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Stopping Behavior of Drivers at Stop-Controlled Intersections: Compositional and Contextual Analysis

by Mintesnot Woldeamanuel

This research examines how drivers conduct themselves at stop signs by looking at the effect of different compositional variables (socio-demographic attributes) and ecological variables (physical attributes that affect people's behavior) on drivers' decisions to make a complete stop, as required by law. Observational study was designed to collect data at different parts of an urban area, and the binary logit model is used for the analysis. The modeling results show that five variables (age of the driver, number of passengers in the vehicle, presence of law enforcement officers within a block radius, using headlights, and time of the day the trip took place) are statistically significant in explaining relationships between those variables and the stopping behavior of drivers.

INTRODUCTION

Stop signs at intersections, predominantly used in the U.S. and Canadian cities, play a crucial role in regulating the movements of traffic and pedestrians and, thus, avoiding traffic accidents. The Fatality Analysis and Reporting System of the U.S. National Highway Traffic Safety Administration (NHTSA) shows that there were 34,017 fatal crashes related to junction and traffic control devices in 2008, out of which 8% are at stop-controlled intersections (NHTSA 2010). According to the 2009 NHTSA Annual Report on Traffic Safety Facts, 36% of fatal crashes at intersections are at stop signs, whereas 33% are at traffic signals, 25% at no traffic control devices, and the remaining at traffic control devices labeled as "other/unknown." The same data source reports that injury crashes at intersections are also higher at stop signs than other traffic control devices (NHTSA 2011). A similar report revealed that there was an increase in urban accidents, although a 7.1% decline in intersection crashes were observed between 2009 and 2010 (NHTSA 2012a). However, statistical projection of traffic fatalities for the first half of 2012 shows that an estimated 16,290 people died in motor vehicle traffic crashes (not location specific). This represents an increase of about 9.0% as compared with the estimated 14,950 fatalities that occurred in the first half of 2011 (NHTSA 2012b).

Several other studies have reported the fact that many injuries and fatalities occurred at intersections (with signals or stop signs) (Campbell et al. 2004; Retting et al. 2003; NHTSA 2001; Van Houten and Retting 2001). As 50% of all urban accidents occur at intersections, studying drivers and pedestrians' behavior is of vital importance for public safety (Neuman et al. 2003). At unsignalized stop-controlled intersections, drivers who fail to stop or after stopping, proceed without looking for traffic on the major road, create a substantial crash risk (Van Houten and Retting 2001). According to a survey by the National Safe Kids Campaign (2003), nearly half of the 25,660 vehicles surveyed at intersections marked with stop signs violated the stop signs by not coming to a complete stop at intersections. The same study shows that more than a third of motorists rolled through the stop signs, whereas nearly a tenth of motorists did not even slow down for the stop signs.

There are various explanations to the question of why drivers are not complying with the stop signs, as required by law. Although ecological issues such as the built environments, stop sign visibility, and road design played a significant role, the compositional variables, such as drivers' behavior, explained in terms of carelessness, lack of attention, or unnecessary overconfidence in controlling their surroundings, and the driver's socio-demographic background, cause a failure to comply to the law of making a complete stop. The compositional variable may also include age, gender, and hand-held cell phone use while approaching a stop sign. There are studies that attempted to create relationships between the socio-economic backgrounds of the travelers, their trip making circumstances, and their stopping behavior. For example, Kishore et al. (2009) conducted an observational study to determine the percentage of vehicles completely stopping at stop-sign intersections. According to the results of the study, the greatest contributing factors that caused most drivers to completely stop were the presence of conflicting vehicle movement, followed by movement of vehicles, vehicle arrival sequences, and the driver's age group. The study also found that drivers, during off-peak periods, have a higher probability of not completely stopping than those during peak periods because of less conflicting movement (either pedestrians or vehicles from other directions).

Other studies identified speeding as an influencing factor. For example, according to a study by NHTSA (2004), speeding was the dominant factor in the vehicle fatal crashes in which the driver violated the traffic signal/stop sign, while inattention ranked second. Van Houten and Retting (2001) assessed several studies on the subject and documented that poor compliance at stop signs, characterized by failure to stop or to look adequately for oncoming traffic, improper lookout, and stop-sign visibility, to be the leading cause of crashes. Age also played a significant role in influencing the behavior of drivers at stop signs. A study by Preusser et al. (1998) shows that drivers aged 65 and above are 2.3 times more at risk of being involved in accidents at all-way stop sign intersections when compared with being 1.3 times more at risk in other situations. Drivers aged 85 years and older are 10.6 times more at risk at stop-sign intersections. Braitman et al. (2007), in their comparative analysis between groups of drivers ages 35-54 and drivers ages 70 and older, found that crashes where drivers failed to yield the right of way increases with age and occurred mostly at stop-controlled intersections. The stopping behavior of the drivers can also be influenced by pedestrian movements at intersections. According to the National Safe Kids Campaign (2003), motorists were more likely to stop when pedestrians were present. However, the same study shows that nearly a third of motorists violated the stop signs when child pedestrians were present. Nearly half of motorists violated the stop signs when no pedestrians were present. Drivers were more likely to stop for pedestrians who were crossing than for those waiting to cross, although a significant percentage of drivers did not come to a complete stop at intersections where pedestrians were crossing. Traffic volumes, urban settings, and the behavior of other drivers can also have an influence on the way drivers behave at stop signs (Keaya et al. 2009; Kishore et al. 2009).

