TOWARD A METHODOLOGY FOR FIELD OBSERVATIONS OF DRIVER BEHAVIOR: A COMPARISON OF FINLAND AND MICHIGAN

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16. Abstract

This study was designed (1) to develop an initial set of measures to observe driver behavior in different countries, in different parts of any country, or in longitudinal studies, and (2) to compare driver behavior in Finland and Michigan by using these measures.

Development of a set of measures emphasized equating environmental factors and traffic rules. For such conditions, the measures proved to be reliable and to give valuable results.

The developed measures were applied in middle-sized cities in both countries, Lahti in Finland and Ann Arbor in Michigan. The results indicated the following main differences in driver behavior. Drivers in Lahti (compared to those in Ann Arbor) signalled more frequently before the lane change or turning, and came to a full stop at intersections with a stop sign more frequently. The safety belts were more frequently used in Finland than in Michigan. The following trends were found: drivers in Lahti exceeded the speed limit more frequently, but decreased the speed earlier while approaching the intersection from the secondary road, accelerated slower after turning onto the secondary road, and accepted longer gaps when entering the main road. The following aspects of driver behavior did not differ in the two cities: the variance of the speed in free-flow traffic, proportion of short headways in car-following situations, the frequency of no stops compared to rolling and full stops at intersections with a stop sign, and yielding to pedestrians at intersections.

It was concluded that, overall, driver behavior is more similar than different in Lahti and Ann Arbor. The main differences found in obeying some specific rules were assumed to be influenced primarily by the more extended driver training in Finland.

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To my children Heikki and Saara who patiently have followed me across the Atlantic Ocean several times.

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INTRODUCTION

The need for measures to collect descriptive and comparable data on actual driver behavior in order to improve traffic safety has been recognized for at least 20 years. In 1974, R. Smeed suggested: "A knowledge of standards of driver behaviour would help to determine which aspects of such behaviour especially need to be improved. If these standards were assessed periodically, it would be possible to assess whether driver behaviour was or was not improving and assess the effects of policies directed to the improvement of driver behaviour. If the standards were assessed in different countries or in different parts of the same country, the results would be of value in explaining differences in accident rates in the countries or parts of the same country concerned." (Smeed, 1974)

Since then, numerous studies have been carried out on the effects of different factors on driver behavior. Without underestimating the importance of these studies, it is surprising that there is a substantial lack of information on actual driver behavior. Until recently, there has been no longitudinal or cross-national study on driver behavior that has collected data by (a) using a broad and unobtrusive set of measures and (b) matching or controlling environmental factors and traffic volumes properly. Consequently, our current databases are insufficient to describe the actual traffic behavior in any one country, and we have even fewer facts about cross-national differences in behavior. Perhaps the most well-known exceptions to this rule are widely conducted measurements of vehicle speed (e.g., Leutzbach, et al., 1988) and the use of seat belts (e.g., Mäkinen, Wittink, and Hagenzieker, 1991) that have provided relatively comparable data.

Most of the cross-national comparisons have not used unobtrusive observation of road-user behavior. The International Drivers' Behavior Research Association (IDBRA) started a broad comparison of overtaking behavior and accidents in the 1970s. This study included following subprojects. Quenault (1973) observed test subjects' overtaking behavior under normal conditions in France, Federal Republic of Germany (FRG), England, Italy, and Sweden. Rumar and Berggrund (1973) compared overtaking behavior on test tracks in England and Sweden. Lewrenz and Pittrich (1973) analyzed overtaking accidents that occurred in France, FRG, England, the Netherlands, and Switzerland. Jeffcoate, Skelton, and Smeed (1973) analyzed overtaking accidents in England, New Zealand, and the United States. Later, IDBRA also carried out a comparative study concerning drivers' close-following and speed behavior on motorways in 11 countries (Benjamin, 1980).

Leutzbach, et al. (1988) compared two aspects of driver behavior in England and Federal Republic of Germany: vehicle speed while approaching an intersection from a secondary road, and acceptance of gaps. The comparisons were based on data collection at one English and two German rural intersections.

Sivak and his coworkers carried out a series of laboratory experiments and a survey. Sivak, Soler, and Tränkle (1989a and b) compared Spanish, West German, and U.S. driver self-assessment and risk-taking. Sivak, Soler, Tränkle, and Spagnhol (1989) compared driver risk-perception in Brazil, Germany, Spain, and the United States.

Lee, Nagayama, and Renge (1990) compared travelling speed on highways, drivers' visual scanning behavior at intersections, and pedestrians' crossing behavior at red traffic signals in Canada, Japan, and Korea. Lee (1990) also conducted a survey of drivers' traffic attitudes in Canada, Japan, Korea, and the United States. Barjonet (1992) investigated attitudes to road traffic risk in 15 European countries. Rothengatter (1993) investigated attitudes toward traffic violations and enforcement in Ireland, The Netherlands, Norway, and Spain.

Evidently, the number of studies dealing with national differences in driver behavior in real traffic is not substantial. Furthermore, the sites of the study reported by Benjamin (1980) varied substantially in terms of a posted speed limit and traffic volume. Lee, Nagayama, and Renge (1989) reported no attempt to match road and traffic conditions (see also Nagayama, 1989). Many of the listed field studies did not select or define observed road users properly. Consequently, it is difficult to draw solid conclusions from these studies.

There are also longitudinal studies that collected data on driver behavior. Slätis (1990) observed drivers' speed behavior, running red lights, use of turn signal when turning, and yielding to pedestrians in Stockholm, Sweden. Unfortunately, most aspects of driver behavior were not defined enough to provide relevant conclusions.

In Finland, Heino (1993) developed a set of measures to observe road-user behavior in the Helsinki Metropolitan Area. The pilot study, conducted in 1992, included the following measures: speed behavior, headways of vehicles driving in line, use of safety belt, use of daytime-running lights, use of turn signal while turning, use of bicycle helmet, and crossing on red lights by pedestrians. On the basis of Heino's (1993) study, The Central Organization of Traffic Safety in Finland started to coordinate data collection of road-user behavior in several locations in Finland (Heino, 1994). This study included some additional measures, such as proportion of drunk drivers and use of retroreflectors by pedestrians. The first data collection was conducted in 1993 and the measures will be repeated once a year and at the same locations. Control of traffic volumes for each measure would improve the comparability of the results with other studies.

In addition, there are several studies that have followed longitudinally some individual aspects of road-user behavior (e.g., Syvänen, 1982; McKelvie, 1987; Pikkarainen and Penttilä, 1990; Walker, 1991; Streff, Eby, Molnar, Joksch, and Wallace, 1993). However, the literature shows that longitudinal studies on road-user behavior are relatively infrequent.

The present study was designed to investigate driver behavior in Finland and Michigan. The primary objective was to develop an initial set of measures to observe driver behavior unobtrusively in different countries (or in different parts of any country or in longitudinal studies). Therefore, we chose only two countries for the comparison. The secondary objective was to obtain comparable data on driver behavior in these counties while testing the measures.

The next chapter will describe the development of the set of measures, primarily for the comparison of driver behavior in Finland and Michigan. However, many of the problems have a more general nature as will be discussed in the next chapter. Therefore, the chapter provides applicable information for other corresponding comparisons.

A detailed description of the sites and the design of each measure conducted in Finland and Michigan will be given along with the results concerning a particular measure.

OUTLINE OF THE DEVELOPMENT OF A SET OF MEASURES

The underlying notion in the development of a set of measures for field observations was that comparison of driver behavior in different countries is appropriate only if the physical environments and the situation-specific traffic rules are matched. Only then can we assume that field observations would provide relevant cross-national information on driver behavior in different countries. Possible differences would reveal the effects of general legislation, social norms, and values of the societies, as well as the effects of, for example, education and driver training. Of course, the traffic environment also reflects cultural differences, but its effect on driver behavior is too difficult to study at the same time as cultural differences in driver behavior themselves.

Sometimes the patterns of driver behavior in different countries have been called *the culture of driving*. However, the culture of driving is not just what is measured objectively on a road (Zaidel, 1992). Therefore, instead of a concept of *cross-cultural*, the concept of *cross-national* is used in this report.

It is also necessary to define the factors that have been matched. Several selections concerning measures, road users, sites, etc., have to be made because it is too time consuming to study all aspects of road-user behavior.

Measures

The following measures were included in this study:

(1) Speed behavior in a free flow traffic situation
(2) Headways while following other vehicles
(3) Use of turn signals before a lane change
(4) Speed while approaching an intersection from a secondary road
(5) Speed after turning onto a secondary road
(6) Use of turn signals before turning
(7) Stopping behavior at intersections with a stop sign
(8) Gap acceptance when entering a main road
(9) Yielding to pedestrians at intersections
(10) Use of safety belts

The underlying logic in the selection of measures was that these measures would show different aspects of driver behavior that have potential safety effects. Measures 1, 3, 6-7, and 9-10 focused primarily on obeying a specific traffic rule. Measures 2, 4-5, and 8 focused on behavior in situations with a general rule of safe driving. However, most of the measures have many aspects. Speed behavior includes two major aspects: exceeding speed limit and speed distribution (speed deviation). Short headways in car-following situations mean that a driver has less time to react if the lead vehicle suddenly brakes. Speed while approaching an intersection from a secondary road and, especially, gap acceptance when entering a main road were expected to reveal possible differences in safety margins. Speed after turning onto a secondary road shows how rapidly (aggressively) drivers accelerate. Use of turn signal, either before a lane change or turning, indicates obeying specific traffic rules and also how well drivers show their intentions to other road users. Stopping behavior at intersections with a stop sign primarily indicates obeying of traffic rules but, perhaps, also provides information about safety margins. Yielding to pedestrians at intersections shows how well drivers give a right-of-way to vulnerable road users (as well as obey a particular rule).

Use of safety belts differs from the other measures in two respects. First, it does not evaluate a situation-specific behavior like other measures do. Second, the data collection for this measure was unnecessary because there were current data available on the use of safety belts in Finland and Michigan.

It is acknowledged that, in most cases, the safety effects of a particular driver behavior are only potential. For example, we cannot quantify the safety effect of violating a specific traffic rule. In general, however, the violation of rules means a negative attitude toward traffic safety, unwillingness to pay attention to other road-users, or willingness to accept smaller safety margin. Even the comparison of exceeding the posted speed limit is not straightforward, because setting of speed limits may vary from one locale to another.

The data collection was performed in one city in Finland and in one city in Michigan. Each measure was obtained from two sites in each city, except for speed while approaching an intersection from a secondary road and speed after turning onto a secondary road (measured at one site each), and stopping behavior (measured at three sites each). In most measures, the sites were selected to cover different environments.

Of course, there are numerous other aspects of driver behavior that are of potential interest. Originally, we intended to observe passing behavior on a two-lane road, how well drivers give space to others in lane-changing situations, and running red lights, for example. However, there were no comparable environments allowing a comparison of space giving, and the observation of passing behavior proved to be time consuming. Because of substantially different durations of red and amber intervals, a valid comparison of running red lights in Finland and Michigan would be difficult.

Drivers

Driver behavior was a dependable variable and, therefore, the drivers were not matched. We focused on driver behavior, and thus we excluded pedestrians and bicyclists, as well as police cars, ambulances, fire engines, taxi cabs, cars driven by student drivers, motorcycles, mopeds, buses, and trucks.

There are substantial differences between minimum driver training and licensing in Finland and Michigan (Table 1). The training measured in hours is longer in Finland than in Michigan. From the year 1989, training in Finland has been given in two phases. The content of training and licensing was not analyzed.

The minimum age for a driver license is 18 in Finland and 16 in Michigan. Consequently, the driver population in Michigan includes teenagers who do not drive cars in Finland.

Table 1
Some aspects of driver training and licensing in Finland and Michigan
(Motor Vehicle Registration Centre of Finland, 1989; Michigan Department of State, 1993; Michigan Department of Education, 1994).

Phase of training and testing	Finland	Michigan
Basic training in classroom	20 x 45 min	10 hours$^{\Delta}$
Basic driving practice	28 x 25 min*	2 hours$^{\Delta}$
Exceptions	A family member having a driver licence may give training (currently about 20% of students)	If an applicant is at least 18 years of age, no education is required
Tests	Medical examination including vision testing, written test, and road test	Vision testing, written test, and road test
Additional training (6-24 months after passing the tests)	4 x 45 min† 8 x 25 min†	

* Initial practice of vehicle handling takes place before this section.

† Starting in 1989.

Δ There are five types of educational programs. The described program was the most frequent one in fiscal year 1992-93 (38% of students). The other programs include 30 hours of classroom education and six hours driving practice (3 to 4 of these 6 hours may be substituted by simulator education or off-street driving experience).

Vehicle population

Because this study was carried out in actual traffic, it was impossible to select vehicle population (make, size, options, etc.). However, it is assumed that differences in vehicle populations are relatively minor. The most substantial difference is that in Finland, cars are generally equipped with manual transmissions, while automatic transmissions are the norm in Michigan. Also cars are generally smaller in Finland than in Michigan. It is assumed that these differences do not have a major impact on the behaviors studied.

