The effect of daily activity patterns on crash involvement

Wafa Elias

[1]Ran Naor Road Safety Research center
Transportation Research Institute
Technion - Israel Institute of Technology
Haifa 32000, Israel
Tel: 972-4-8295135, Fax 972-4-9888003, email: Wafae@tx.technion.ac.il

Yoram Shiftan and Tomer Toledo

Transportation Research Institute
Technion - Israel Institute of Technology
Haifa 32000, Israel

Abstract

The main purpose of this study is to analyze the effect of daily activity and travel patterns on the risk of crash involvement. To this end, we develop a model that integrates daily activity and travel choices in a single framework, recognizing that these variables affect the risk of crashes. This model can therefore provide predictions of the expected changes in risk levels from the implementation of measures that affect the daily activity patterns and the socio-economic characteristics of the population.
The empirical analysis makes use of data collected during a household survey that included crash information and trip diaries. The model is applied in a case study of an Arab village in Israel to analyze various transportation policies. The results of this research show that in addition to an individual's demographic and socio-economic characteristics, his or her daily activity and travel patterns also have an impact on the risk of being involved in accidents. The case study showed the potential of this framework for analyzing the effect of various social and transportation policies on road safety. To the best of our knowledge, this is the first time such relationships have been tested by using a disaggregate model and the first time activity-based models have been used to analyze exposure to the risk of road crashes.

Keywords: Daily activity patterns; Crash involvement; Risk

1. Introduction

Car crashes have become an epidemic around the world, with more than one million traffic fatalities occurring globally every year (Evans, 2004). Car crashes are already the main cause of death of males aged 15-44, and are expected to become the third highest overall cause of death by 2020 (Murray and Lopes, 1996). Accordingly, the issue of road safety has a high priority in public policy (Garcia et al., 2007). The wide variety of measures that have been proposed and implemented in order to improve safety treat the three main factors present in crashes: the roadway, the vehicle, and the driver (Ogle, 2005). However, further research is clearly needed in all three areas. Most of the studies relating to the driver factor focus on human performance and errors. In contrast, this paper focuses on the effect of an individual's activity patterns and travel behavior on his/her risk of being involved in a crash.

Car-crash involvement is a by-product of participation in activities and the travel they require. Thus, an individual's risk of involvement in a car crash depends not only on the activities themselves in which the individual takes part, but also on their location, timing, and the attributes of the trip undertaken to participate in these activities, such as mode, route, and time of day/week. These activity and travel patterns are affected by the socio-economic characteristics of the individual and the activities of other members of the household (e.g., through shared and drop-off trips), as well as by urban-form and land-use variables. The latter are directly influenced by infrastructure investments, which can change the level of access to various activities. Most studies employ simple and crude measures of risk exposure, such as distance traveled, trip duration, or average speed (Junkwood et al., 2007a). These measures, however, may not be able to fully capture the potential effects of various transport, urban, and social policies to improve road safety.

This study will report on the development of a model is that integrates daily activity choices with the risk of crash involvement in a single framework even though it is recognized that activity and travel patterns themselves may affect the risk of crash involvement. This model, therefore, can provide predictions of the expected changes in risk levels that are due to the implementation of measures affecting the daily activity patterns and socio-economic characteristics of the population.

The paper is organized as follows: The next section briefly reviews the variables, causes, and models that have been proposed to explain crash involvement. The third section presents the methodology of the present research. The fourth section describes the data used in this study. The fifth section presents the results of the model estimated and its application in a case study; and the final section offers conclusions.

2. Literature review

A large body of literature deals with the variables that affect the risk of crash involvement. These studies commonly aim to identify useful road designs and safety devices, and so stress the influence of the geometric design of the road (Noland and Oh, 2004; Mayora and Robio, 2003; Okamoto and Koshi, 1989; Hadi et al., 1995) and traffic-flow characteristics (Kononov and Allery, 2004; Sawalha and Sayd 2003; Hadi et al., 1993; Golias, 1992); they also incorporate environmental factors, such as light and weather conditions (Daniel et al., 2002; Shankar et al., 1995;Janson et al., 1997;Kim, 2001; Cardoso et al., 2004).

In the context of individual risk, significant research has been conducted to identify the connection between demographic and socio-economic characteristics and crash involvement, using such variables as driver age and gender (Junkwood et al., 2007a; Harre, 2000; McColl, 2001; Foret et al., 2003; Al-Balbissi, 2003; Al-Bustan, 2003; Busch et al., 2002; Spallek et al., 2006) and income and level of education (Hasselberg et al., 2005; Kulanthay et al., 2004; Al-Bustan, 2003; Abdulmajid, 2007; Van-Vuuren, 2001; Petridou and Belechri, 2002; Al-Balbissi, 2003; Spallek et al., 2006).

Travel habits and trip attributes have also been connected to crash risk through simplified aggregate variables, such as the distance traveled or the number of intersections crossed (Junkwood et al., 2007a; Thouez et al., 2005; Spallek et al., 2006; Al-Balbissi, 2003; Junkwood et al., 2007b; Knoblauch et al., 1984). These variables, though, have limited power to explain the risk of crash involvement (Janke, 1991; Greenshields and Platt, 1967), since they do not account for trip attributes. For example, Chliaoutakis et al. (1999, 2005) showed that the travel distance alone is insufficient to reflect the exposure to risk, since risk levels are affected by trip purpose. They also found that the crash involvement risk is higher in trips without a specific purpose and that it is affected by the lifestyles of young drivers. Similarly, Thouez et al. (2005) showed that pedestrian risk varies with residence location. Spallek et al. (2006) claimed that crash-risk estimates generally do not account for different risk levels in different situations. They attributed this deficiency mainly to the lack of knowledge in regard to a traveler’s exposure to various situations (e.g., time of day, type of road. etc.).