This paper reports findings from an observational study of stopping behavior by including additional new explanatory variables that have not often appeared in previous studies, such as cell phone use, number of passengers in the vehicle, and presence of a law enforcement officer that could have an influence on the stopping behavior and decisions of drivers when approaching a stop sign at intersections. The study is based on a field observation in St. Cloud, Minnesota, and application of probabilistic models. Unlike previous studies, the model is based on utility theory. The paper aims to investigate the distractions that may inhibit St. Cloud drivers from making a complete stop in order to provide an insight on variables that are responsible for influencing stopping behaviors of drivers.

St. Cloud is located about 60 miles northwest of the Twin Cities (Minneapolis-St. Paul and metro area), the largest populated region in Minnesota. Located in three different counties and on the Mississippi River, it is located in the heart of central Minnesota. With a population of 63,000 and a metro population of 167,392 residents, St. Cloud is also the transportation hub of Central Minnesota. St. Cloud has high manufacturing employment relative to the rest of the state and the nation.

This paper is organized into five sections. Following the introduction, the second section presents the data used and the methodology. The third section explains the analysis results, focusing on the effect of compositional and ecological/contextual variables on the stopping behavior of motorists. Section four explains and discusses the results, and the final section offers concluding remarks and policy recommendations.

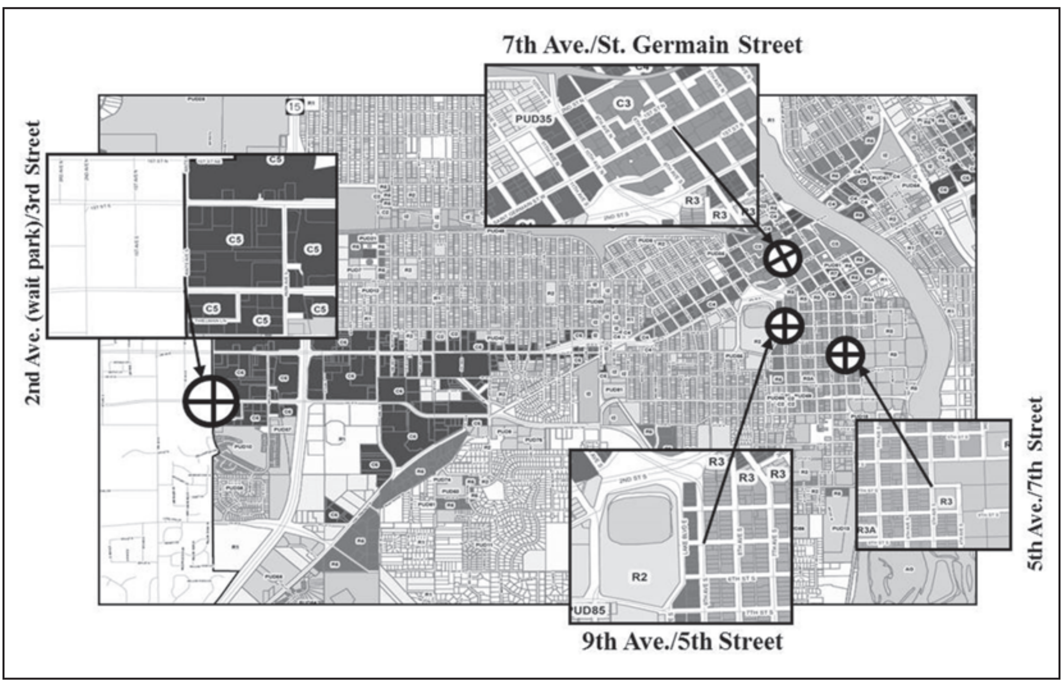
MATERIAL AND METHODS

The research approach involved modeling drivers' stopping behavior using data obtained from an observational survey. Observations were undertaken from March 25 to March 30, 2010, to understand drivers' behavior when they approach a two-way or four-way stop-controlled intersection and produce certain stopping types (complete, rolling, or no stop)[1]. A binary logit model was used to explain the relationship between the selected explanatory variables (compositional and contextual) and stopping types. The premise of the selection of variables is that behavior is a function of the individual's characteristics as well as contextual/environmental variables. Therefore, the independent variables were divided into two major categories: compositional (such as gender, age, number of passengers in the car, cell phone use while driving) and ecological (such as urban characteristics of the area [density and land use], day and time of the observation). A regulatory variable (availability of law enforcement) and a mechanical variable (headlight) are also added as independent variables. Indicator coefficients were estimated using the model in order to examine whether those variables really affect the decisions of the driver when approaching intersections regulated by stop signs.