Rules and enforcement

Measures were taken in traffic situations and environments where similar basic rules applied. At intersections compared, for example, similar yielding rules applied, traffic was controlled or uncontrolled, a possible sign for approaching vehicles was a stop sign or yielding sign, etc.

The posted speed limit has substantial influence on driver behavior, and the posted speed limit, in turn, depends on the environmental factors. Consequently, matching of speed limits was emphasized. However, the speed limits are shown in kilometers per hour (kph) in Finland, while in miles per hour (mph) in Michigan.

In observations of obeying specific traffic rules, it is important that the subjective risk of being caught is similar. Consequently, instead of evaluating the enforcement, the rank order of risk of being caught while violating the rules was (subjectively) estimated to be similar. In both countries, drivers may believe that it is more likely to get a ticket because of exceeding the speed limit than because of an incomplete stop at an intersection with a stop sign. Further, it is even less likely to get a ticket because of the failure to use a turn signal or safety belt, or because of not yielding to pedestrians. Naturally, this is the case in normal traffic situations, but not if an accident occurs. However, there is one obvious exception: although the subjective risk of being caught while failing to use a safety belt was estimated to be small in both countries, the Finnish law permits primary enforcement, while the Michigan law does not.

Sites

This study focused on driver behavior in urban and suburban areas of middle-sized cities. For the comparisons we chose one city from each country: Lahti from Finland and Ann Arbor from Michigan. Basic demographic data on these two cities are given in Table 2. The populations of the two cities are relatively similar. The proportion of elderly people is higher in Lahti than Ann Arbor, but this difference might be only a minor problem because Lahti's older drivers do not drive very actively. As will be shown later, the proportion of elderly drivers was not systematically higher in Lahti than in Ann Arbor, and the proportion of middle-age drivers was dominating in both cities. Despite the higher proportion of women in Lahti, the proportion of female drivers observed was lower in Lahti than in Ann Arbor. The relatively similar median income indicates that the standard of living plays no major role in possible behavioral differences. A substantial difference in income would indicate clear differences in vehicle population, for example.

Table 2
Basic demographic data on Lahti and Ann Arbor.

	Lahti	Ann Arbor ∞
Area (km^2)	135.0*	67.1
Population	93,414*	109,592
Percentage of men	46.8†	49.3
Age distribution (%):		
≤18	21.6†	20.2
19-64	64.0†	72.5
≥65	14.4†	7.3
Median age (years)	38.1†	27.3
Per capita income (US$)	14,900Δ	17,800

* for 1992 (Statistics Finland, 1992)
† for 1991 (City of Lahti, 1992)
Δ for 1990 (City of Lahti, 1991)
∞ all information for 1990 (U.S. Bureau of the Census, 1992)

Rural areas were excluded because of frequently small traffic volumes. Consequently, data collection would be very time consuming. Limited-access highways have substantial traffic volumes, but in the case of Finland and Michigan, the volumes are totally different. In some measures limited-access highways were substituted with suburban highways. It would have been possible to collect data also from larger cities, Helsinki and Detroit, for example. However, it has been argued, although with no evidence, that driver behavior in large cities differs substantially from that in other areas. Consequently, it was assumed that data about middle-sized cities are more representative than data from large cities. However, given that data were collected from two cities only, the results do not necessarily represent general driver behavior in Finland and Michigan.

The environment type (downtown, urban, or suburban) and function (downtown, residential, or industrial) were matched because traffic volumes, composition of vehicle population, purposes of trips, etc., may differ by environment. All these aspects influence driver behavior.

At the micro level two types of sites (intersections and road sections outside of intersections) were chosen in order to cover different features of driver behavior. Most of the driving takes place on sections outside of intersections, but there are only a limited number of features that are not too time consuming to measure. Intersections provide better possibilities to measure different features of driver behavior.

Road and traffic conditions

In order to match road conditions, this study attempted to match sight distances, number and width of lanes, curvature, and gradient. The roadway conditions (surface) were always good or fairly good. The surface was asphalt.

A match of traffic volumes was based on a count made six to nine months before the actual collection of the performance measures. Therefore, some differences existed. Traffic volumes were also counted during data collection (except for the use of turn signal before lane change). All volume counts are provided to allow the evaluation of possible bias effects.

Equipment

Data were collected by video recording and/or note taking, except for the measurement of speed behavior and headways. They were measured by a traffic counter connected to detector loops or photocell pairs.

Procedure

In both cities, data were collected on Tuesdays through Thursdays, between 9 am and 4 pm. Length of data collection at each site was three to six hours, depending on the availability of valid observations. The roadway surface was always dry. Atmospheric conditions were good, with no rain, snow, or fog. Because the author collected all the data with an assistant, the data were collected during different time periods—in Lahti May 4-18, 1993, and in Ann Arbor, September 14-October 6, 1993. These time periods are assumed to be fairly comparable because they do not include winter or summer holiday seasons.

The main target of observations was a particular driver behavior. In addition, driver's sex and age was classified and documented on videotapes or by making notes. However, sex and age effects were not of primary interest in this study, partly because the proportions of young and elderly drivers were too small to provide comparisons of the age categories.

Generally, taking unobtrusive observations is easier said than done (Bochner, 1986). Fortunately, the road environment in urban and suburban areas is usually not the most difficult environment for that purpose. However, attention must be paid to the problem. In the present study, the observation car was an ordinary car or van. It was parked in a normal manner on a private parking lot or along the road among other parked cars. However, while investigating the use of turn signal before lane-chance, the observation car drove on the road in a normal manner. In some measures conducted in Lahti, no observation car was present and the video camera was on the roof of a shopping center.

In all measures involving the use of the video technique, the camera was hidden so well that drivers were not able to see it before or while the behavior occurred. However, it is possible that somebody noticed the camera, and if he/she approached the site later, the later behavior might have been influenced by this information. This bias was impossible to exclude completely. However, those few situations, in which the observer noticed that a driver paid exceptional attention to the observation car, observer, or devices, were not included.

Hypotheses

Simple hypotheses for the comparison of Finland and Michigan were difficult to design since the literature showed that researchers have been extremely cautious to express their opinions explicitly on possible cross-national differences in driver behavior. This is the case although many studies have compared the frequency and type of traffic accidents in different countries. Perhaps researchers have been cautious because of lack of any evidence.

In contrast, oral discussions frequently include these kinds of assumptions. In addition, journalists have presented opinions about the possible differences between European and American driver behavior. For example, driver behavior in the U.S.A. has been described with the following attributes (compared to Europe): polite, harmonious, unhurried, cultivated, and cautious (e.g., Nortamo, 1992). These positive features have been explained with the longer history of (1) a widely-spread motorized transportation and (2) a general speed limit system. Furthermore, a frequent use of stop signs instead of yield signs, and vehicles equipped with an automatic transmission instead of a manual one, have been seen to promote those preferable features. However, from the scientific point of view, it is not easy to derive hypotheses from these general statements. Nevertheless, the following working hypotheses were assessed.

First, it was assumed that, overall, driver behavior is more similar than different in Finland and Michigan, if the components of the traffic system are matched as presented earlier. If differences are to be found, they are not substantial. This hypothesis was based on the fact that the patterns of road accidents in Finland and the U.S.A. are relatively similar (Luoma and Sivak, 1992). While no comparison of road accidents in Finland and Michigan has been conducted, there is no reason to believe that the patterns are more different than between Finland and the U.S.A. The general presumption about substantial differences between European and American driver behavior was rejected because it was assumed that those presumptions are based on subjective and unreliable observations.

Second, it was assumed that, on average, Finnish drivers obey specific rules better than Michigan drivers. This assumption was based on the fact that minimum driver training is more extended in Finland than in Michigan. Of course, the primary goal of driver training is safe driving. However, the applicants usually concentrate on learning specific rules because they are much more concrete to follow than directions for safe driving (Luoma, 1984). Consequently, the training may improve the frequency of obeying specific rules. In addition, it is also possible that more substantial driver training in Finland reflects values and norms of the society and, therefore, the rules are better obeyed.

Third, it was assumed that some indication of the longer history of motorized transportation would be detected, though the general effect was rejected in the first hypothesis. The more polite and cautious behavior, if any, should manifest itself, for example, in measures such as speed behavior while approaching an intersection from a secondary road, speed behavior after turning onto a secondary road, or yielding to pedestrians.

SPEED BEHAVIOR AND HEADWAYS

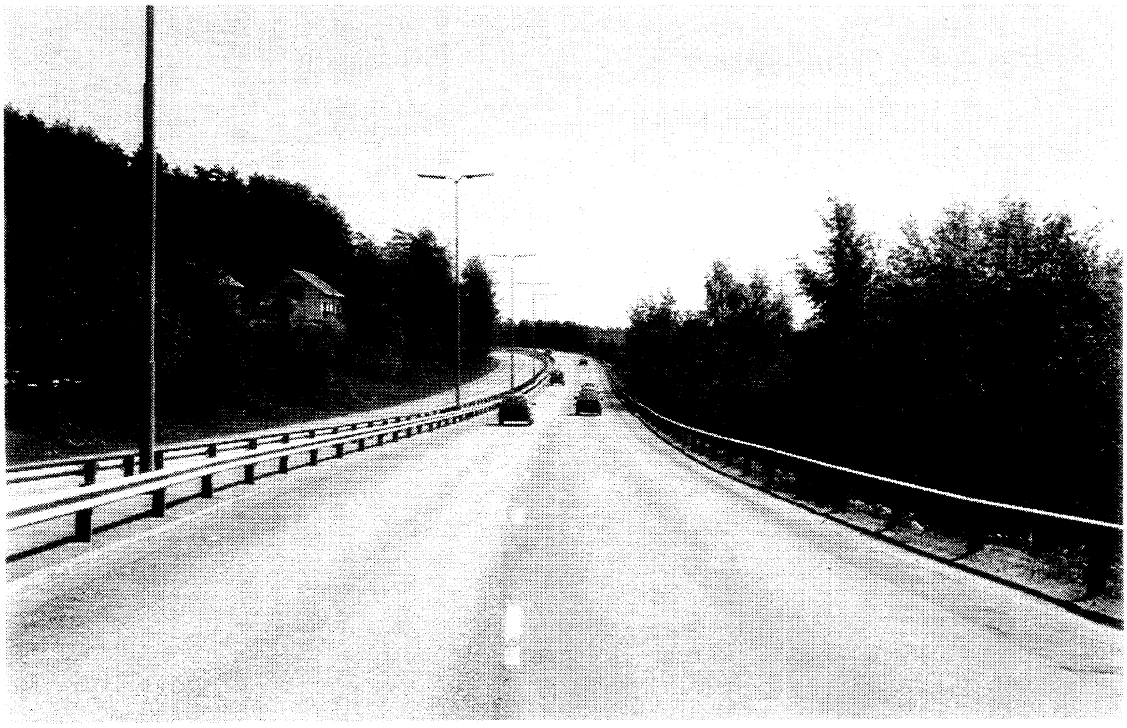
Sites

The suburban sites of the speed and headway measurements are shown in Figures 1 and 2. The road and traffic conditions of the sites are summarized in Table 3.

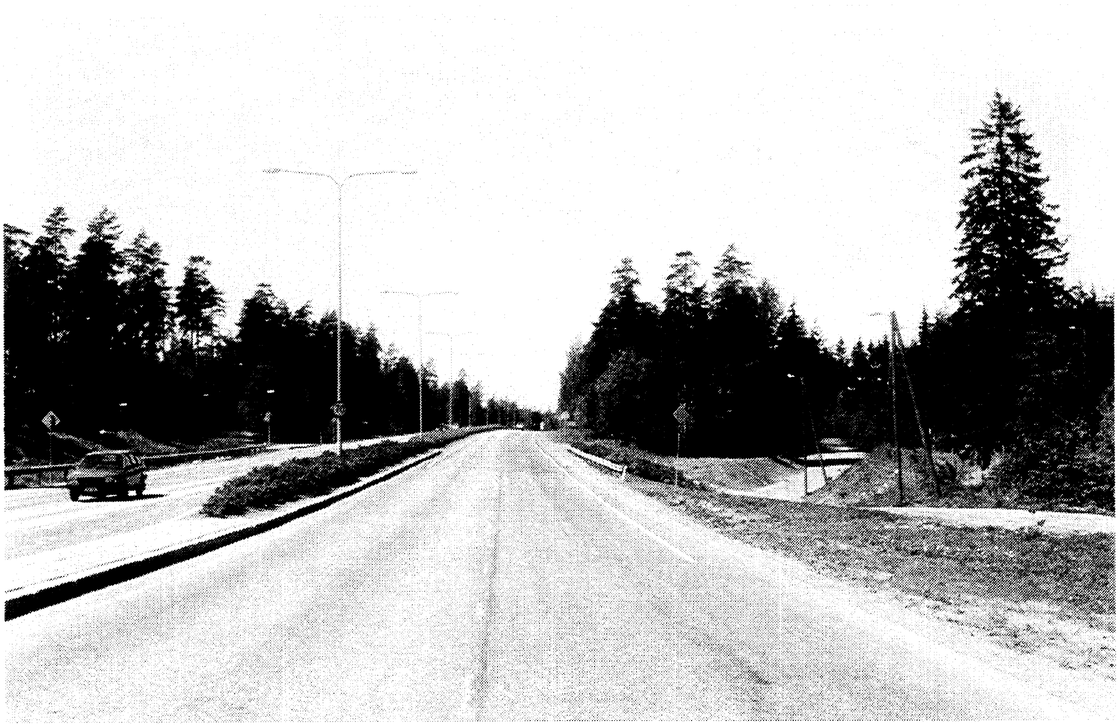
Table 3
Road and traffic conditions of speed and headway measurements.

