934	1.842	1.382	1.541
2	83.91	65.21	1.923	1.922	1.749	1.924
3	19.38	58.00	1.910	1.833	1.316	1.603
4	44.62	31.73	1.923	1.834	1.451	1.415
Scenario 1	0	0	1.907	1.897	1.283	1.356
Scenario 2	100	100	1.972	1.986	1.895	1.990
Scenario 3	54.9	51.88	1.929	1.934	1.500	1.525

time and saturation headway at the intersection of Sun City Boulevard and Pebble Beach Avenue. Three special scenarios were also considered in order to obtain more data points for the modeling purpose. These scenarios included 0% older drivers, 100% older drivers, and the percentage of older drivers in the entire 18-hour period. For the 0% older driver scenario, only the data for middle age and young drivers were used to calculate the saturation headway and start-up lost time. In reference to the 100% older driver scenario, only the data for older drivers were used to obtain the start-up lost time and saturation headway. Finally, for the percentage of older drivers for the entire time period at the intersection, all drivers were considered.

Next, the data calculated for all intersections were used to model the statistical relationships between the percentage of older drivers and the start-up lost time and between the percentage of older drivers and the saturation headway. Linear models were developed to determine the statistical relationships because the original data indicated that the start-up lost time and saturation headway vary linearly with different percentages of older drivers. The combined data from all sites were used during the modeling process in order to have a larger sample size and better represent the traffic characteristics in Florida for the development of capacity adjustment factors. The models obtained for the combined data are shown as follows:

- Saturation Headway Models:

Through $h = 0.0017\ POD + 1.8031$ .... (4)

Left-turn $h = 0.0015\ POD + 1.7782$ .... (5)

- Start-up Lost Time Models:

Through $l_{1T} = 0.0036\ POD + 1.5757$ .... (6)

Left-turn $l_{1L} = 0.0022\ POD + 1.8362$ .... (7)

where:

h = saturation headway, sec.;

POD = percentage of older drivers;

l_{1T} = start-up lost time for through movement, sec.; and

l_{1L} = start-up lost time for left-turn movement, sec.

According to the four equations listed above, any increase in the percentage of older drivers will increase the start-up lost time and the saturation headway for the through and left-turn movement at the intersection.

4.2 Capacity reduction due to the population of older drivers

The final step in the capacity evaluation was to estimate capacity reduction due to the special population of older drivers in the traffic stream. For this purpose, the linear models for each study site and for the combined data were used to estimate the values of the start-up lost time and saturation headway for every 10% increase in the older driver population. Table 4 presents the values for these parameters for the combined data.

The intersection capacity can be estimated using Eq. (1). Practically, capacities can be analyzed with the use of simulation software. In the study, the capacities for each of the lane group in the study locations were determined by using the HCS[14]. This software implements the procedures contained in the 1994 HCM. In order to estimate the capacity for each lane group, the software requires detailed information concerning geometric, traffic, and signalization conditions at the intersection. In the study, the number and width of lanes were considered as

Table 4 Predicted values for combined data and older driver adjustment factors

Percentage of Older Drivers (%)	Saturation Headway (sec.)		Start-up Lost Time (sec.)		Capacity (vph)		Adjustment Factors		
	Through	Left	Through	Left	Through	Left	Through	Left	Average
0	1.803	1.778	1.575	1.836	1213	642	1.000	1.000	1.000
10	1.820	1.793	1.611	1.858	1199	634	0.988	0.987	0.988
20	1.837	1.808	1.647	1.880	1185	626	0.976	0.975	0.976
30	1.854	1.823	1.683	1.902	1172	618	0.966	0.962	0.964
40	1.871	1.838	1.719	1.924	1158	610	0.954	0.950	0.952
50	1.888	1.853	1.755	1.946	1146	603	0.944	0.939	0.942
60	1.905	1.868	1.791	1.968	1133	595	0.934	0.926	0.930
70	1.922	1.883	1.827	1.990	1120	588	0.923	0.915	0.919
80	1.939	1.898	1.863	2.012	1108	581	0.913	0.904	0.909
90	1.956	1.913	1.899	2.034	1095	574	0.902	0.894	0.898
100	1.973	1.928	1.935	2.056	1084	567	0.893	0.883	0.888

those obtained in the field. Traffic volumes on each of the approaches were counted using JAMAR volume counters. The rest of the geometric and traffic conditions were all assumed to be the default values of HCS. Signal-timing plans, which include phases, cycle length, green time, and change intervals, were all measured in the field using a stopwatch. Any other adjustment factors that were required for the capacity estimation were set to HCM default values.