Data Collection

All data were gathered at four different intersections: two two-way stops and two four-way stops. All intersections were located in different urban settings (density and land use). These included high-density commercial, medium-density residential/university, low-density commercial, and low-

Figure 1: Observation Locations



Source of map: City of St. Cloud

density residential. Intersections observed include that of 7th Avenue & St. Germain Street (high-density commercial; a four-way intersection), 5th Avenue & 7th Street (medium-density residential/ University; a four-way intersection), 2nd Avenue & 3rd Street (low-density commercial; a two-way intersection), and 9th Avenue & 5th Street (low-density residential; a two-way intersection). All of the observed intersections are located within the municipal boundaries of the City of Saint Cloud, Minnesota. To gather a consistent set of data, all intersections were observed 12 times for a total of 2,400 vehicle observations (50 vehicles per observation; 600 observations per intersection). In order to ensure the consistency of observations, the data collectors were given a set of guidelines for each variable. Observations with any kind of ambiguity were eliminated from the sample.

To examine whether there is a relationship between *the days of the travel* and stopping type, weekday and weekend observations were conducted. Times chosen for observation on weekdays were 8:00 A.M., 1:00 P.M., and 6:00 P.M. These times were selected to examine whether there are varying stopping behaviors at different times of the day. The weekend observations included 12:00 P.M., 6:00 P.M. and 12:00 A.M. as we believed that such times would be necessary for observation, because most motorists do not work on the weekend and, therefore, start their day later and stay out for extended hours.

Variables

The dependent variable is the observed stopping types at intersections. A driver's stopping type is classified into three different types. The first is a *complete stop,* which would mean that the automobile would reach a velocity of exactly zero mph. The second type of stop, and most common among most motorists, was that of a *rolling stop,* which would mean that the automobile was traveling *about* a rate of five mph or less and moved forward without making a complete stop. The third stopping type is that of a *no stop,* which, to happen, would require the motorists be traveling at above five mph past the stop sign. The descriptive statistics showed that out of the 2,400 vehicle observations, 35% of the drivers made a complete stop, whereas 65% of them did not comply with the law of making a complete stop (52% made a rolling stop and 13% did not make any stop at all).

Table 1: Descriptive Statistics of the Dependent Variable

The Dependent Variable	Cases	Percentage
Stopping types		
0- No stop/rolling stop	1570	65%
1- Complete stop	830	35%

The independent variables were chosen to include the following. This study focuses on variables whose influence on the drivers' decision to make or not to make a complete stop is not well tested in previous research endeavors on the subject.

Compositional Variables:

- Gender: a binary variable with 1 = female and 0 = male
- Age: taking into consideration the difficulty of recording age in an observational study, the variable is categorized into three ordered variables based on the observer's judgment; 1 = young, 2 = middle-age, 3 = old. "Young" is considered to be less than 30 years old, "middle-age" is between 30 to 60 years old and "old" is more than 60 years old. If the age of the driver could not be determined during nighttime, the observation was deleted from the sample. However, this rarely occurred since all the intersections observed have very good street lighting.
- Cell phone use: a binary variable of 1 if the driver is using a *hand-held* cell phone while approaching the stop sign and 0 otherwise

Table 2: Descriptive Statistics of the Independent Variables

Independent Variables (predictors)	No stop		Rolling stop		Complete stop		Total Cases	
	Mean	SD	Mean	SD	Mean	SD	Count	Percentage
Gender of the driver	0.47	0.50	0.48	0.50	0.46	0.50		
1= Female	47%		48%		46%		1138	47%
0= Male	53%		52%		54%		1262	53%
Age of the driver	1.92	0.77	1.74	0.74	1.70	0.72		
1= Young	34%		44%		45%		1031	43%
2= Middle-age	40%		39%		39%		940	39%
3= Old	26%		17%		16%		429	18%
Number of passengers in the vehicle	0.94	1.14	0.68	0.96	0.81	0.97		
0	51%		57%		50%		1288	54%
1	19%		26%		27%		621	25%
2	17%		10%		16%		305	13%
3+	13%		7%		7%		186	8%
Cell phone use at intersections	0.27	0.45	0.23	0.42	0.24	0.43		
1=Yes	27%		23%		24%		577	24%
0= No	73%		77%		76%		1823	76%
Law enforcement within one block	0.09	0.29	0.05	0.22	0.11	0.32		
1=Yes	9%		5%		89%		2215	92%
0= No	91%		95%		11%		185	8%
Headlight	0.38	0.49	0.39	0.49	0.43	0.49		
1=On	38%		39%		43%		958	40%
0=Off	62%		61%		57%		1442	60%
Time of observation	0.57	0.50	0.50	0.50	0.47	0.50		
1=Day time	57%		50%		47%		1200	50%
0= Night time	43%		50%		53%		1200	50%
Day of observation	0.55	0.50	0.49	0.50	0.50	0.50		
1= Weekdays	55%		49%		50%		1200	50%
0= Weekends	45%		51%		50%		1200	50%
Urban setting	2.34	1.13	2.58	1.10	2.45	1.14		
1= low density residential	30%		22%		27%		600	25%
2= low density commercial	18%		29%		22%		600	25%
3= medium density residential/univ.	30%		24%		26%		600	25%
4= high density commercial	23%		26%		25%		600	25%