	Lahti		Ann Arbor	
	1	2	1	2
Environment	suburban			
Speed limit (kph)	70		64 (40 mph)	72 (45 mph)
Number of lanes	2+2			2+1+2[∞]
Lane width (m)	3.5			
Distance from the previous major intersection (m)	1,250*	620	1,480*	500
Traffic volumes in the direction measured (vehicles/h)†				
mean	357	667	509	1,157
standard deviation	133	92	145	214
minimum	156	480	204	744
maximum	720	888	864	1,800

∞ A center lane for left-turning vehicles because of residential streets on the left side of the road.
* There was an additional minor intersection at a distance of 200 m. However, the proportion of vehicles entering from those secondary roads was less than 10% during the measurements.
† Derived from the traffic volumes of time sequences of 5 minutes.



(1)



(2)

Figure 1. The sites of speed and headway measurements in Lahti: (1) Valtatie 12, eastbound, (2) Hämeenlinnantie, westbound.

(1)

(2)

Figure 2. The sites of speed and headway measurements in Ann Arbor: (1) Huron Parkway, northbound (2) Washtenaw Avenue, eastbound.

In order to match the traffic volumes, only time sequences of 5 minutes involving 200-899 vehicles per hour were included in further analysis. The traffic volumes, as well as the number of vehicles and the proportion of cars and vans used in further analyses, are presented in Table 4.

Table 4
Number of vehicles, proportion of cars and vans, and traffic volume by site for the selected data.

	Lahti		Ann Arbor	
	1	2	1	2
Number of vehicles	2,642	2,047	3,722	534
Proportion of cars and vans	83.6	88.3	97.6	98.3
Traffic volumes in the direction measured (vehicles/h)				
mean†	363	667	509	813
standard deviation†	131	92	145	49
minimum†	204	480	204	744
maximum†	720	888	864	888

† Derived from the traffic volumes of time sequences of 5 minutes.

Design

In order to compare the speed behavior, it is appropriate to examine only drivers who are able to choose their driving speed, i.e., only drivers who were travelling in free-flow traffic. The measures of speed behavior (speed deviation and exceeding speed limit) included only vehicles with a minimum headway of 10 seconds between the actual vehicle and the vehicle in front (in the same lane).

In comparison, the proportion of short headways is appropriate to examine only in car-following situations. The measure of short headways used the following, generally accepted, definition (Mäkinen and Kulmala, 1987): a vehicle is in a car-following situation if the headway is 5 seconds or less and the speed difference between the actual vehicle and the vehicle in front (in the same lane) is 10 kph or less.

The headway should be long enough to provide a necessary reaction time if a vehicle in front decelerates suddenly. However, drivers' reaction times in car-following situations vary widely. Sivak (1987) listed mean reaction times of unalerted drivers to signals on lead vehicles from four studies. The values ranged from 0.92 to 1.45 seconds. Consequently, there is no unequivocal definition for hazardous headway. This study investigated the proportions of headways less than 1.0 and 1.5 seconds.

Speed behavior and headways were measured by a traffic counter connected to temporary detector loops. After measurements the files were transferred into a portable PC-computer for further analysis. The counter, DSL-1, provided the following information for each vehicle (Jokela, 1992): time of day, speed (kph), length (m), direction of travel, and lane. In addition, the counter classified vehicles into seven vehicle groups (cars and vans, buses, trucks, trucks with semitrailers, trucks with full trailers, trailers of cars and vans, long trailers of cars and vans) and computed two kinds of headways (1/100 sec) for each vehicle. In this study, headway was defined as the elapsed time between the rear of the lead vehicle passing the loop and the front of the following (actual) vehicle passing the same point in the same lane.

Driver's sex and age were not recorded.

Results

General speed behavior. Main speed results and the number of vehicles in free-flow traffic for each site are given in Table 5. The cumulative speed frequencies are presented in Figure 3.

Table 5
Mean and median speed, standard deviation of the speed, maximum speed, and the number of vehicles in free-flow traffic by site.

	Lahti		Ann Arbor	
	1	2	1	2
Mean speed (kph)	80	77	73	75
Median speed, v_{50} (kph)	80	77	73	75
Standard deviation (kph)	9	7	9	9
85-percentile of the speed, v_{85} (kph)	89	84	82	85
Maximum speed (kph)	137	99	106	95
Number of vehicles	1,153	380	1,458	106

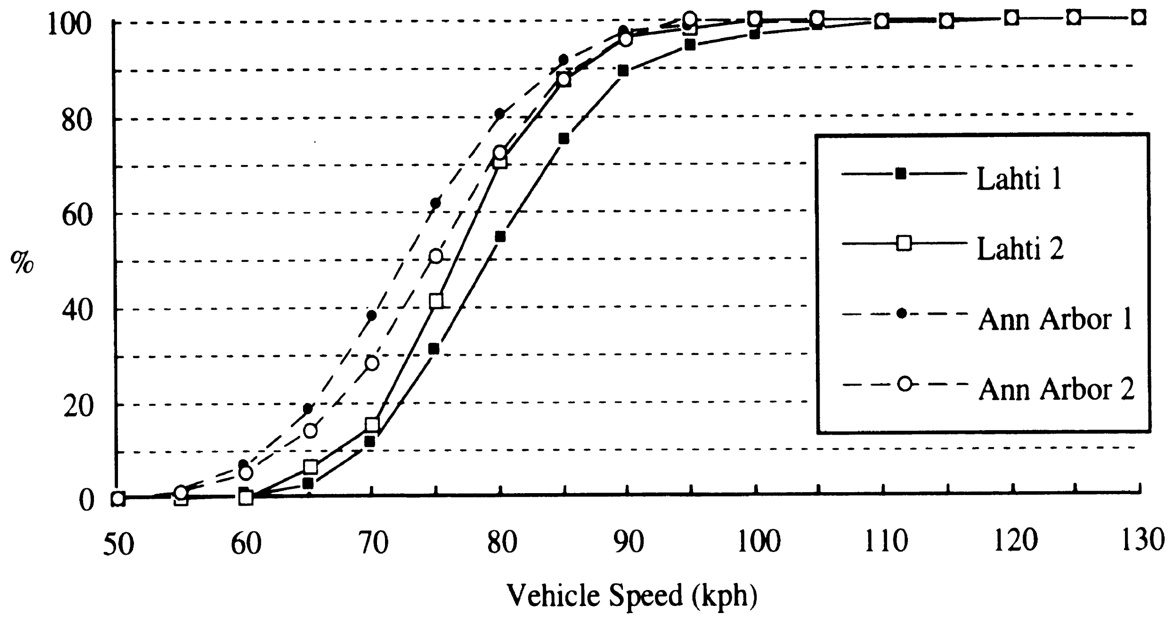


Figure 3. Cumulative speed frequency for each site.

Table 5 shows that the number of vehicles at the second site in each city was substantially smaller than at the first one. Nevertheless, Bartlett's test was performed to test the difference of standard deviations (variances). The test was computed between the cities and between the first sites (that included the majority of data). There was no significant difference between the two cities in either case.

Exceeding speed limit. The proportions of drivers exceeding the posted speed limit are given in Table 6.

Table 6
Proportion of drivers exceeding speed limit by site for drivers in free-flow traffic.

	Lahti		Ann Arbor	
	1	2	1	2
Exceeding speed limit (%)	88.3	84.5	84.0	63.2
Exceeding speed limit by more than 15 kph (%)	24.6	12.1	23.2	4.7
Number of vehicles	1,153	380	1,458	106

The proportion of the drivers exceeding the speed limit was different at the two sites in Ann Arbor ($X^2(1) = 29.5$, $p < 0.00001$), but not in Lahti. At each site in Ann Arbor, the proportion of the drivers exceeding the speed limit was smaller than the average in Lahti (for the first Ann Arbor site: $X^2(1) = 7.02$, $p < 0.008$; for the second Ann Arbor site: $X^2(1) = 47.4$, $p < 0.00001$).

There was no significant difference between the cities in the proportions of drivers exceeding the speed limit more than 15 kph, but the difference between the sites was significant in each city (for Lahti: $X^2(1) = 25.5$, $p < 0.0001$; for Ann Arbor: $X^2(1) = 19.7$, $p < 0.001$).

Proportions of the drivers exceeding the speed limit are given by lanes in Table 7.

Table 7
Proportion of drivers exceeding speed limit on each lane by site for drivers in free-flow traffic.

	Lahti		Ann Arbor	
	1	2	1	2
Right lane (%)	87.6	82.8	79.5	52.7
Left lane (%)	89.2	86.1	89.1	74.5
Drivers in right lane (%)	56.8	48.9	54.0	51.9

In Lahti, there was no difference by lanes in the percentage of drivers exceeding the speed limit. In Ann Arbor, drivers in the left lane exceeded the speed limit more frequently than those in the right lane (for the first site: $X^2(1) = 24.7$, $p < 0.0001$; for the second site: $X^2(1) = 5.39$, $p < 0.03$). There were no significant differences in lane distributions between the four sites.

Headways while following other vehicles. This analysis was performed for each city with combined results of two sites because (a) the traffic volumes varied considerably between the sites in each city and (b) it is necessary to study the proportion of short headways by traffic volume. In addition, there was no specific, a priori reason to compare this aspect of driver behavior by site.

Number of drivers in car-following situations by traffic volume is presented in Table 8. Proportions of drivers having a short headway in car-following situations are shown in Figure 4 by traffic volume.

Table 8
Number of drivers in car-following situations by traffic volume.

Traffic volume (vehicles per hour)	Lahti	Ann Arbor
200-299	183	47
300-399	222	190
400-499	103	279
500-599	208	396
600-699	461	228
700-799	224	231
800-899	84	294

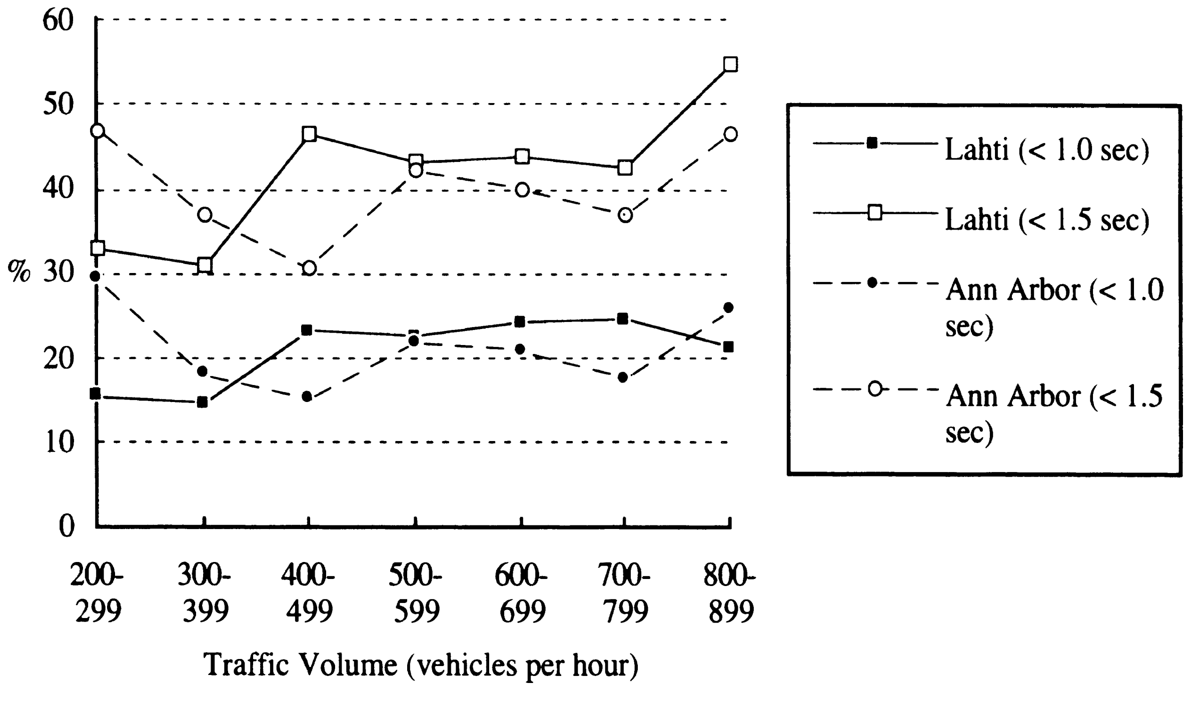


Figure 4. The proportion of drivers having a headway of less than 1.0 or 1.5 sec in car-following situations.

There were no systematic differences in the proportion of short headways whether the cutoff was set at 1.0 sec or 1.5 sec. The proportion of headways less than 1.0 sec was smaller in Lahti than in Ann Arbor when the traffic volume was 200-299 vehicles per hour ($X^2(1) = 5.26$, $p < 0.03$). In contrast, the proportion of headways less than 1.5 sec was greater in Lahti than in Ann Arbor when the traffic volume was 400-499 vehicles per hour ($X^2(1) = 8.63$, $p < 0.01$). None of the other differences was significant.