Capacities for each 10% increase in the older driver population were estimated for the left-turn and through movements with the predicted values of the start-up lost time and saturation flow rate for each study site and for the combined data. The intersection of Sun City Center Blvd. & Pebble Beach Ave. was selected as the standard intersection for capacity analysis for the combined data. Based on the calculation, intersection capacities were reduced with the increase of the older driver population. Capacity reductions due to the increase of the older driver population in the left-turn movement were higher than those in the through movement for almost all study sites and for the standard intersection, which can be attributed to high start-up lost time in the left-turn movement. Figure 5 shows the computed capacities for left-turn and through movements. It can be observed that capacities are reduced with the increase of the older driver population. Based on Table 4, the reduction in the capacity for left-turn lanes was 11.68% and 10.63% for through lanes when the older driver population increased from 0% to 100%.

4.3 Development of adjustment factors for an older driver population

Current capacity estimation methods, which are based on the driving behavior of an average population, may overestimate the capacity at intersections where a large older driver population exists. Therefore, intersections that are designed based on the performance of an average driver population may not provide adequate operational services to the traveling public, especially, the older driver population. In consequence, efforts are needed to adjust the capacity estimation procedure so that the effects of the older driver population can be considered. With such an adjustment, the intersection capacity and level of service can be more adequately estimated, and the operational services to older drivers can be improved.

In this study, an effort was made to develop older drivers' adjustment factors for different percentages of older drivers in the traffic stream. For the development of the older driver adjustment factor table, the capacity estimated for the standard intersection with the combined data were used. The capacity for each 10% increase in the older population was divided by the base capacity with 0% older drivers. The following equation was used:

$$f_{old}\,(i) = c_i / c_o \qquad (8)$$

where:

i = percent of older drivers in the traffic stream;
f_{old} = older driver adjustment factor;
c_i = capacity when "*i*" percent of older drivers are present in traffic stream; and
c_o = capacity when 0% older drivers are present in traffic stream.

Table 4 also provides the older driver adjustment factors calculated with the use of Eq. (8) for different percentages of older drivers. These adjustment factors account for the presence of older drivers in the traffic stream in left-turn and through lanes and may be used when the intersection capacity is to be analyzed with consideration of older drivers. In order to use the older driver adjustment factor, the percentage of older drivers at the intersection is needed. This percentage could be estimated from the elderly population in the area or by doing an on-site survey.

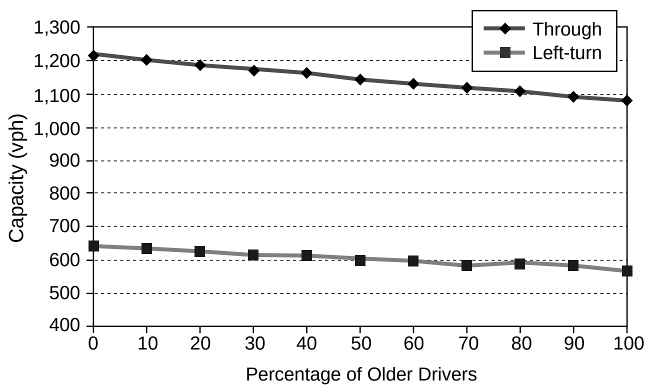

Fig. 5 Capacity variation for combined data

5. CONCLUSIONS

Capacity at intersections decreases for left-turn and through lanes with the increase in the older driver population in the traffic stream. This increase in the older population also causes an increase in the relative differences in start-up lost time and saturation flow rates between older drivers and other drivers. Current design and capacity estimation methods at intersections are based on the driving behavior of the average population, which may not provide adequate operational services to the traveling public and may over-estimate capacity at intersections where the older driver population is significant. For these reasons, older driver adjustment factors for different percentages of older drivers may be used in the capacity analysis and design procedures for intersections with a significant older driver population to account for the presence of older drivers in the traffic stream. The design with such a consideration may provide a better traffic service to older drivers and improve the safety of older drivers.

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