3. Methodology

This study develops a theoretical framework to explain the risk of crash involvement by means of the attributes of the travel that individuals undertake. These travel-demand patterns are derived from the participation in various activities. A model that integrates both activity and travel patterns on one hand and crash involvement on the other has important advantages for evaluating various social and transportation policies (e.g., educational programs, changes in traffic arrangements) that can affect daily activity and travel patterns and thereby influence traffic safety. The overall framework of this activity-based risk model is composed of a series of multi-nomial logit (MNL) models, presented in Figure 1. It includes two main sub-models:

A daily activity model that captures activity and travel patterns and can predict changes in these patterns in response to various policies.

A crash-risk model that captures the impact of travelers' daily activity and travel patterns on the risk of their crash involvement.

Activity-based travel-demand models derive the demand for trips from the demand for participation in various activities. These models look at the overall daily activity and travel pattern, taking into account time and space constraints, rather than examining each trip individually. For a detailed discussion of these models, see, for example, Kitamura, 1988; Ettema and Timmermans, 1997; Axhausen and Garling, 1992; Ben-Akiva and Bowman, 1998a; and Arentze and Timmermans, 2000. In the past decade, these models have become practical planning tools in various metropolitan areas, including New York, Columbus OH, Atlanta (Bradley and Vovsha, 2005), and Tel Aviv, Israel (Shiftan et al., 2004).

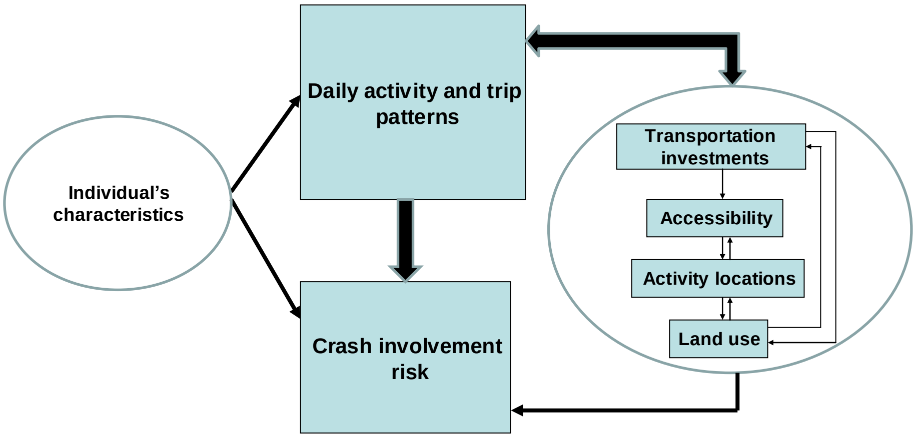

Figure 1. Framework of the activity-based risk model

4. Data

To demonstrate the activity-based risk-model framework, the model was estimated and applied in the town of Majd-Elcrum in rural northern Israel. Majd-Elcrum is an Arab town whose population is 12,700, with about 2,300 households (the average household size is 5.04). Regional Route 85, the main highway in the area, bypasses the town to the south. This bypass, opened in 1996, replaced an earlier bypass, which has now become a major artery in the town. This town suffers from relatively high crash-involvement rates among its residents.

Data on the town's population were collected through a household survey, which included trip diaries. The survey conducted in 2007 encompassed 161 households, 101 of which were randomly selected. The random sample was enriched by 60 households with individuals who had been involved in car crashes in the prior three years in order to provide the sample with a sufficient number of such subjects. Ben-Akiva and Lerman (1985) showed that the parameters of a logit model with a full set of alternative-specific constants can be efficiently estimated in such cases by using an exogenous sample maximum likelihood with proper correction of the alternative-specific constants and all other coefficients consistent. Phone calls were made in advance to set up a convenient time for each interview, which was conducted in the respondents' homes. Travel diaries were completed for each member of the household over age six for the day preceding the visit. A typical survey session took an hour and a half per household.

The resulting sample consisted of 655 individuals, 344 male and 311 female, ranging from ages 6 to 93 as shown in Table 1.

Table 1
Socio-demographic traits of Majd-Elcrum, according to the study survey

			Male	Female
Gender (entire sample)		655	344	311
Age	Mean	28.4%	29.6%	28.6%
	S.D.	16.9%	17.9%	16.3%
Education Level (over age 17)	0 to 8 years	22.9%	22.5%	23.5%
	9 to12 years_	52.1%	49.6%	54.9%
	13 to 16 years	21.2%	22.9%	19.2%
	>16 years	3.8%	5.1%	2.3%
Status	Married	70.0%	64.4%	75.6%
	Unmarried	30.0%	35.6%	24.4%
Income level	Below the average*	30.5%	-	-
	Around the average	12.0%	-	-
	Above the average	57.5%	-	-
Work location**	Outside the town	50.6%	58.0%	38.0%
	Within the town	49.4%	42.0%	62.0%
Work Status (over age 17)**	Salaried	38.8%	50.0%	26.3%
	Self-employed	13.6%	18.6%	8.0%
	Unemployed	6.0%	9.7%	1.9%
	Pensioner	9.6	17.8	0.5
	Housewife	28.3%	0%	59.6%
	Student	3.8%	3.8%	3.8%
Have driving license **	Yes		63.1%	36.9%
Number of cars in household	0	16.1%	-	-
	1	66.4%	-	-
	2	16.8%	-	-
	3	0.7%	-	-

***Average = 7,500 Shekels. (1US$=3.75 Shekels)**
**** Significant difference: p<0.05.**

Table 1 shows that 58% of the men worked outside the town, compared to 38% of the women. Not surprisingly, female participation in the workforce is less than half (34.3%) that of the males (68.6%). More than half of the women are only housewives (59.6%). Finally, 63.1% of the men have a driving license, compared to 36.9% of the women.