Contextual/Ecological Variables:

- Number of passengers: This is a continuous value of the number of passengers observed; 0 is given if it is a “drive alone” situation
- Time: although there are four different times of day chosen for observation (morning, afternoon, evening, and night), for analytical convenience the nominal nature of the variable is converted into a binary variable of 1 = day time (morning and afternoon) and 0 = night time (evening and night)
- Day: although there are four different days of the week chosen for observation (Tuesday, Thursday, Saturday, and Sunday), for analytical convenience the nominal nature of the variable is converted into a binary variable of 1 = weekdays (Tuesday, Thursday) and 0 = weekends (Saturday and Sunday)

- Urban setting: to account for traffic volume on the major street, four zonal types (urban settings based on activity types and buildings per square meter) were selected for observation, and the variable is arranged in an ordered fashion based on density, i.e.,
    - 4= high density commercial (downtown area: a four-way intersection);
    - 3= medium density residential/university (residential neighborhoods around campus: a four-way intersection);
    - 2= low density commercial (areas in suburban shopping centers: a two-way intersection);
    - 1= low density residential: a two-way intersection

Regulatory Variable:

- Law enforcement is a binary variable of 1 if there is a police officer or patrol within one block radius from the stop sign and 0 otherwise

Mechanical Variable:

- Headlights: a binary variable of 1 if the driver used headlights and 0 otherwise. The use of headlights was observed during daytime and nighttime and in both cases, there were drivers with headlights on and off.

Model Structure: Binary Logit Model

The model to be estimated in this study is the effect of compositional, contextual, regulatory, and mechanical variables on stopping behavior of motorists. Since the dependent variable (stopping behavior) is a binary variable with 1 = making a complete stop and 0 = making no stop or rolling stop, a Binary Logit Model is chosen for the analysis. Binary models are widely used in economic, marketing, transportation, and other fields to represent the choice of one among a set of mutually exclusive alternatives. When drivers are faced with two choices [a choice of making a complete stop (i) over not making a stop (j)], the probability that j is equal to [1-P(i)]. The general form of the binomial logit model is:

(1) Prob [Y_i=1| making a complete stop] = Exp $(\alpha+\sum\beta_i x_i)$ / [1+ Exp $(\alpha+\sum\beta_i x_i)$]

The model application is based on the utility theory, which assumes that the decision maker's choice to stop or not to make a complete stop is captured by a value called utility (U). The decision maker selects the alternative in the choice set with the highest utility.

(2) $U = \alpha + \beta_i x_i$

Where β_i is the coefficient associated with the independent variables; x_i is the value of the independent variables; α is the constant estimated by the model (Greene 2000).

RESULTS

Table 3 reports the estimated utility coefficients (β) of the explanatory variables with their t-values and p-values as a test of statistical significance. Figures 2 to 5 show the estimated likelihood of making or not making a complete stop. The model fits the data set as the chi-square, and the log likelihood ratio are within acceptable range. Results show that five variables (out of the selected nine variables) have a likely influence on stopping behavior of drivers. The positive and the negative signs attached to the coefficients describe the functional relationships between the dependent variable (stopping behavior) and the independent variables. The null hypothesis of relationships between the dependent and independent variables was rejected with p-value above 0.05 for 95% confidence level. The marginal effect (Table 4) is also estimated to show the percentage increase in the independent variable either to increase or reduce the probability of making a complete stop by one percentage point. According to the modeling result, the gender of the driver, cell phone use, the day of observation, and urban setting have no significant influence on how drivers behave when approaching the stop sign. The remaining statistically significant variables are discussed in the following sections.

Table 3: Modeling Results

Independent variables	β	Exp (β)	Standard error	t-value	p-value
Constant (α)	-0.591		0.181	-3.272	0.001
Gender of the driver	-0.081	0.922	0.087	-0.933	0.351
Age of the driver	-0.133	0.875	0.059	-2.239	0.025*
Number of passengers in the vehicle	0.085	1.089	0.044	1.931	0.050*
Cell phone used while approaching intersections	-0.035	0.965	0.103	-0.343	0.732
Law enforcement within one block radius	0.754	2.125	0.156	4.830	0.000*
Headlight	0.211	1.235	0.094	2.253	0.024*
Time of observation	-0.222	0.801	0.092	-2.411	0.016*
Day of observation	0.053	1.054	0.092	0.577	0.564
Urban setting	0.040	1.041	0.042	0.970	0.332