USE OF TURN SIGNAL BEFORE LANE CHANGE

Sites

The measure of the use of turn signal before lane change was performed on two, relatively long road sections. Consequently, many features given in Table 9 varied along the route, and Figures 5 and 6 give only some examples of each route.

Table 9
Road and traffic conditions of the measure of the use of turn signal before lane change.

	Lahti		Ann Arbor	
	1	2	1	2
Environment	urban/suburban			
Length of the route (km)	6.5	4.3	6.3	6.2
Speed limit (kph)	50 or 60	50 or 60	48 or 56 (30 or 35 mph)	56 (35 mph)
Number of lanes	2+2 or 3+3	2+2 or 3+3	2+(1)+2*	2+(1)+2*
Lane width (m)	3.5	3.5	3.5	3.6
Traffic volumes (vehicles per hour)†:	400-1,000	400-1,000	600-900	700-1,000

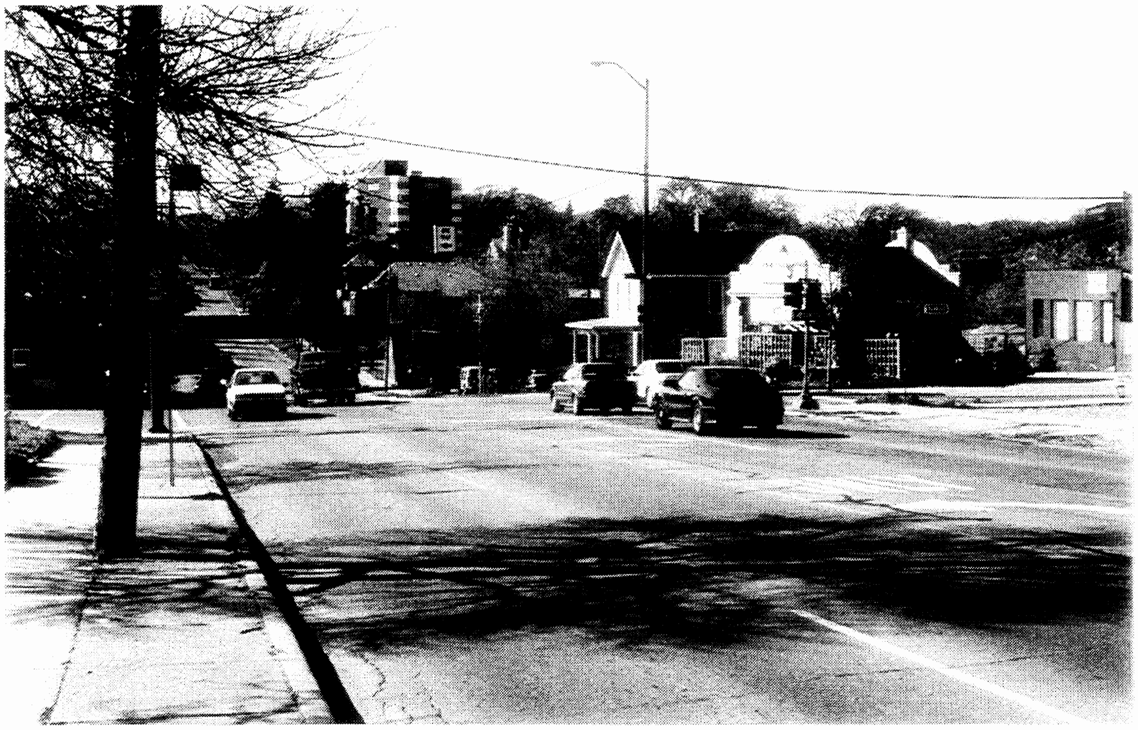
* Center lane for left-turning vehicles.

† For one direction, the hourly traffic volume was calculated to be about 6% of daily traffic volume (City of Lahti, 1994; Ann Arbor-Ypsilanti Urban Area Transportation Study Committee, 1994).

(1)

(2)

Figure 5. Two examples of the routes for the measurement of the use of turn signals before a lane change in Lahti: Uudenmaankatu - Vesijärvenkatu - Lahdenkatu - Vääksyntie, (2) Hämeenlinnantie - Hollolankatu - Aleksanterinkatu - Karjalankatu.



(1)

(2)

Figure 6. Two examples of the routes of the measurement of the use of turn signal before a lane change in Ann Arbor: (a) Jackson Street - Huron Street - Washtenaw Avenue, (b) Stadium Boulevard - Maple Road.

Design

Use of turn signal before lane change was observed from a car that drove along the route in both directions. Data were collected by note taking (without the use of a video camera). Two observers recorded every lane change in the vicinity with a good visibility of possible use of turn signal. Because the purpose of the use of turn signal is to show an intention to change a lane, the following classification was used:

(1) A driver was categorized as *using a turn signal* if he/she signalled before crossing a lane marking.

(2) A driver was categorized as *not using a turn signal* if he/she (a) signalled later or (b) did not signal at all.

Most of the data involved vehicles driven in the same direction as the observation car. The signalling behavior was recorded only if a vehicle was observed before a lateral movement or signalling. This limitation was imposed to avoid a bias caused by more substantial conspicuity of vehicles using turn signals, especially in the case of vehicles in the opposing lane of travel.

The lane-change behavior of an individual vehicle was intended to be recorded only once. However, it is possible that the data include a limited number of multiple observations of the same vehicle. Each recorded lane change included other traffic travelling in the same direction as the observed car. Drivers' sex and age were not recorded.

Results

The totals of drivers observed in the two Lahti routes were 303 and 281, while in Ann Arbor the numbers were 225 and 285. The proportion of drivers using a turn signal before a lane change for each route is presented in Figure 7. Drivers in Lahti signalled more frequently than those in Ann Arbor ($X^2(1) = 19.7$, $p < 0.0001$). The differences between the two routes were not statistically significant in either city.

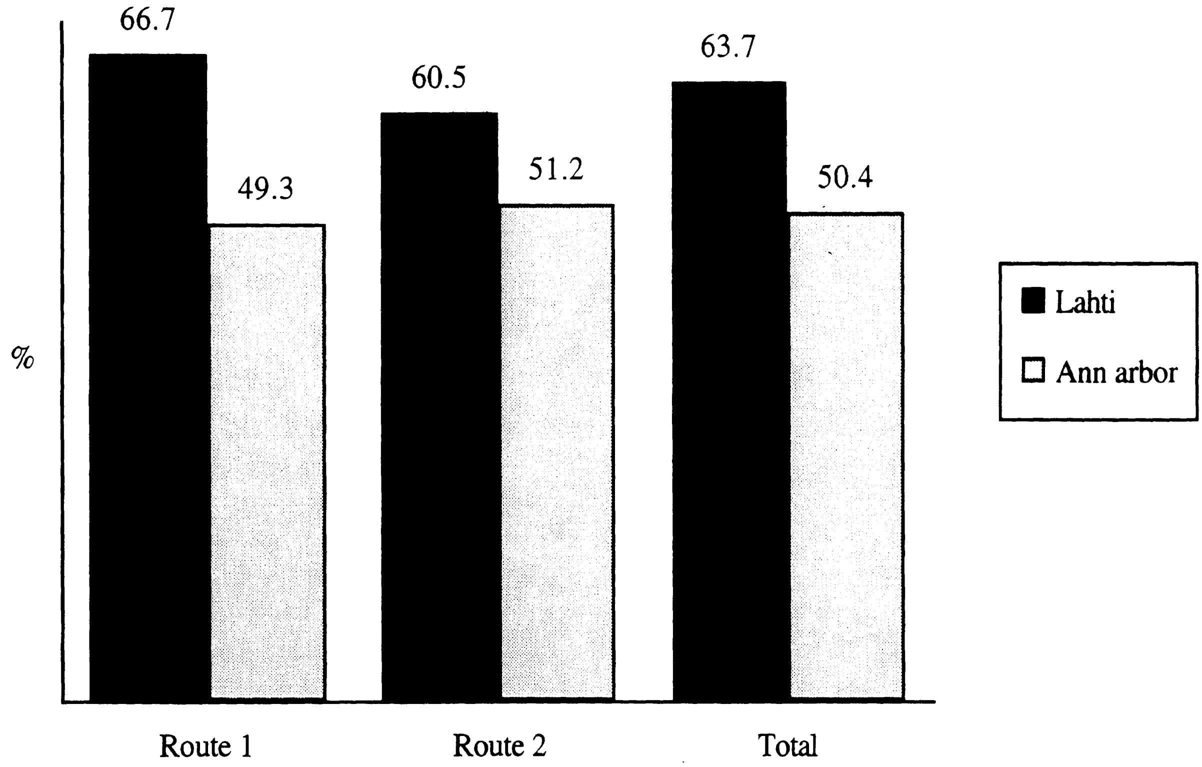


Figure 7. Proportion of drivers using turn signal before lane change by route.

SPEED WHILE APPROACHING AN INTERSECTION FROM A SECONDARY ROAD

Sites

Speed behavior for this measure was studied on suburban secondary roads where drivers had a possibility of approaching an intersection with a stop sign at a relatively high speed. Road and traffic conditions at the sites are given in Table 10. Figures 8 and 9 illustrate the sites in each city.

Table 10
Road and traffic conditions at the sites for measuring speed while approaching an intersection from a secondary road.

	Lahti	Ann Arbor
Environment	suburban	
Speed limit (kph):		
secondary road	50	56 (35 mph)
main road	80	72 (45 mph)
Number of lanes on the secondary road	1+1	1+1*
Width of the secondary road (m)	8.6	8.2
Traffic island	yes	no
Gradient	no	slight uphill
Sight distances (m) at the distance of	left right	left right
0 m	450 300	400 500
30 m	300 300	200 120
60 m	250 160	170 80
90 m	220 140	150 70
120 m	200 110	100 60
Traffic volumes (vehicles/h):		
from secondary road	140	140
onto secondary road	150	140
main road, from left	180	320
main road, from right	210	330

* At the intersection, an additional lane for left-turning vehicles.

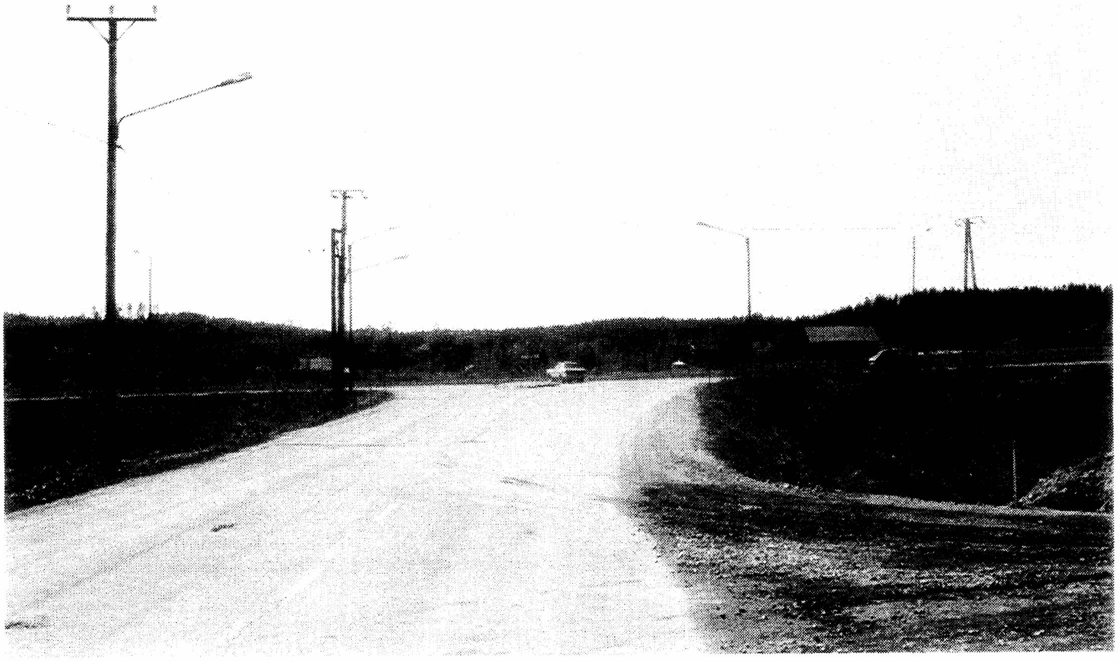


Figure 8. The site of the measure of speed while approaching an intersection from a secondary road in Lahti: Hennalankatu (secondary road), Ala-Okeroistentie (main road).

Figure 9. The site of the measure of speed while approaching an intersection from a secondary road in Ann Arbor: Stone School Road (secondary road), Ellsworth Road (main road).

Design

Only vehicles with a minimum headway of 20 sec between an approaching vehicle and a vehicle in front of it were included. Other drivers were excluded because they could not choose their speed freely. In Ann Arbor, it was possible to cross the intersection, but not in Lahti. Therefore, all the across-travelling drivers were excluded.