The survey results show that only 15% of the respondents involved in crashes as drivers were women, which is 2.5 times lower than their proportion in the Majd-Elcrum driver population. . In contrast, 27.6% of the crashes involved novice drivers (up to 2 years after licensure), which is almost three times their share in the Majd-Elcrum driver population (9.6%).

The most important factor that can account for the predominance of men involved in car crashes is the differences in the exposure to the risk of a crash. Table 2 shows that women made less trips than men. Furthermore, only 37.8% of the travel conducted by women is done by driving, compared to 65.5% of men’s travel. Furthermore, the average travel time for women is shorter than that for men— as Table 3, which shows travel patterns by gender, reveals—and women make fewer tours (defined as a sequence of trips that commences and terminates at the residence) and fewer stops per tour.

Table 2
Distribution of trips according to travel mode and gender

Gender/ Frequency	Women Frequency (%)	Men (%) Frequency
Car "driver"	158 (37.8)	510 (65.5)
Car "passenger"	103 (24.7)	74 (9.5)
Bus	2 (0.5)	18 (2.3)
Employer Provided Transportaiton	19 (4.5)	11 (1.4)
Taxi	2 (0.5)	2 (0.3)
Walking	134 (32.0)	164 (21.0)
Total	418 (100%)	779 (100)

Significant difference ,p<0.0001) at 0.05 level

Table 3
Comparison of men and women (age 17 and older) according to travel pattern

		Women (n=214)_		Men (n=210)		Comparison	
	Daily Travel Behavior	**μ_{women}**	**σ_{women}**	**μ_{men}**	**σ_{men}**	***μ_{women}/μ_{men}***	***z***
Tour	Number of Tours	1.40	0.93	2.01	1.01	0.70	**6.47**
Tour	Total Travel Time (Minutes)	46.61	34.43	82.65	70.83	0.56	**6.64**
Stops	Number of Stops	1.76	1.32	2.97	2.10	0.59	**7.09**
Stops	Total Activity Duration (Hours)	4.90	3.15	7.62	3.16	0.64	**8.88**

Note: Z scores that are significant at the 95 percent confidence level are in **boldface**. All comparison statistics are *italicized*.

A further analysis of crashes was made only for those drivers who were convicted for having caused the crash. Based on the interviews, significant differences were found between convicted driver and all drivers in Majd-Elcrum. The rate of convicted drivers possessing up to 9 years of education is 39.3%, which is 2.1 times the rate of this education level among all drivers (15.7%). The rate of convicted drivers possessing 13 or more years of education is 10.7%, which is 2.7 times less than the rate among all drivers (35.5%). Table 4 presents the distribution of convicted drivers according to the purpose of the trip in which the crash occurred. One can see that trips to work are significantly (at the 5% level) under-represented in crashes compared to other trip purposes.

Table 5 presents the distribution of daily activity patterns for both those involved in car crashes and those that were not. One can see that the highest risk of being involved in a crash occurs when the daily activity pattern includes a number of trips for various purposes, excluding work and study (pattern 5). Additionally, and as expected, the risk of being involved in a car crash is higher when the daily activity pattern includes, besides the work trip, a number of various activities by mix mode (car, bus or car passenger, on foot) and when the driver is unemployed or retired (pattern 2). This result can indicate two problems: the lack of social activities within the town and the lack of job opportunities; therefore, driving without a purpose becomes a means of leisure.

Table 4
Distribution of convicted drivers according to the trip purpose in which the accident occurred

Trip Purpose	Convicted Drivers Frequency (%)	All Drivers Frequency (%)
Work	6 (10.5)	267 (39.8)
Leisure	17 (29.8)	157 (23.4)
Personal arrangements	13 (22.9)	125 (18.6)
Pick-up and drop-off	10 (17.5)	118 (17.6)
No particular purpose	11 (19.3)	12 (0.6)
Total	57 (100%)	671 (100)

Significant differences, p<0.0001

Table 5
Distribution of daily activity pattern, by involved/not involved in road accidents

Activity Pattern	Daily Activity Pattern	Not Involved in Road Accidents Frequency (%)	Involved in Road Accidents Frequency (%)
1	Back and forth to work by car	80 (15.0)	19 (15.8)
2	Trip to work and additional trips to various activities	95 (17.8)	26 (21.7)
3	Back and forth to school on foot	97 (18.1)	3 (2.5)
4	Back and forth on foot to other activities (excluding work and study)	40 (7.5)	6 (5.0)
5	A number of trips to various destinations by using mixed modes (excluding work and study)	82 (15.3)	37 (30.8)
6	Walking back and forth to school with additional walk(s) to various activities after school	50 (9.3)	21 (17.5)
7	Trip to school and to other destinations, such as shopping and leisure, using mixed modes	58 (10.8)	8 (6.7)
8	Staying home	33 (6.2)	
	Total	535 (100%)	120 (100)

Significant differences, p<0.0001

Table 5 shows that children whose daily activity pattern includes, in addition to the walk to school, other trips on foot after school (pattern 6) are at a higher risk of being involved in crashes compared to those who only walk to and from school (pattern 3) and those who participate in various activities by mix modes (pattern 7). Among the children involved in crashes, 73.6% are under 15 years old, and 55.2% are under 9. This last figure is roughly double their share in the population (28.0%). Furthermore, the results showed that children whose parents possess a low level of education are at a higher risk of crash involvement. The rate of injured children whose mothers have 13 or more years of education is 8.6% less than the average rate in the town. The rate of injured children whose fathers have 13 or more years of education is 3.5% less than the average rate in the town.