Maximum Likelihood Estimates

Number of observations	2400
Log likelihood function	-1527.366
Restricted log likelihood	-1547.59
Chi-squared	40.44
Degrees of freedom	9

* statistically significant variables for 95% confident level

Table 4: Marginal Effects on Probability of Making a Complete Stop

Independent variables	β	Standard error	t-value	p-value
Constant (α)	-0.133	0.040	-3.303	0.001
Gender of the driver	-0.018	0.020	-0.933	0.351
Age of the driver	-0.030	0.013	-2.240	0.025
Number of passengers in the vehicle	0.019	0.010	1.932	0.053
Cell phone used while approaching intersections	-0.008	0.023	-0.343	0.732
Law enforcement within one block radius	0.170	0.035	4.831	0.000
Headlight	0.048	0.021	2.254	0.024
Time of observation	-0.050	0.021	-2.413	0.016
Day of observation	0.012	0.021	0.577	0.564
Urban setting	0.009	0.009	0.970	0.332

Age

As well documented in previous research papers, age is one of the demographic variables that could have an influencing effect on the stopping behavior of drivers. The modeling result in this study reflects the existence of age's influence on stopping behavior. The variable is statistically significant with a negative β coefficient (means a less than 1 exp(β) value). The negative coefficient associated with the utility value of variable age (β_{age}) explained that older drivers have a lower likelihood of making a complete stop. On the other hand, young drivers have the tendency of making a complete stop (Figure 2). The marginal effect -0.030 also shows that a 3% increase in age reduces the probability of making a complete stop by one percentage point.

Number of Passengers in the Vehicle

The number of passengers in the car greatly influences the stopping behavior of the driver. People behave differently when they are alone as opposed to when they are with people. When they are alone, there is an extended freedom in their mind to "break" the law. The result in this study shows that the likelihood of making a complete stop increases with the number of passengers in the car.

Presence of Law Enforcement Officers

Law enforcement presence is defined in this study as the availability of law enforcement officers within a *one block radius* of the intersections being observed (with the visual reach of the field observer). Drivers have more incentive to obey traffic laws when law enforcement officers or a police car is around. The modeling result in this study proves that a positive relation does exist between law enforcement presence and making a complete stop. It is found that if an officer of the law is present, motorists are far more likely to refrain from making a rolling or no stop. The probability estimate, as well as the descriptive statistics, (only 9% did not make a stop in the presence of the law enforcement) show that the likelihood of making complete stops increase in the presence of police officers (refer to Table 2 and Figure 4).

Headlights

Operating without headlights at night and during periods of low visibility is a common cause of traffic crashes. The result of this study indicated that there is indeed a significant influence of having headlights on for the stopping decisions of drivers. According to the modeling result, there is a positive relationship between the use of headlights and making a complete stop. This implies that the visibility of the surrounding area might have an effect on drivers' judgment while approaching intersections. The probability estimate shows that drivers with no headlights on at appropriate times have a lower likelihood of making a complete stop. Figure 5 shows that there is a slight drop of the likelihood of drivers making a complete stop without their headlights on. It is worth noting that the use of headlights was observed during daytime and nighttime and in both cases there were drivers with headlights on and off. The distribution of observation was as follows: nighttime-on= 451 drivers; nighttime-off= 749 drivers; daytime-on=507 drivers; and daytime-off=693 drivers.

Time of the Day

The time of the day when the trip is occurring is believed to affect the stopping behavior of drivers. The result in this study shows that there is a notable functional relationship reflecting the effect of the time of the day on the stopping behavior of drivers. Time by itself may not have any effect. However, spatial activities (activities at different places at different times) and the driver's disposition or reaction to activities could vary with time. Although there were four time categories used to observe drivers at stop-controlled intersections (morning, afternoon, evening, and night), for analytical convenience, the nominal nature of the variable is converted into a binary variable (1 = daytime and 0 = nighttime). The negative sign attached to the utility coefficient of the variable (β_{time}) shows that there is high probability of making a complete stop during nighttime.