The approaching speed was measured by a traffic counter, DSL-1, connected to eight photocell pairs. The design of the measurement is shown schematically in Figure 10. While collecting data from photocell pairs, the counter provided the following information for every vehicle at each location having two transmitters and two reflectors: time of day, speed (kph), length (m), and direction of travel. In addition, the approach of vehicles was recorded by a camera, and the driver's sex and age were recorded by an observer.

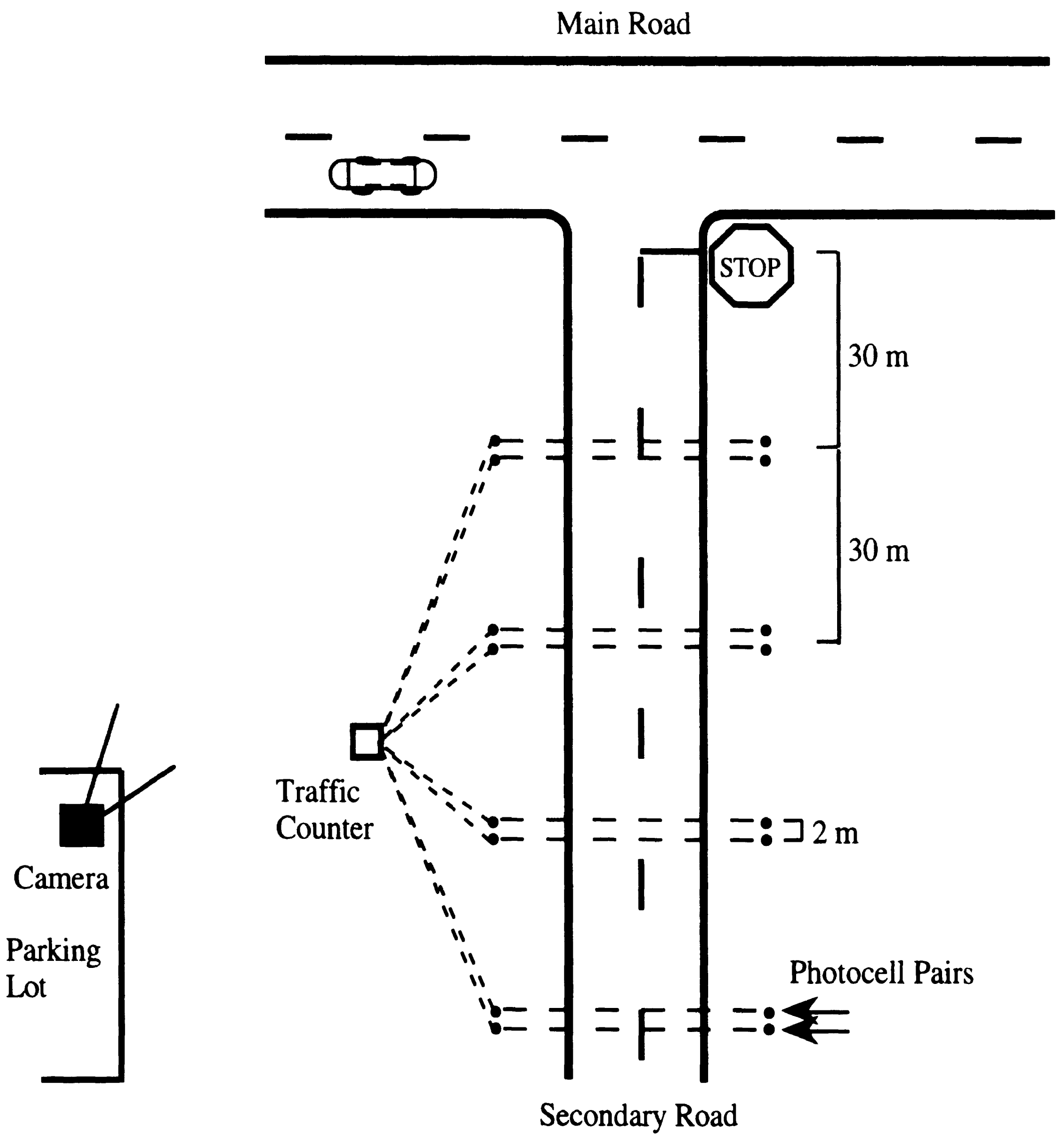


Figure 10. A schematic diagram of setup for measuring the speed of vehicles approaching the intersection from a secondary road.

Results

The number and characteristics of the observed drivers are shown in Table 11. The proportion of males was higher in Lahti than in Ann Arbor ($X^2(1) = 20.83$, $p < .0001$). Middle-age drivers were the largest age group in both cities.

Table 11.
Number of drivers and their characteristics.

	Lahti	Ann Arbor
Number of drivers	164	170
Male drivers (%)	85.7	63.5
Estimated driver's age (%):		
<25	13.0	5.6
25-65	86.3	90.6
>65	0.6	3.8

The proportion of right-turning drivers did not differ significantly (in Lahti, 65.2%, and in Ann Arbor, 57.6%). In Lahti, 63.1% of drivers accepted the first gap when entering the main road, compared to 53.8% in Ann Arbor. The difference was not statistically significant.

The mean initial speed at the distance of 120 m before the intersection was 58.6 kph in Lahti and 64.2 kph in Ann Arbor, reflecting the difference in the posted speed limits. The proportions of drivers exceeding the speed limit initially were not significantly different (82.9% in Lahti and 81.4% in Ann Arbor).

Figure 11 shows, for each city, the mean approach speed at the distances of 120, 90, 60, and 30 m before the intersection. Because of the different initial speeds (and the speed limits), the average speed changes are presented, also, in comparison to the initial speed (Figure 12). On average, the speed change was greater in Lahti than in Ann Arbor at 90 m ($F_{1,324} = 51.9$, $p < 0.0001$) and at 30 m ($F_{1,309} = 7.38$, $p < 0.02$). There was no significant difference at 60 m. (A comparison using percent speed change, as oppose to absolute speed change, yielded analogous results.)

While interpreting the results, it should be taken into account that in Ann Arbor (but not in Lahti), there was a slight uphill that helped to decrease speed. Consequently, the results suggest that the drivers in Lahti approached the intersection from the secondary road slightly more cautiously than the drivers in Ann Arbor.

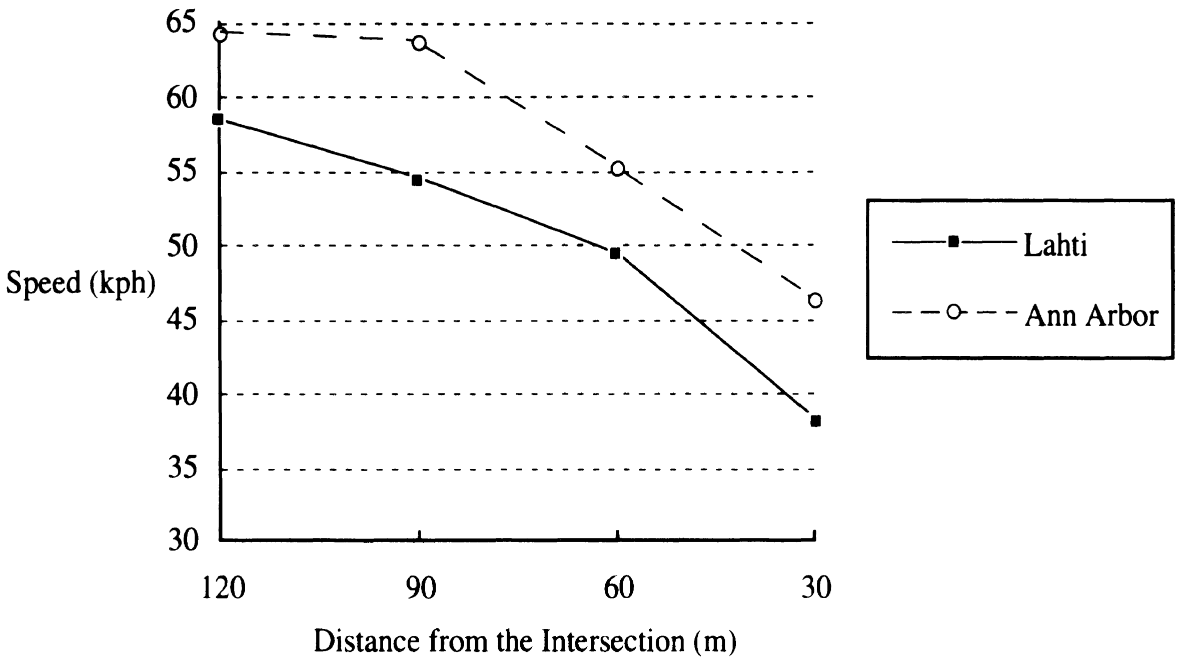


Figure 11. The mean speed while approaching an intersection from a secondary road.

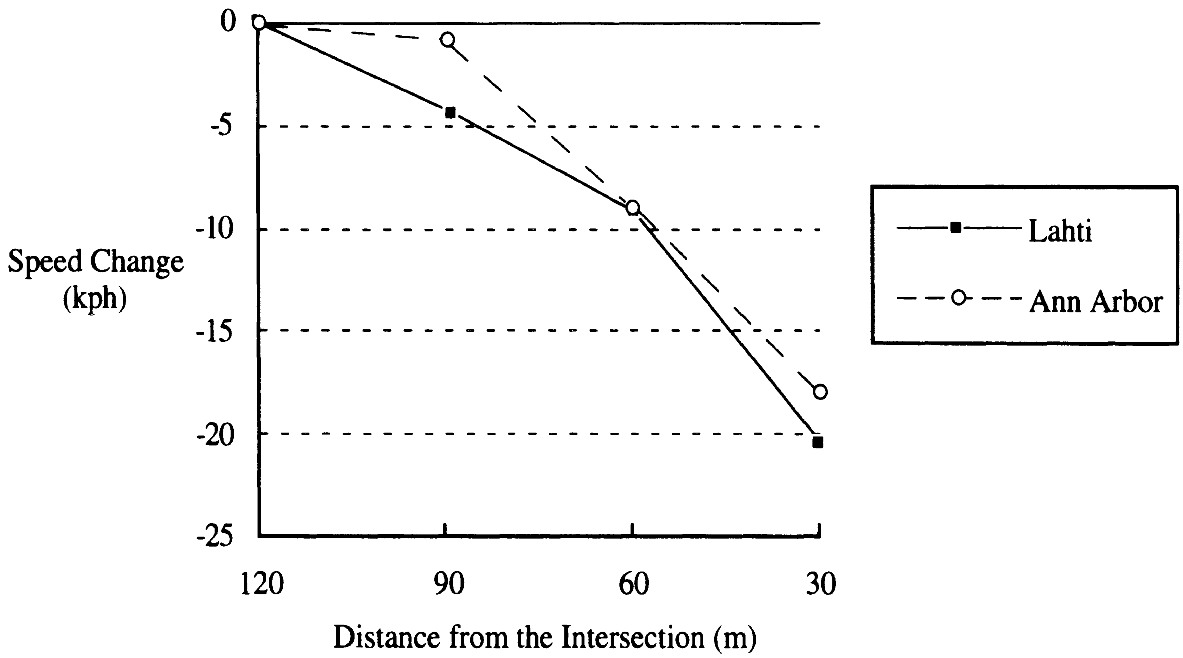


Figure 12. Mean speed change while approaching an intersection from a secondary road.

Table 12 shows the standard deviations of the speed distributions. The Bartlett's test showed that the difference between the cities was significant only at 60 m ($X^2(1) = 4.53$, $p < 0.04$).

Table 12
Standard deviation of the approaching speeds at four distances from the intersection.

Distance from the intersection (m)	Lahti	Ann Arbor
120	9.7	8.3
90	8.8	8.0
60	7.9	6.7
30	5.9	5.9

The speed at the four locations was submitted to an analysis of variance using the following three variables: city, sex, and acceptance of the first gap (yes/no) while entering the main road. The effect of city was significant, mostly because of the higher initial speed. More interestingly, the effect of gap acceptance was significant at each distance: 120 m ($F_{1,286} = 7.09$, $p < 0.01$), 90 m ($F_{1,286} = 6.89$, $p < 0.01$), 60 m ($F_{1,286} = 5.63$, $p < 0.02$), and 30 m ($F_{1,286} = 12.9$, $p < 0.001$). As shown in Figure 13, drivers accepting the first gap drove faster at each location, with a tendency for this difference to be greater in Lahti than in Ann Arbor. The effect of sex was not significant, as were all interactions. However, as shown in Figure 14, male drivers in Lahti tended to drive faster than female drivers. A similar analysis of variance was performed for both cities separately. It showed that the effect of gap acceptance was significant only in Lahti.