5. Model structure and estimation

The structure of the activity-risk model, shown in Figure 2, includes two main elements:

1. A daily activity model consisting of three sub-models: the highest level estimates the choice of main daily activity; the second level estimates the choice of a daily activity pattern; and the third level estimates the choice of travel routes. The choices at the lower levels of the model depend on the choice at the higher levels. The availability of various travel modes in this rural town of Majd- Elcrum is limited, and therefore mode choices are incorporated into the daily activity alternatives and not modeled explicitly.

2. A crash-risk model estimating the probabilities of three alternatives: non-involvement in car crashes; crash involvement as a pedestrian; and crash involvement as a driver or passenger. The explanatory variables in this model include demographic and socio-economic characteristics of the household, residential location, and the daily activity patterns as endogenously estimated by the activity-based models described above.

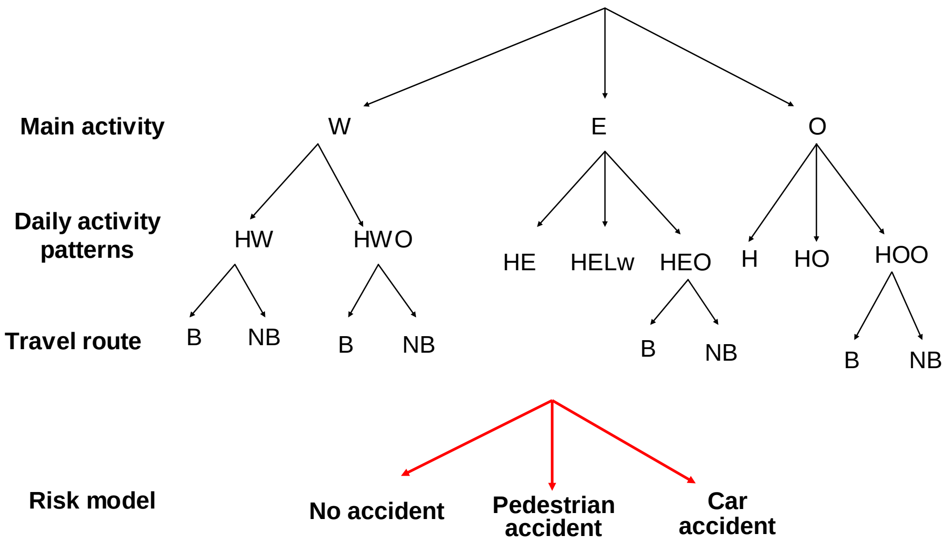

Figure 2. Structure of the daily activity crash-risk model

5.1. Daily activity model

The highest level model is the main daily-activity choice model, consisting of three alternatives: Work (W), Education (E), and Other (O), this last representing such activities as shopping, leisure, dropping off a child, a trip without purpose, or staying at home

The second level is the daily-activity pattern model; the various alternatives were aggregated to eight choices, depending on the main activity:

1. When the main activity is work, there were two alternatives: a simple tour to and from one's home/work by car (HW) and a more complex tour that may include more destinations for any purpose, as well as the use of additional travel modes (HWO).
2. When the main activity is schooling, there were three alternatives: walking from home to school and back without any further activities during the day (HE), walking to school with additional walk trips for leisure after returning from school (HELw), and traveling to school and other destinations, such as shopping and leisure, using mixed modes of transportation (walking and using a vehicle as a passenger) (HEO).
3. When the main activity is other, there are three alternatives: staying at home without any travel (H), walking from and to home for a single activity (HO), and undertaking multiple trips to various destinations by using mixed modes of transportation, which may include walking and using a vehicle either as a driver or a passenger (HOO).

In the third level model, the route selection is modeled as a binary choice. The two alternatives are defined as either a route that uses the historic main street (NB) or a route that uses the old bypass (B). This choice characterizes the only real alternatives facing travelers in this town.

6. Estimation results

6.1. Daily activity model

For brevity, we will present here only the principal results of the daily activity model.

The highest level—the main activity model

The results of the main activity model show that participation in the labor force increases with the level of education, and this result is much stronger for women than for men. It is also higher for individuals, male or female, who possess a driving license. Married woman are less likely to work. Among other things, this may reflect the combined effect of a lack of employment opportunities within the town and the lack of well-developed public transportation, resulting in limited job opportunities for those who do not drive. The high positive correlation between education level and women's participation in the labor force arises from the occupational structure. Many studies show that most Israeli Arab women work in the public sector (Epstein et al., 1994), and this type of work necessitates a high level of education; at the same time, there are not enough job opportunities for uneducated women.