Figure 2: Probability of Stopping vs Age

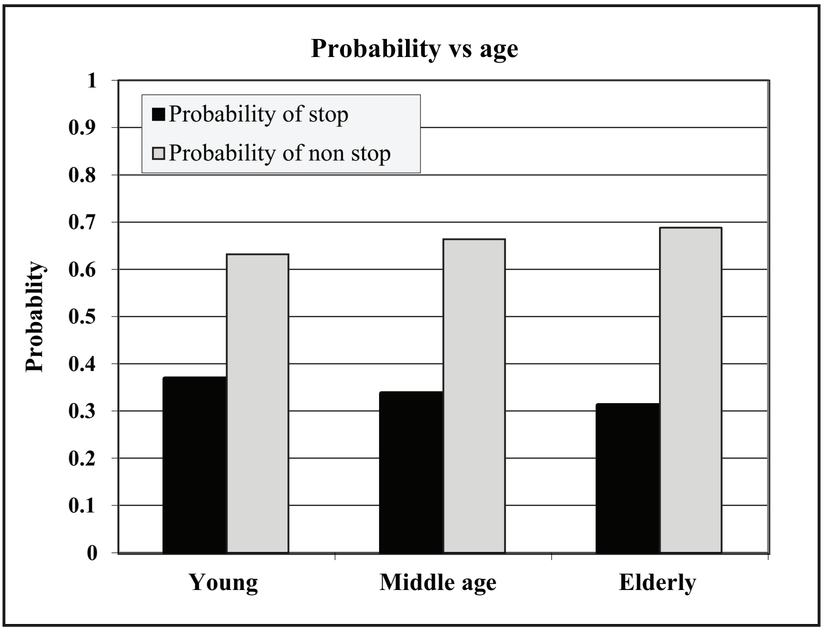


Figure 3: Probability of Stopping vs. No. of Passengers

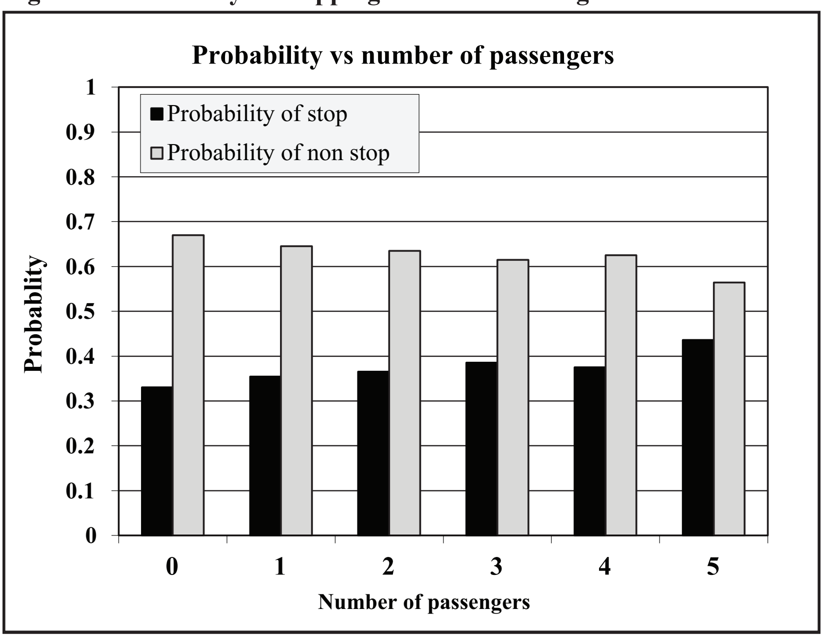


Figure 4: Probability of Stopping vs. Law Enforcement

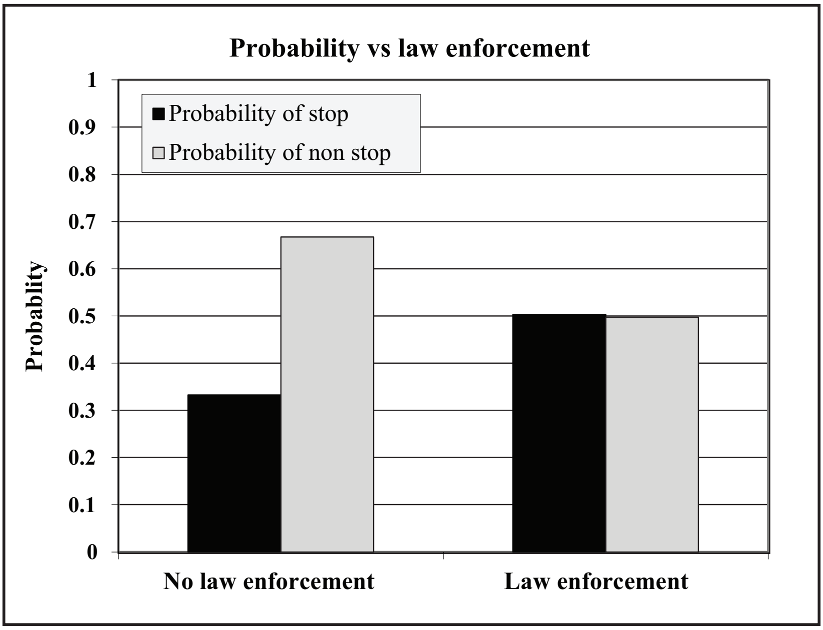


Figure 5: Probability of Stopping vs. Headlights

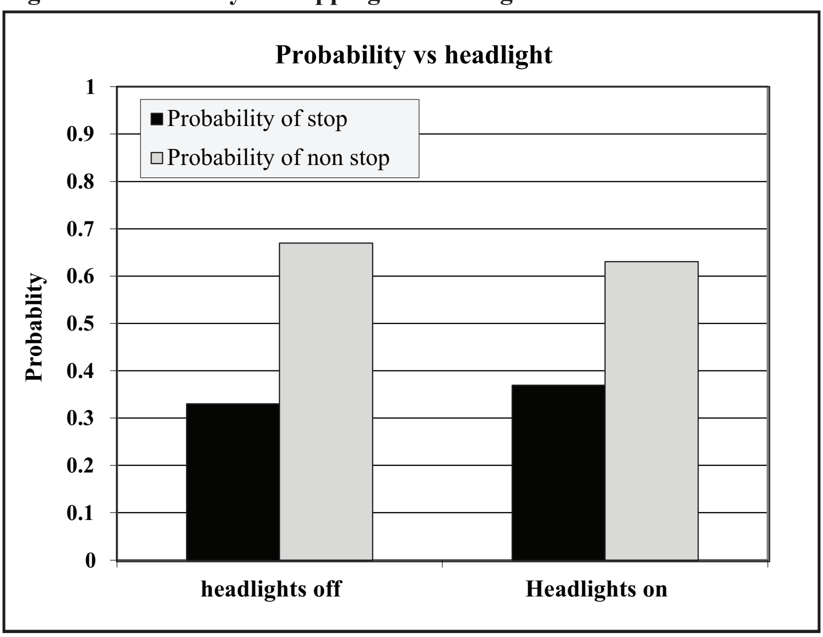
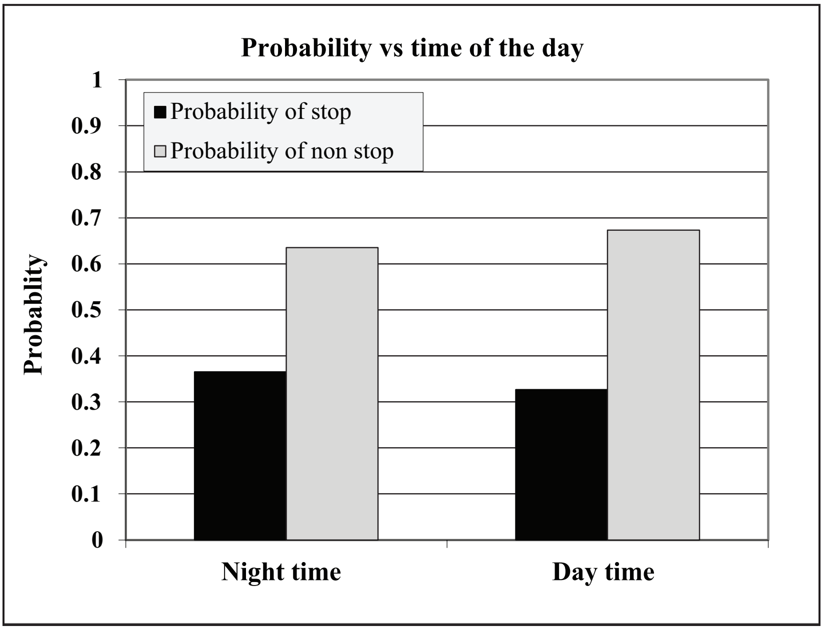


Figure 6: Probability of Stopping vs. Time of the Day



DISCUSSION

This study focused on examining compositional and contextual predictors such as demographic variables, time, availability of law enforcement, and number of passengers with the driver and their influence on the way drivers make decisions while approaching stop signs (whether to make a complete, a rolling, or no stop). The result yielded that age (among compositional variables), presence of law enforcement officers, the use of headlights during appropriate hours, time of the day when the driving takes place, and number of passengers in the car (contextual/ecological variables) have a significant influence on how drivers comply with the law of stopping at stop-controlled intersections.

Among the compositional variables chosen, gender seems to have no effect on the stopping behavior of drivers. The descriptive statistics showed that the majority of both male and female drivers make a rolling stop. On the other hand, age is found to be the compositional predictor to have a significant influence on the decision of the driver. Using the probability estimate equation 1, the likelihood of making a complete stop by a different age group was calculated and presented in Figure 2. The graph shows that the probability of making a complete stop decreases with age. The likelihood estimate on age shows that there is a 29% probability of making a complete stop by a driver of age 60+ compared with 38% likelihood by the young and 34% probability by the middle-aged drivers. The "age" parameter is an interesting predictor as stop sign visibility (size and color of the sign) could have an effect on older drivers. Other studies also indicated similar concerns. For example, Keay et al. (2009) described the old drivers' failure to stop at stop signs as a visual and cognitive failure. Braitman et al. (2007), in their comparative analysis between groups of drivers aged 35-54 and drivers aged 70 and older, found that crashes where drivers failed to yield the right of way increases with age and occurred mostly at stop-controlled intersections.

Number of passengers also showed an effect on the drivers' decision and behavior at stop-controlled intersections. Interestingly, the model results indicate people behave better when they are accompanied by passengers. Hand-held cell phone use, which was selected as an explanatory variable, hoping to see its effect on stopping behavior, has not exhibited significant influence.