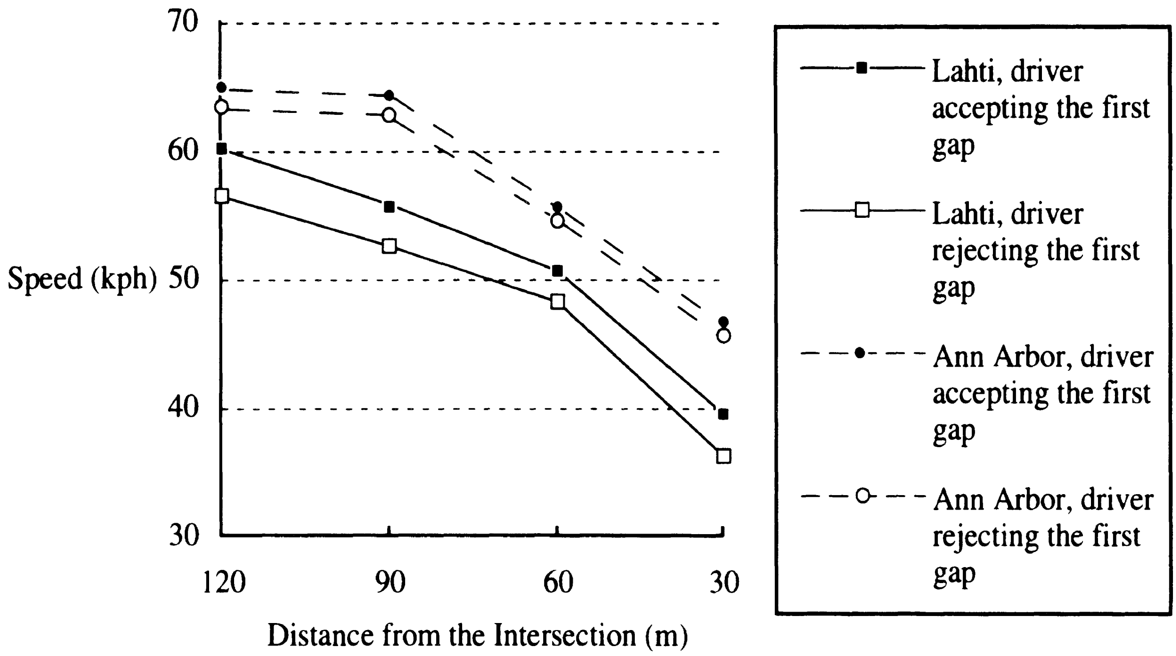


Figure 13. Mean speed change while approaching an intersection from a secondary road, by the acceptance of the first gap at the intersection.

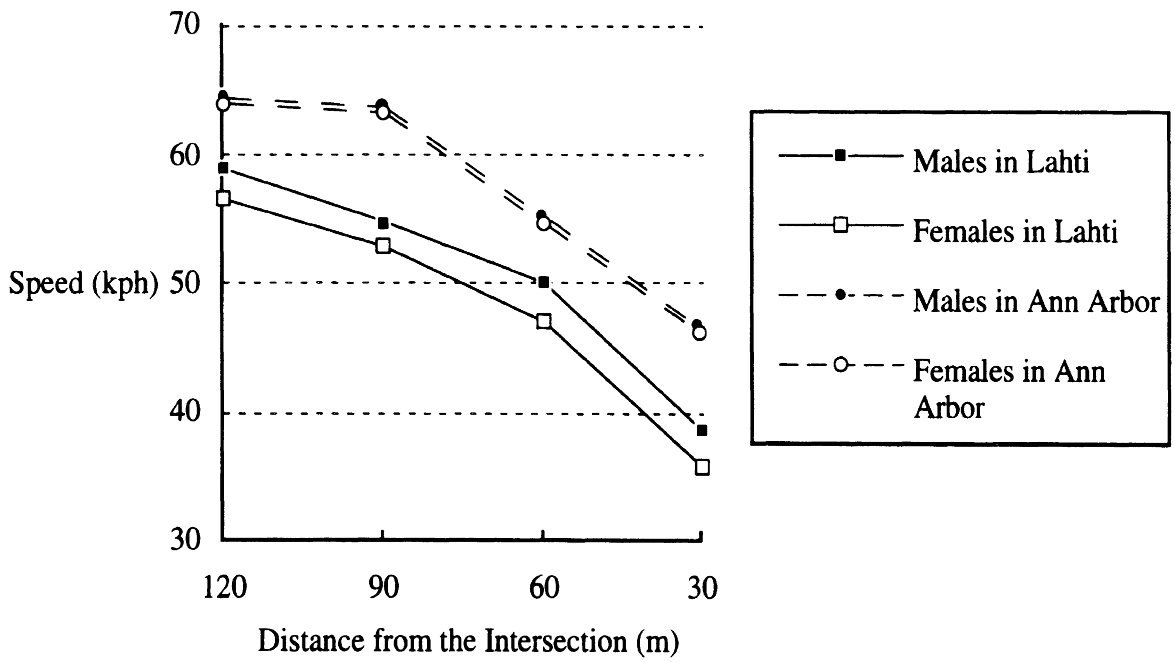


Figure 14. Mean speed change while approaching an intersection from a secondary road, by driver's sex.

SPEED AFTER TURNING ONTO A SECONDARY ROAD

Sites and design

Because the data collected for the measure of the speed while approaching an intersection from a secondary road included speed behavior of drivers who turned onto the secondary road, the data of their behavior were also analyzed. Naturally, the sites are the same as presented in Figures 8 and 9, and information on the road and traffic conditions of the sites are given in Table 10. Driver's sex and age were not recorded.

This measure was collected for vehicles with a minimum headway of 20 sec between an actual vehicle and a vehicle in front of it.

Results

Data included 199 drivers in Lahti and 209 drivers in Ann Arbor. The main result, shown in Figure 15, is that the drivers in Lahti tended to accelerate more slowly than those in Ann Arbor. However, the result must be interpreted cautiously, because of the higher speed limit and the slight downhill in Ann Arbor.

Standard deviation of the speed was greater in Ann Arbor at each distance (4.7-6.1 kph in Lahti, and 5.6-6.4 kph in Ann Arbor). However, Bartlett's test showed that the differences were significant only at 30 m ($X^2(1) = 6.03$ $p < 0.02$) and 60 m ($X^2(1) = 6.54$ $p < 0.02$).

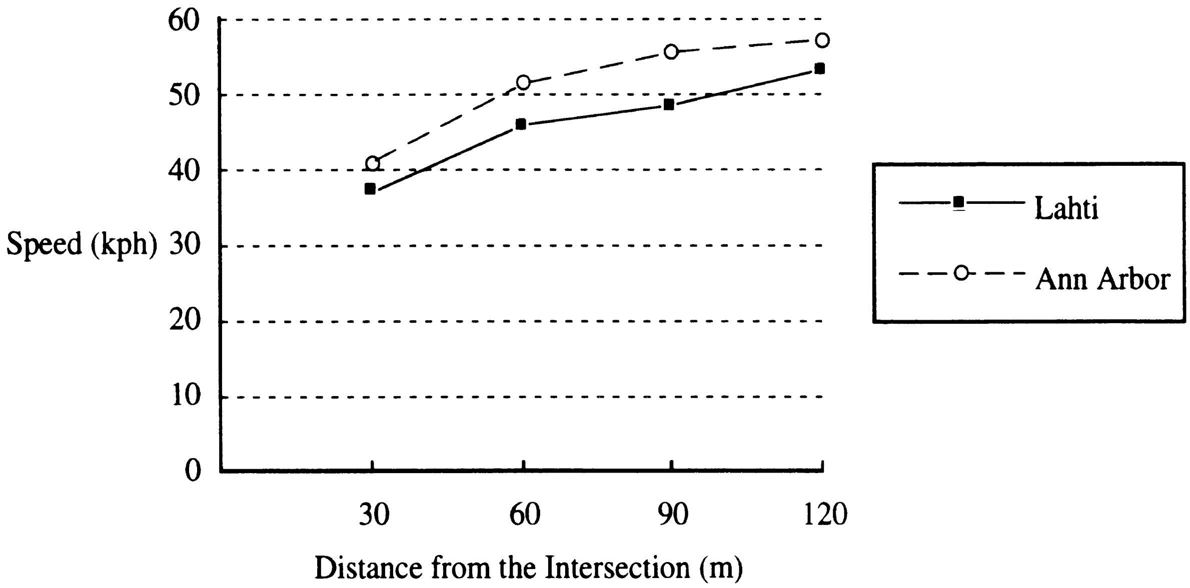


Figure 15. Mean speed after turning onto the secondary road.

The last speed measurement at the distance of 120 m from the intersection showed that 69.3% of drivers in Lahti and 56.5% in Ann Arbor exceeded the speed limit ($X^2(1) = 7.24$, $p < 0.01$).

In Lahti, the data were collected on two days. Before the second measurements all the equipment was reinstalled, and presumably the driver populations were different on the two days. This allowed us to evaluate the reliability of the speed measurement of photocell pairs. The mean speeds on the two days were very similar (Figure 16). Only the difference at 30 m was significant ($F_{1,197} = 5.69$, $p < 0.02$).

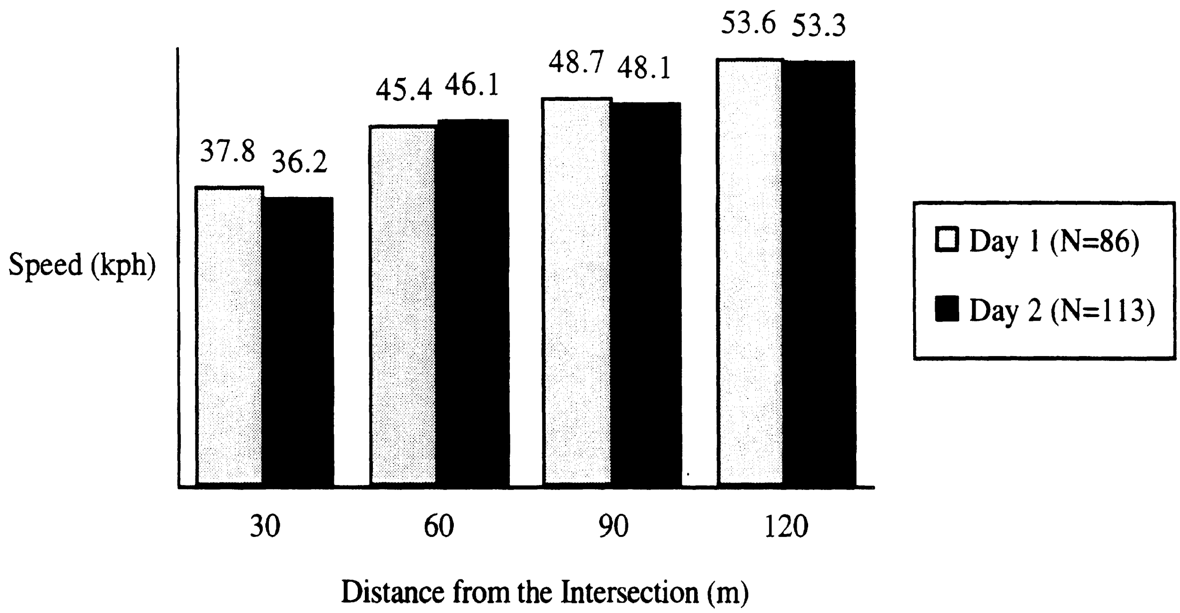


Figure 16. Mean speed after turning onto the secondary road on two days in Lahti.

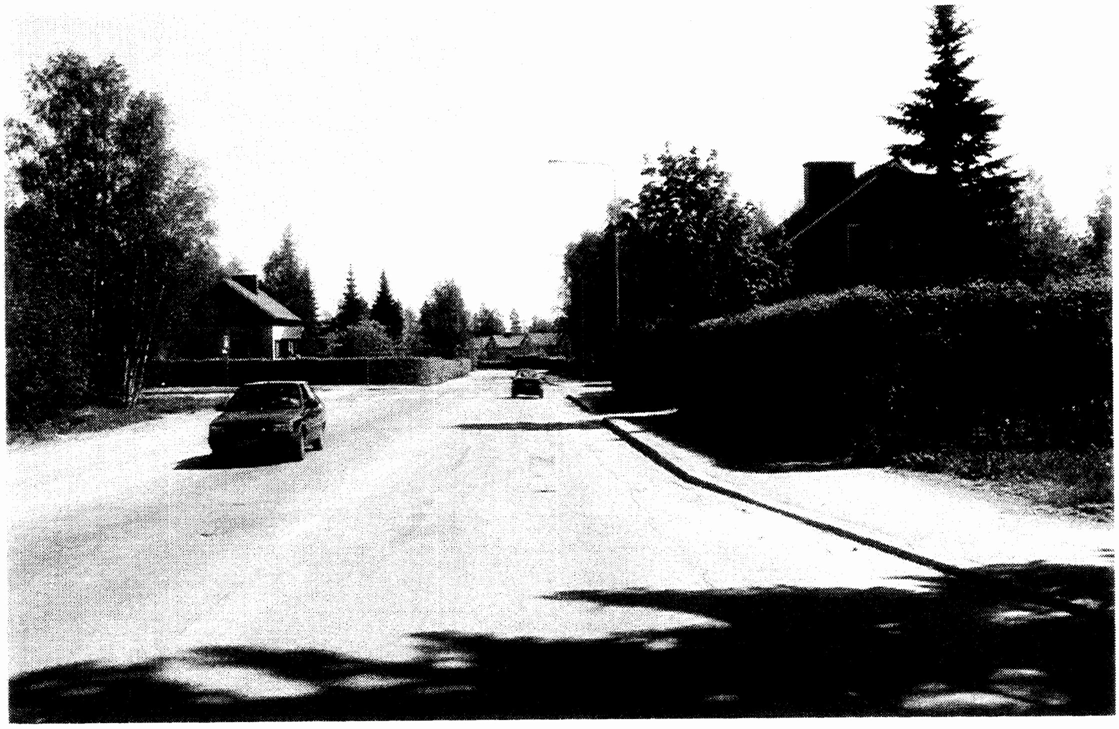
USE OF TURN SIGNALS BEFORE TURNING

Sites

Use of turn signals before turning was observed at urban and suburban intersections (see Figures 17 and 18). The road and traffic conditions of the sites are summarized in Table 13.