The second level—daily-activity pattern model

The estimation results show that men with a higher level of education are more likely to choose a more complex pattern of activity. A possible explanation for this is that the harsh physical labor and the low wages usually experienced by men with a lower level of education do not encourage participation in a variety of activities beyond work. The results also show that the more children living at home, their mother is significantly less likely to make complex tours. Men with more children living at home, on the other hand, are more likely, though not significantly, to make more complex tours. This result was expected, since it is the men who are usually responsible for performing most of the chores involved in maintaining the household, such as banking, and also because it is customary in Arab society for men to go out after work, whether to visit the mosque or a coffee shop, while their wives are busy with the housework, and thus the women do not frequently leave their home.

Among children's daily activity patterns, the results show that when mothers have a driving license, the likelihood of a child's having a daily activity pattern that includes trips to various activities, in addition to walking to school by mixed modes, is significantly higher than if the mother does not possess a license. In comparison, the same variable among fathers was not significant. This means that it is mostly the mothers who drive their children to various activities, and that men's possessing a driving license does not affect the participation of their children in activities. The more children in a household, they less they are likely to participate in various activities using mixed modes. As expected, the more cars in a household, the more likely children are to participate in various activities. Finally, the results show that the further the home is from the school, the greater is the tendency for children to remain at home upon returning home and not to go out to additional activities, even on foot.

Among people whose main daily activity is other (i.e., neither work nor study), the results show that married people are more likely to take part in activities outside home, and that women aged 18 to 40 are more likely to stay at home than are men and women over the age of 40, since that age range is normally when women raise their children and are busy with housework. Women with more children over the age of 18 are also less likely to go out. This result appears surprising, since it was expected that after the children had grown up and passed the age of 18, women would have more time to go out. However, many children over 18 who go to work still live at home with their parents in Arab society. Thus, mothers still have to continue caring for them.

The third level—the route-choice model

The estimation results for the route-choice model show, as expected, that people tend to choose the route that saves them travel time. However, the model also shows that route choice depends on trip destination and purpose, as well as individual daily activity patterns. This model highlights the importance of trip chaining on route choice, demonstrating how such trips are connected to one another. A Few socio-economic characteristics were found to have a significant effect on route choice. These include: employment status, gender, number of cars in the household, and marital status.

6.3 Crash-involvement-risk model

The estimation results of the Risk Model, presented in Table 6, show that various daily activity patterns are significant. Children who walk back and forth to school and have additional walk trips for leisure after returning from school (DACTIVITY6) are more likely to be involved in pedestrian traffic accidents than are all others. Those who only walk to school (DACTIVITY3) are less likely to be involved in pedestrian traffic accidents than those who walk to school and make additional trips in mixed modes.

People whose main activity is work and whose daily activity pattern is only a round trip to work by car (DACTIVITY1) and those who go to work and to various other activities using mixed modes of travel (DACTIVTY2) are more likely to be involved in road accidents as a driver or passenger. People whose daily activity pattern consists of neither work nor study, but includes a number of trips for various activities using mixed modes (DACTIVITY5) are even more likely to be involved in traffic accident either as driver or passenger than those who travel to work.

The results show that the more someone uses a bypass road (BYPASN), the more likely it is for that person to be involved in a car accident (significant only at the 15% level), and the less likely to be involved in pedestrian accidents (significant at the 5% level).

Among the demographic factors, it was found that children aged 6-12 (AGE1) are at a significantly higher risk of being involved in road accidents as pedestrians. The results show that drivers aged 26-40 are at a higher risk of becoming involved in a road accident than are both young drivers aged 17-25, and older drivers over the age of 40. This result may reflect the fact that the middle age-group constitutes half the total number of drivers in Majd-Elcrum and that this group probably travels more, as well. This finding corresponds to the aggregate analysis, which indicates that this group constitutes 40% of those involved in traffic accidents. As expected, men have a higher probability of being involved in road accidents both as pedestrians and as drivers or passengers, and at a significant level. This finding may again reflect men's higher exposure; travel diaries showed that women made significantly fewer trips than did men. Married people are significantly less likely to be involved in all kinds of accidents than are the unmarried. This expected result corresponds to our hypothesis, that married adults are more responsible and cautious.

The more cars households have (CARN and CARN2) people are significantly less likely to be involved in pedestrian accidents. This result is in accordance with previous findings that showed that most of those involved in pedestrian road accidents were young children; therefore, the more vehicles there are in a household, the more likely that these children will be driven by their parents rather than will walk, and hence they will be less exposed to pedestrian accidents.

To test the significance of the daily-activity-patterns effect on involvement in road accidents, a likelihood ratio test was conducted by comparing this model to a model without the daily-activity-pattern variable. The results showed that this significantly improved the explanatory power of the model, from a likelihood of -333.03 to -306.06. According to the likelihood ratio test with four degrees of freedom, this is a significant improvement at the 5% level.

7. Demonstration application

For application purposes, three possible scenarios were defined as follows:

1. "Business as usual"; namely, nothing is changed; there is the same infrastructure and urban plan.
2. Social improvement, including a rise in the level of education and status of women, an increase in the proportion of licensed women drivers from their current 37% to 52%, and an improvement in education levels, such that the proportion of people with higher education (i.e., more than 12 years) increases from 26% to 45% (Table 7). Based on the daily activity models, these two variables have an important impact on participation in the work force and a significant influence on the travel patterns of children. For men, the scenario included an increase in the proportion of persons who have received a higher education, from 29% to 46%. The purpose of this scenario is to test how such changes influence the daily activity patterns of women and men, and whether they also have an impact on people's involvement in road accidents. This scenario does not include any changes in the transportation system or accessibility levels and relates only to changes in demographic and socio-economic characteristics.