Interestingly though, 24% of the observed drivers were using cell phones while approaching the stop-controlled intersections. However, their stopping behavior is proportionate to those who are not using cell phones while attempting to stop. A study on mobile phone use and traffic accidents suggested that braking reaction time is slower during a telephone conversation, so phone users come to a standstill closer to the vehicle in front of them, a stopping line, or an intersection (Dragutinovic and Twisk 2005).

Turning the headlights on at appropriate times is positively and significantly related to making a complete stop. While many cars have automatic headlights or daytime running lights (DRL) as a safety feature, there are thousands of cars on the street with manual headlights that drivers, at times, forget to turn on during appropriate times. DRL as a road safety measure is often difficult to understand for the road user because he or she "knows" that with sufficient attention every road user can be seen in daylight. Nevertheless, studies show that visual perception in daytime traffic is far from perfect and it is worse in conditions of low ambient illumination (where the natural light from the surrounding environment is obstructed). In a striking example, 8% of cars in an open field in broad daylight were not visible from relevant distances without the use of DRL (Hörberg and Rumar 1975, 1979; Allen and Clark 1964; Koornstra et al. 1997; Wang 2008). On shady roads or those with backgrounds which mask objects in the foregrounds, the visibility and contrast of cars in popular colors is greatly reduced. It is known from in-depth accident studies that failing to see another road user in time (or at all) is a contributing factor in 50% of all daytime accidents, and for daytime intersection accidents this increases to as much as 80% (Koornstra et al. 1997). According to the NHTSA (2008b), the passenger vehicle occupant fatality rate during nighttime is about three times higher than the daytime rate. This has been a concern for practitioners for a long time. Therefore, awareness programs and technological interventions (such as illuminating color marks that enhance visibility) are essential.

Although previous studies (such as Keaya et al. 2009; Retting et al. 2003) found that there are differences between high- and low-density areas when it comes to failure to stop at stop-controlled intersections, the variable is statistically insignificant in this study. However, the positive sign attached with the β coefficient shows that drivers residing in low-density neighbourhoods or rural areas were less likely to stop than those in high-density areas. Although there is better visibility in low density areas, it is believed that a higher failure to stop rate may be related to lesser traffic, more visibility around the stop-sign area, and a perception that it is safe to proceed through or turn in the intersection without stopping. Besides, lower density areas have a two-way stop sign, whereas the higher-density areas have a four-way stop sign, making drivers stop at four-way signs more that two-way signs.

While time of the day has a significant influence on what type of stop the drivers make, days of the week (whether it is weekdays or weekends), on the other hand, seems to have no influence on the stopping behavior of the drivers.

Although most of the variables mentioned above are conventional variables, there are three variables that are added value to this study, which give a new perspective on improving safety at stop-controlled intersection. Variables such as cell phone use, number of passengers in the vehicle, and availability of law enforcement officers, which are introduced in this study, have an influence on the stopping behavior and decisions of drivers when approaching a stop sign at intersections.

CONCLUSION AND RECOMMENDATIONS

This research presented the effect of some compositional and contextual variables on the stopping behavior of drivers at stop-controlled intersections in St. Cloud, Minnesota. The variables chosen to have an influence on the stopping behavior of the drivers include socio-demographic characteristics of the drivers (compositional) and the built environment-related (contextual/ecological) variables. Drivers' behavior at stop signs was investigated by using data gathered from observational studies.

The influence of different variables on drivers' decisions to make a complete stop, as required by law, or going against the law by making a rolling or no stop was examined. The binary logit model found that more contextual/ecological variables are statistically significant in explaining relationships between those variables and drivers' decisions to make or not to make a complete stop than the compositional variables. Variables that showed statistical significance (especially those new variables introduced in this study, such as number of passengers in the vehicle and availability of law enforcement officers) could be predictors for policy analysis and strategies to improve stop-controlled intersections and introduce drivers' safety awareness programs, thus reducing traffic accidents occurring at intersections. The presence of law enforcement officers and using headlights indicate that enforcement and safety measures could be an effective mechanism to reduce accidents at intersections. Police departments could use the results to deploy enforcement resources to the most accident prone intersections.

Supporting the finding in this study, a NHTSA report indicated that, for personal cars and light truck vehicles, Daytime Running Lights (DRL) would reduce injury crashes by 3.9 % (NHTSA 2008a). Therefore, increasing the current automatic DLR and phasing out manual DRLs would be considered as one of the policy options to decrease crashes at intersections.

Regarding cell phone use while driving, although the variable is statistically insignificant, the negative sign attached to it indicates that it is negatively correlated with making a complete stop. Thus, policies that restrict cell phones (unless drivers employ hands-free devices) are crucial as distracted driving is a factor in one out of four vehicle crashes in Minnesota, and text messaging and Internet use is outlawed for all drivers in the state. Therefore, policies that outlaw hand-held cell phone use, as other states do, would be essential to improve traffic safety.

Endnotes

1. Each observation was made at the intersection. Therefore, it is assumed that every driver has the same visibility distance from the point of observation.

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