Table 13
Road and traffic conditions of the sites of the measure of use of turn signals before turning.

	Lahti		Ann Arbor	
	1	2	1	2
Environment	urban	suburban	urban	suburban
Speed limit (kph)				
secondary road	50	50	48 (30 mph)	40 (25 mph)
main road	50	80	48 (30 mph)	72 (45 mph)
Lane width (m)				
secondary road	4.0	4.3-4.7	5.6	6.5
main road	5.0	3.5	4.8	3.8
Intersection sight distances (m) at the distance of	left right	left right	left right	left right
(direction 1) 0 m	270 50	310 270	150 90	320 640
10 m	70 20	110 250	30 40	170 100
20 m	20 10	40 190	20 20	170 50
40 m	70 10	40 90	20 10	160 30
(direction 2) 0 m	220 50	600 250	100 105	
10 m	40 20	600 250	35 50	
20 m	30 20	600 110	20 50	
40 m	20 10	150 110	10 20	
Traffic volumes on secondary road, direction 1, 2 (vehicles/h)	60, 60	80, 80	30, 40	80, 0
Traffic volumes on main road from left and right, direction 1 (vehicles/h)	40, 40	230, 310	30, 60	160, 390



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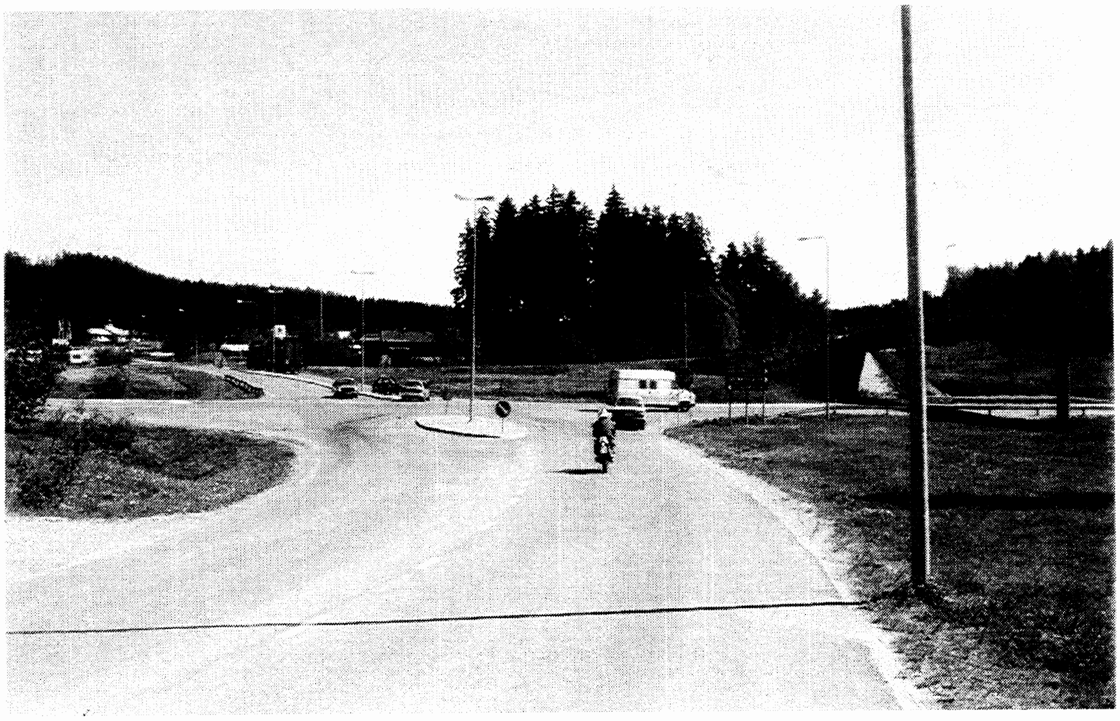

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Figure 17. The sites of the measure of the use of turn signals before turning in Lahti: (1) Mustamäenkatu at Mäntsäläntie (from direction 2 in Table 13), (2) Launeenkatu at Uudenmaankatu (from direction 1 in Table 13).

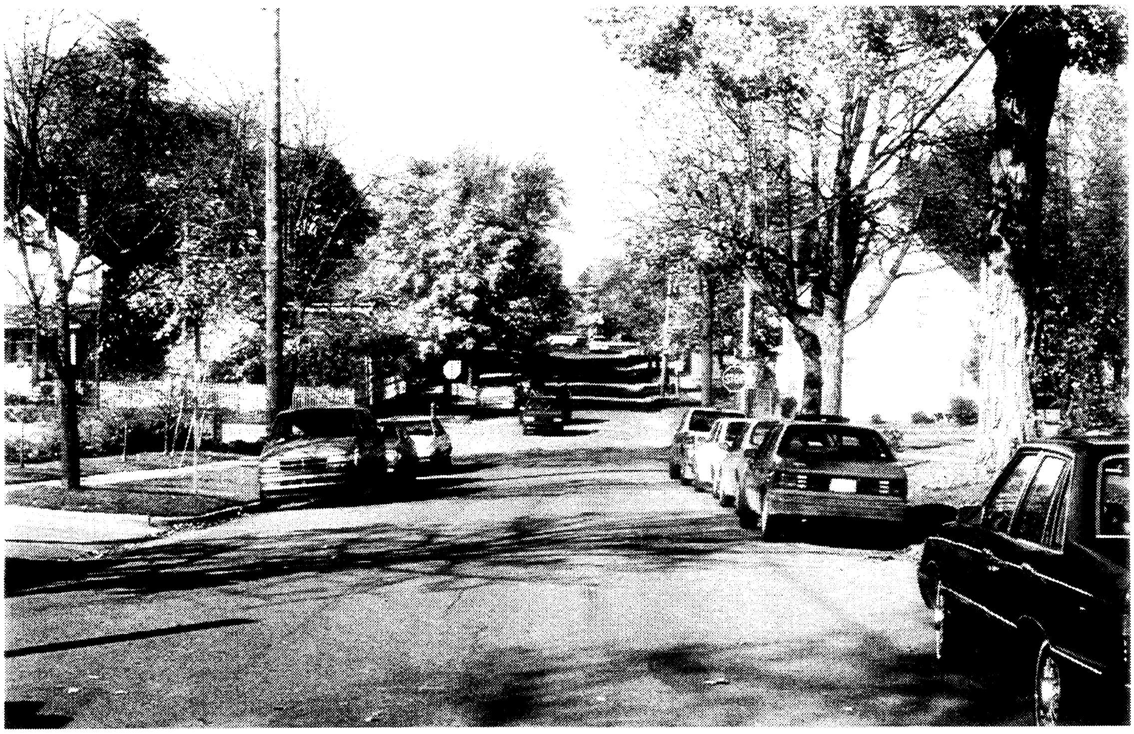

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Figure 18. The sites of the measure use of turn signals before turning in Ann Arbor: (1) Third Street at West Williams Street (from direction 1 in Table 13), (2) Glenco Hills Drive at Clark Road (from direction 1 in Table 13).

Design

Because the purpose of signalling is to show an intention to turn, the observation focused on behavior before turning instead of when turning. Consequently, the use of turn signal was categorized in the following way:

(1) A driver was categorized as *using a turn signal* if he/she signalled before (a) the wheels began to turn or (b) the vehicle stopped.

(2) A driver was categorized as *not using a turn signal* if he/she (a) signalled later or (b) did not signal at all.

The turn direction and other traffic in the vicinity, as well as the driver's sex and age, were also recorded. The other traffic in the vicinity included the following road users in front of the vehicle (while approaching the intersection during the previous 10 sec): (a) oncoming vehicles waiting at the intersection or approaching it, and (b) pedestrians and bicyclists in the vicinity of the intersection whom the driver in question was able to detect, and with whom a driver might have a conflict possibility at the intersection.

Results

Number and characteristics of drivers are given in Table 14.

Table 14
Number and characteristics of drivers.

	Lahti		Ann Arbor	
	1	2	1	2
Number of drivers	110	248	115	267
Male drivers (%)	72.8	87.8	71.6	62.4
Estimated driver's age (%):				
<25	21.9	11.4	5.9	13.3
25-65	70.2	86.2	93.1	84.7
>65	7.9	2.4	1.0	2.0

At the urban intersections, the proportions of male and female drivers were not significantly different from each other. However, at the suburban intersections, the proportion of male drivers was higher in Lahti than in Ann Arbor ($X^2(1) = 43.0$, $p < 0.00001$).

The middle-age drivers were the largest group at each intersection. However, the age differences were significant only for urban intersections ($X^2(2) = 18.45$, $p < 0.0002$).

Figure 19 shows that drivers in Lahti signalled more frequently than those in Ann Arbor. This was the case at the urban intersections (for left turn, N = 48 vs. 43*, $X^2(2) = 22.9$, $p < 0.00001$, for right turn, N = 62 vs. 72, $X^2(2) = 16.3$, $p < 0.0001$) and at the suburban intersections (for left turn, N = 40 vs. 87, $X^2(2) = 2.05$, ns; for right turn, N = 208 vs. 180, $X^2(2) = 16.3$, $p < 0.0001$). Effect of turn direction was insignificant at each intersection.

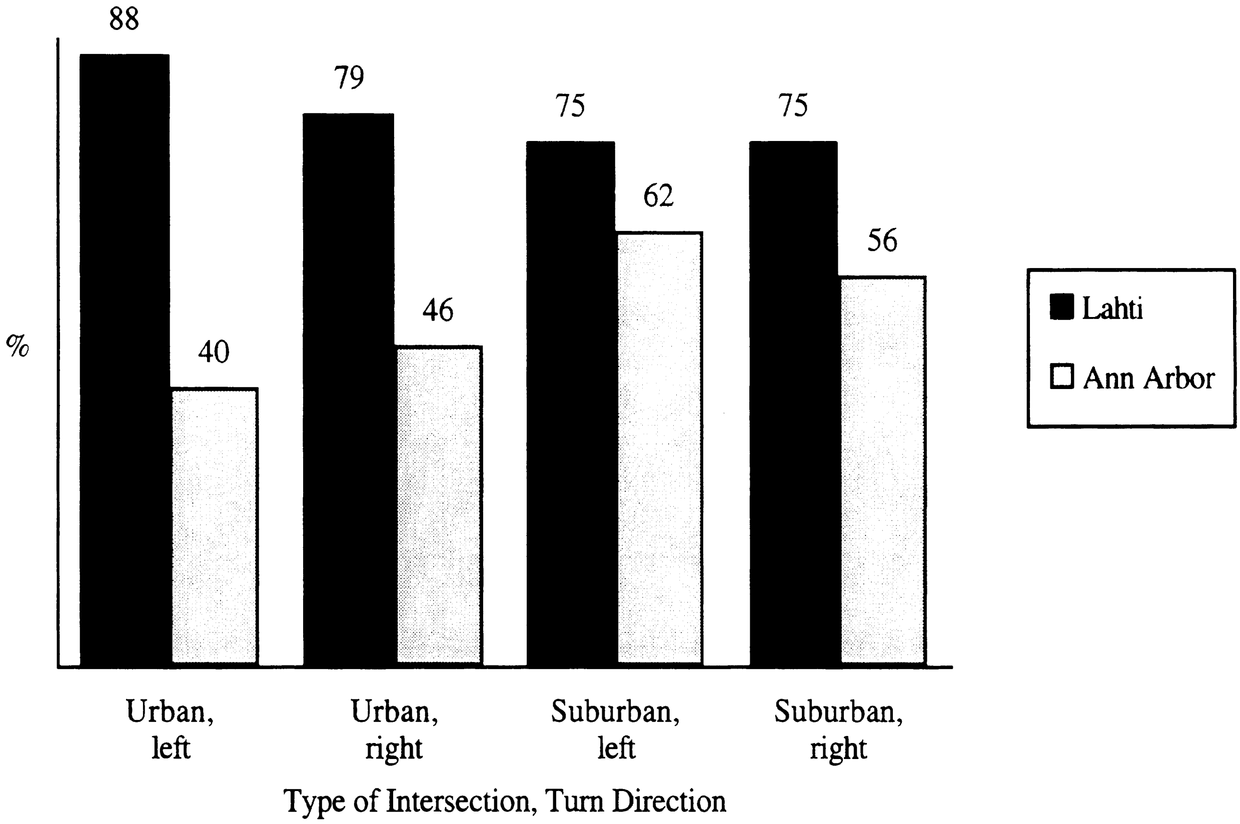

Figure 19. Percentage of drivers using turn signals before turning.