3. Transportation: accessibility is changed by reducing the speed limit on the Old Bypass road, which today passes through the village and contains "road bumps," traffic islands, etc. The risk model is sensitive to variables that express access to activities; such variables include travel time and the number of times the road user travels along the bypass road. In view of this scenario, it is suggested that the travel speed on the Old Bypass be reduced from 70 kmh to 30 kmh; this will likely divert some trips from the Old Bypass to the Historical Main Street, especially in situations in which the driver has a choice between the routes; as a consequence, there will be a reduction in road accidents.

The application of the model is based on the sample enumeration method, which involves calculating the probabilities of choosing each of the alternatives along each of the selected dimensions for each individual within the sample. The calculation of the probability for each individual is based on his/her characteristics and does not take actual choices into consideration. Equation 1 represents the expectation of risk of involvement in an accident; it was calculated as the sum of the product of probabilities of an individual's involvement in an accident, given the specific daily activity patterns and the probability of choosing certain patterns.

(Equation 1)

$$
\begin{aligned}
P(crash = l) = \sum_{1}^{i} & P_i(W, HW) P_i(crash = l \mid HW) + P_i(W, HWO) P_i(crash = l \mid HWO) + \\
& + P_i(O, HO) P_i(crash = l \mid HO) + P_i(O, HOO) P_i(crash = l \mid HOO) + \\
& + P(O, H)_i P_i(crash = l \mid H) + P_i(E, HE) P_i(crash = l \mid HE) + \\
& + P_i(E, HELw) P_i(crash = l \mid HELw) + P_i(E, HEO) P_i(crash = l \mid HEO)
\end{aligned}
$$

Where:
i is the index of the individual within the sample;
l is the index for alternatives within the risk model.

7.1. Application results

Table 7 presents the probabilities of participating in the work force for women and men for two scenarios: business as usual and social improvement. . (The results of the third scenario did not appear in Table 7, because this scenario does not affect the daily activity model). The results show that the major change in the social improvement scenario is an increase in women's employment rate, from 36% to 73%. For men, who already had an employment rate of 72%, there was a marginal increase of some 2%. Given the changes in socio-economic characteristics, the daily-activity-pattern model estimated the resulting changes in activity and travel patterns. Table 8 presents the changes in daily activity patterns in the social improvement scenario compared to the business as usual scenario (not including the pattern with trips to education activities). There is a significant increase in work as the main activity. It can be also seen that after the social improvement, there is a decrease in the percentage of persons who remain at home, from 4.9% to 3.0%. There is also a decrease in the patterns of activity that include one trip on foot and in the patterns that include a number of trips using mixed modes of transportation. The question is how these changes in daily activity patterns will influence the risk of being involved in traffic accidents. Table 9 shows the effects. According to the social improvement scenario, the risk of car-crash involvement reduces by 15.7%, and the risk of involvement in crashes as pedestrians is also reduced.

The accessibility scenario also contributes to a decrease in the risk of car-crash involvement, by 9.8%. This reduction is a result of the reduced number of times the bypass road is used. In comparison, when the traffic was diverted from the bypass road to the inner road, the conflict between pedestrians and cars increased. Consequently, in parallel with the decrease in car-crash involvement, there is an increase in car-pedestrian crash involvement. The integrated activity-risk model enables researchers and planners to evaluate more fully the effect of various measures and policies.

8. Summary

The results of this research show that in addition to an individual's demographic and socio-economic characteristics, his or her daily activity and travel patterns also have an impact on the risk of being involved in car crashes. To the best of our knowledge, this is the first time that such relationships have been tested using a disaggregate model and the first time that activity-based models have been employed to analyze exposure to the risk of road crashes. The application of the model showed its potential in analyzing the effects of various social and transportation policies on road safety. The case studies showed that travel patterns affect the risk of car-crash involvement; for example, an improvement in women’s education levels and an increase in the proportion of licensed female drivers had a significant impact on increasing the percentage of women in the work force. Similarly, a change in the level of women’s education contributed to a decrease in pedestrian crashes in which small children are normally involved.

As this is the first study to explore and find some relationships between daily activity and travel activity patterns, on the one hand, and the risk of being involved in accidents, on the other, there are certain limitations that should be addressed in future work. The activity-based model used in this study is a simplified version of activity-based models in use today, Better, more detailed activity-based models should be integrated with crash-risk models and better activity-based risk-exposure measures should be developed representing how various activity and travel patterns and conditions affect the risk of being involved in a car crash. These studies should be conducted in broader geographical and cultural situations to test for differences among various population segments.

Table 6
Estimation results of the road-accident model

		Alternative (2) Pedestrian Road Accident	Alternative (3) Car Accident
	Variable	β (t-statistics)	β (t-statistics)
Constraints	Constant (ONE1)	-2.553 (-4.1)	-
	Constant (ONE2)	-	-3.26 (-6.1)
	Daily activity pattern includes walking to school and additional walking for leisure (DACTIVITY6)	0.832 (1.8)	-
	Daily activity pattern consists only of walking to school (DACTIVITY3)	-2.68 (-2.5)	-
	Daily activity pattern includes back and forth to work by car (DACTIVITY1); another daily activity pattern includes in addition to work, many other trips for various activities by mixed mode (DACTIVITY2)	-	1.22 (2.8)
	Daily activity pattern includes a number of trips to purposes other than work and study by mixed mode (DACTIVITY5)	-	2.077 (4.8)
	Number of times an individual uses the bypass road (BYPASN)	-0.363 (-2.1)	-
	Number of times an individual uses the bypass road (BYPASN)	-	0.110 (1.6)
	Age category from 6-12 (AGE1)	1.015 (2.3)	-
	Age category from 6-12 (AGE1)	-	-0.251 (-0.4)
	Age category from 26-40 (AGE4)	-	0.794 (2.8)
	Gender – men	1.723 (3.5)	-
	Gender – men	-	0.58 (2.1)
	Married (STATUS)	-0.577 (-2.2)	-0.577 (-2.2)
	One car in the household (CARN)	-1.30 (-2.8)	-
	One car in the household (CARN)	-	0.028 (0.1)
	Two or more cars in the household (CARN2)	-1.745 (-2.4)	-
	Two or more cars in the household (CARN2)	-	-0.434 (-0.9)
	Residential location is region 3, between the two bypasses (LOCATN3)	0.6 (0.8)	-
	Residential location is region 3, between the two bypasses (LOCATN3)	-	-1.54 (-1.9)

Statistical Summary

Likelihood with Zero Coefficients = -714.09
Likelihood with Constants Only = -382.44
Final Value of Likelihood = -306.06
ρ^2 = 0.571

Number of Observations = 650

Table 7
Probability of the main daily activity according to two scenarios

Scenario/ Gender	Business As Usual		Women's Advancement and Education		Business As Usual	Women's Advancement and Education
	$P(W)$ %	$P(O)$ %	$P(W)$ %	$P(O)$ %	Education 12+ %	Education 12+ %
General	54.8	45.2	73.9	26.1	25.8	45.4
Women	36.2	63.8	73.1	26.9	22.0	45.0
Men	72.2	27.8	74.7	25.3	29.0	46.0

Table 8
Day activity pattern probability according to the two scenarios

	Women's Advancement and Education (%)	Business As Usual (%)
	N=406	N=406
$P(W,HW)$	28.3	22.9
$P(W,HWO)$	45.6	31.8
$P(O,HO)$	5.9	10.6
$P(O,HOO)$	17.7	29.8
$P(O,H)$	2.5	4.9

Table 9
Changes in the risk of crash involvement compared to the base scenario of "Business as Usual"

Crash type/ Scenario	Pedestrian crash (%)	Car crash (%)
Increase in travel time along the bypass road	9.3%+	-9.8%
Women's advancement and education	7.0%-	-15.7%

References

Abdulmajid, A.A., 2007. Road Traffic Accidents: The Number One Killer in Libya. Libyan Journal of Medicine 2. (Available at www.ljm.org.ly)

Al-Balbissi, A., 2003. Role of Gender in Road Accidents. Traffic Injury Prevention 4, 64-73.

Al-Bustan, M., 2003. An investigation of seat belt and mobile use impacts on youth road accidents in Kuwait. ARRB Transport Research Conference, 21ST, 2003, CAIRNS, Queensland, Australia Road Engineering Association of Asia and Australasia.

Arentze, T., & Timmermans, H.J.P., 2000. ALBATROSS: A Learning-Based Transportation Oriented Simulation System. Eindhoven University of Technology.

Axhausen, K.W., & Garling, T., 1992. Activity-Based Approaches to Travel Analysis: Conceptual Frameworks, Models and Research Problems. Transport Review 12(4), 323-341.

Ben-Akiva, M., & Bowman, J. L., 1998a. Activity-Based Travel Demand Model Systems. Equilibrium and Advanced Transportation Modeling, Kluwer Academic Publishers, Boston, MA, 27-46.

Ben-Akiva, M. & Lerman, S.R., 1985. Discrete Choice Analysis, Theory and Applications to Travel Demand, The MIT Press, Cambridge, MA.

Bradley M., & Vovsha, P., 2005. A model for joint choice of daily activity pattern types of household members, Transportation 32, 545-571.

Busch, S., Zobel, R., & Kreiss, J.P., 2002. Determination of risk factors of accident causation. In: Proceedings of the International Conference on Vehicle Safety, Imeche Headquarters, London, 11-22.

Cardoso, J.K., Lemonde, D.E., Macedo, A., Trigoso, J.M., & Bettencourt, I., 2004.The Portuguese road safety plan. Routes Roads 323, 5-15.

Chliaoutakis, J.E., Koukouli, S., Lajunen, T., & Tzamalouka, G., 2005. Lifestyle traits as predictors of driving behavior in urban areas of Greece, Transportation Research Part F: Traffic Psychology and Behavior 8 (6), 413-428.

Chliaoutakis, J.E., Darviri, C., & Demakakos, P.T., 1999. The impact of young drivers' lifestyle on their road traffic accidents risk in the greater Athens area. Accident Analysis and Prevention 31 (6), 771-780.

Daniel, J., Tsai, C., & Chien, S., 2002. Factors Influencing Truck Crashes on Roadways with Intersections. In: Proceeding of the Transportation Research Board 81st Annual Meeting, Washington, DC.

Ettema, D., & Timmermans, H., 1997. Theories and models of activity patterns. In: D. Ettema and H. Timmermans (eds.), Activity-Based Approaches to Travel Analysis, Pergamon, Oxford, 1-36.

Evans, L., 2004. Traffic Safety. Science Serving Society, Bloomfield, MI, 444

Foret-B, J.Y., Faverjon. G., Brun-C, F., Tarriere, C., Patel, A., & Guillon, F., 2003. Females more vulnerable than males in road accidents. Seat Belts: The Development of an Essential Safety Feature. Society of Automotive Engineers, Warrendale, PA, 477-482.

Garcia, F.A., & De Juan, A., 2007. The relationship between traffic accidents and real economic activity in Spain: Common cycle and health issues. Journal of Economics 16(6), 603-626.

Golias, J.C., 1992. Establishing relationships between accidents and flows at urban priority. Accident Analysis and Prevention 24 (6), 689-94.

Greenshields, B.D., & Platt, F.N., 1967. Development of a method of predicting high-accident and high-violation drivers. Journal of Applied Psychology 51 (3), 205-210.

Hadi, M.A., Aruldhas, J., Chow, L.F., & Wattleworth, J.A., 1993. Estimating safety effects of cross-section design for various highway types using negative binomial regression. Transportation Research Record 1500, 169-177.

Harre, N., 2000. Risk evaluation, driving, and adolescents: a typology. Developmental Review 20 (2), Academic Press, city, 206-226.

Hasselberg, M., Vaez, M., & Laflamme, L., 2005.Socioeconomic aspects of the circumstances and consequences of car crashes among young adults. Social Sci. Med. 60, 287-295.

Janke, M., 1991. Accidents, mileage, and the exaggeration of risk. Accident Analysis and Prevention 23 (3), 183-188.

Janson, B., Awad, W., Robles, J., Kononov, J., & Pinkerton, B., 1997. Truck accidents at freeway ramps: Data analysis and high-risk site identification. Journal of Transportation and Statistics.

Jungwook, J., Jennufer, O., Randall, G., Johnell, B., 2007a. Assessing mileage exposure and speed behavior among older drivers based on crash involvement status. In: Proceedings of the Transportation Research Board 86th Annual Meeting, Washington, DC.

Jungwook, J., Jennufer, O., & Randall, G., 2007b. Relationship between crash involvement and temporal-spatial driving behavior activity patterns using GPS instrumented vehicle data. In: Proceedings of the Transportation Research Board 86th Annual Meeting, Washington, DC, 00-00.

Kim, Y.S., 2001. Effects of driver, vehicle, and environment characteristics on collision warning system design. Master’s degree thesis, Department of Science and Technology, Linkoping University.

Kitamura, R., 1998. An evaluation of activity-based travel analysis: a review paper. Transportation 15, 9-60.

Knoblauch, R., Yobey, H., & Shunaman, E., 1984. Pedestrian characteristics and exposure measures. Transportation Research Record 959, 35-41.

Kononov, J., & Allery, B., 2004. Road accident predictions modeling and diagnostics of accident causality – a comprehensive methodology. In: Proceedings of the 2nd International Congress – Societa Italiana InfrastructureViarie, University of Firenze, 27-29.

Kulanthayan, S., Raha, A.R., Law, T.H., & Radin, R. S., 2004. Seat belt among car users in Malaysia. IATSS Research 28 (1), 19-25.

McColl, R., 2001. Age and sex profiles of speeding and drink driving offenders and drivers involved in casualty crashes. Road Accident Research Unit, Adelaide University, 2001.

Murray, C.J., & Lopez, A.D., 1996. Global Health Statistical: A Compendium of Incidence, Prevalence, and Mortality Estimates for over 2000 Conditions, Harvard University Press, Boston.

Noland, R.B., & OH, L., (2004). The effect of infrastructure and demographic change on traffic-related fatalities and crashes: A case study of Illinois county-level data. Accident Analysis and Prevention 36, 525- 532.

Ogle, J., 2005. Quantitative Assessment of Driver Speeding Behavior Using Instrumented Vehicles. Doctoral dissertation, Dept. of Civil Engineering, Georgia Institute of Technology, Atlanta, GA.

Petridou, E., & Belechri, M., 2002. Poverty and injury risk among children: Always together. Social and Prevention Medicine 47 (2), 65-66.

Sawalha, Z., & Sayed, T., 2003. Statistical issues in traffic accident modeling. In: Proceedings of the Transportation Research Board 82nd Annual Meeting, Washington, DC, 00-00.

Shankar, V., Mannering, F., & Barfield, W., 1995. Effect of roadway geometrics and environmental factors on rural freeway accident frequencies. Accident Analysis and Prevention 27 (3), 371-389.

Shiftan, Y., & Ben-Akiva, M. (2006). A practical policy sensitive activity-based model. Paper presented at the 11th International Conference on Travel Behavior Research, Kyoto, August 16-20.

Shiftan, Y., Ben-Akiva, M., Proussaloglou, K., & DeJong, J., 2004. An advanced activity-based model for Tel-Aviv. In: Proceedings of the EIRASS Workshop on Progress in Activity-Based Analysis, Maastricht, The Netherlands, May 28-31.

Spallek, M., Turner, C., Spinks, A., Bain, C., & McClure, R., 2006. Walking to school: Distribution by age, sex, and socio-economic status. Health Promotion Journal of Australia 17 (2), 00-00.

Thouez, J.P., Gangbe, M., Bergeron, J., Bussiere, Y., Rannou, A., & Bourbeau, R., 2005. Measurement of pedestrian exposure to the potential dangers of daily activity-travel patterns in the region of Montreal. In, L.J. Sucharov & C.A. Brebbia (Eds.) Urban transport 2005, Boston, WIT Press, 249-256.

VanVuuren, F., 2001. Addressing lifestyles of lower income groups as contributing factors to high incidence of pedestrian fatalities on South Africa roads. Road users' characteristics with emphasis on life-styles. In: Quality of Life and Safety—Proceedings of 14TH ICTCT Workshop Held in Caserta, Italy, October. 98a-98k.