One could assume that there might be drivers who signalled only if they saw other traffic in the vicinity. Furthermore, the suburban intersection in Ann Arbor had traffic from only one secondary road, while other intersections had traffic from two directions. Therefore, the effect of other traffic was computed by each turn direction at urban intersections, which allowed a valid comparison (see Figure 20).

* N is always given in the following order: Lahti and Ann Arbor.

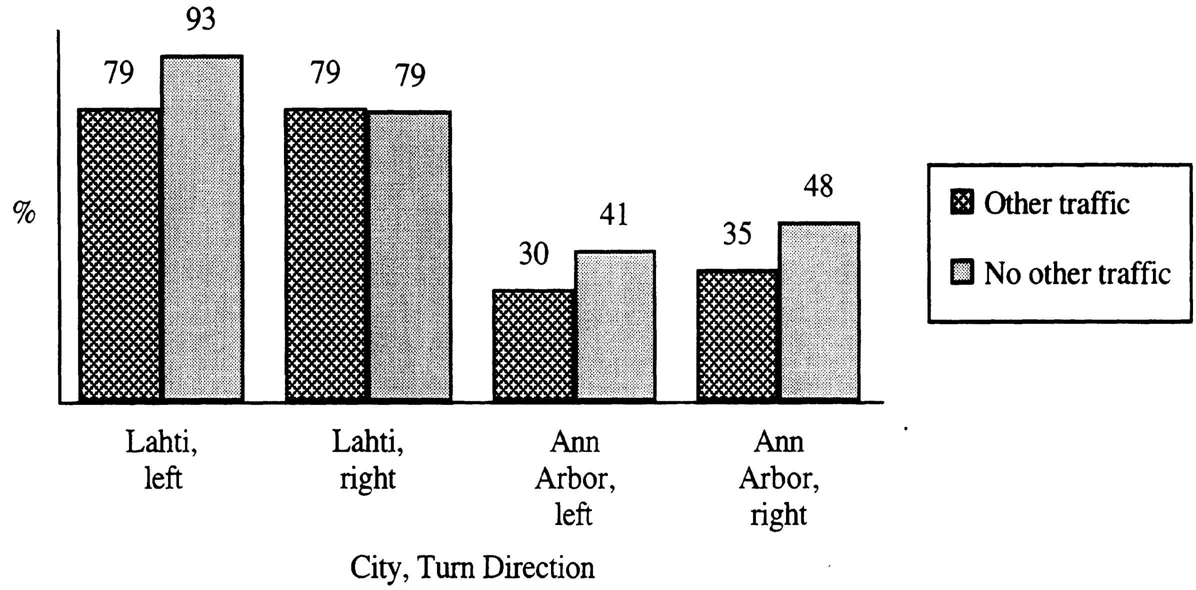

Figure 20. Percentage of drivers signalling before turning by other traffic in the vicinity at urban intersections.

The results did not support the assumption that drivers would signal more frequently if other traffic was in the vicinity. On the contrary, drivers tended to signal more frequently if no traffic was in the vicinity. However, none of the four pairwise differences were significant.

The effect of sex on the frequency of turn signal before turning is shown in Figure 21. While at the urban intersection in Ann Arbor, female drivers tended to signal more frequently than male drivers, none of the effects were significant.

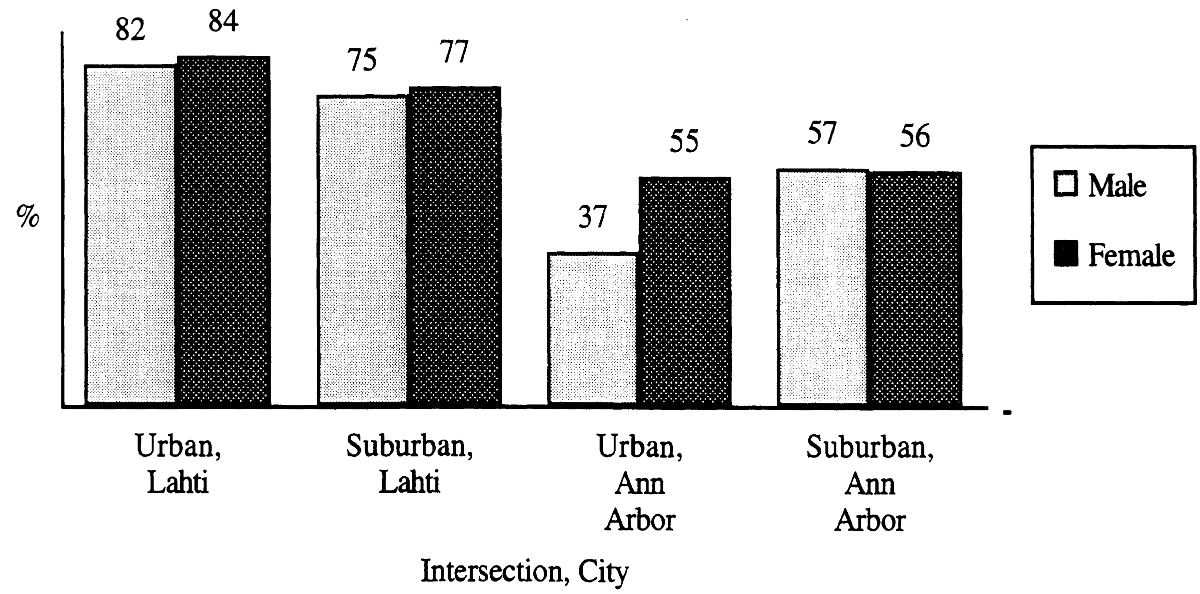

Figure 21. Percentage of drivers signalling before turning, by driver's sex.

STOPPING BEHAVIOR AT INTERSECTIONS WITH A STOP SIGN

Sites

Data concerning stopping behavior at intersections with a stop sign were collected at the same intersections as data for (a) approaching an intersection from a secondary road (referred to as suburban intersection number 2 in this chapter) and (b) use of turn signal before turning (referred to as urban intersection and suburban intersection number 1 in this chapter). The sites were described earlier (see Figures 8, 9, 17, and 18, and Tables 10 and 13).

Design

The analyses included: (a) vehicles with a minimum headway of 20 sec between an approaching vehicle and a vehicle ahead, (b) no oncoming vehicles, pedestrians, or bicyclists that affected driver behavior, and (c) drivers who accepted the first gap of the traffic flow on the main road. Other drivers were excluded because they were unable to choose their speed or enter or cross the road without distraction from other traffic. The stopping behavior was classified into three categories:

(1) Full stop = the wheels of the vehicle did not roll.

(2) Rolling stop = the vehicle speed was about the same as the walking speed.

(3) No stop = the vehicle speed was constant or might be reduced, but the speed was higher than in a rolling stop.

Results

The number of drivers and their characteristics are given in Table 15.

Table 15
Number of drivers and their characteristics.

	Lahti			Ann Arbor		
	urban	suburban 1	suburban 2	urban	suburban 1	suburban 2
Number of drivers	248	62	100	183	79	91
Male drivers (%)	73.7	85.2	89.9	67.1	55.1	64.4
Estimated driver's age (%):						
<25	20.2	14.8	14.1	4.9	17.9	6.9
25-65	67.6	82.0	84.8	92.0	80.8	88.5
>65	12.1	3.3	1.0	3.1	1.3	4.6

At the urban intersections, there was no significant difference in the sex distribution. At the suburban intersections, the proportion of male drivers was higher in Lahti than in Ann Arbor (for the first intersection: $X^2(1) = 14.4$, $p < 0.001$; for the second intersection: $X^2(1) = 17.6$, $p < 0.0001$). The age distribution was different for urban intersections only ($X^2(2) = 33.06$, $p < 0.0001$). Stopping behavior by turn direction is presented in Figures 22 through 24.

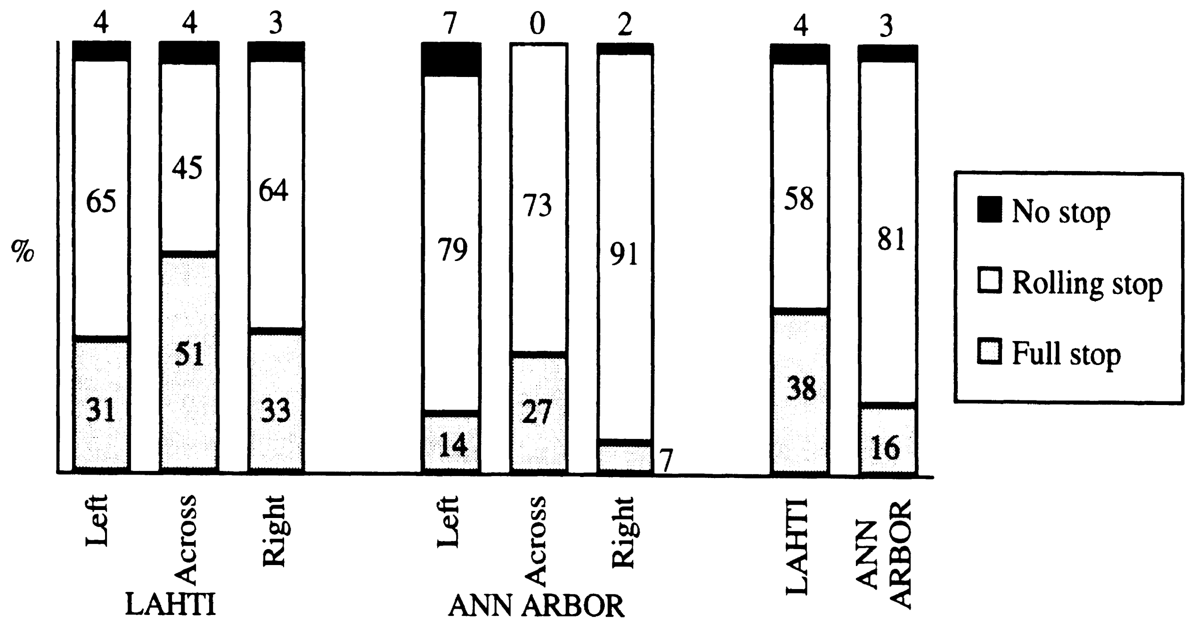

Figure 22. Stopping behavior at the urban intersections, by turn direction, and combined across turn directions.

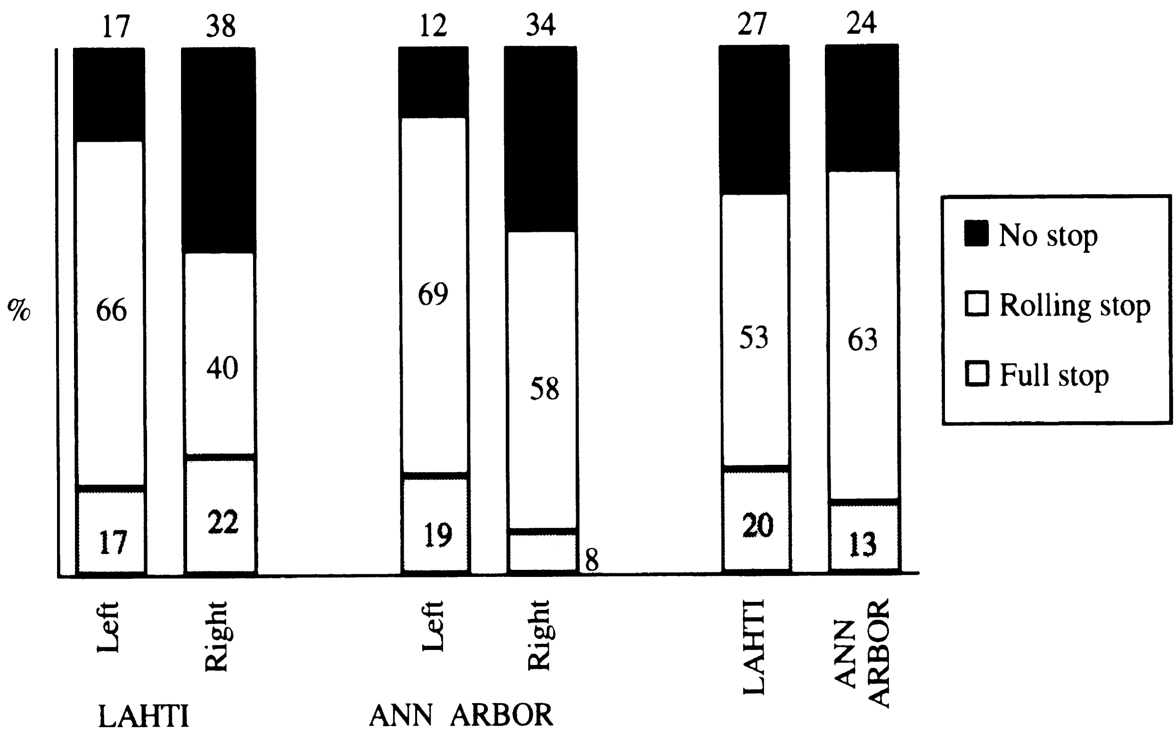

Figure 23. Stopping behavior at the first suburban intersections, by turn direction, and combined across turn directions.

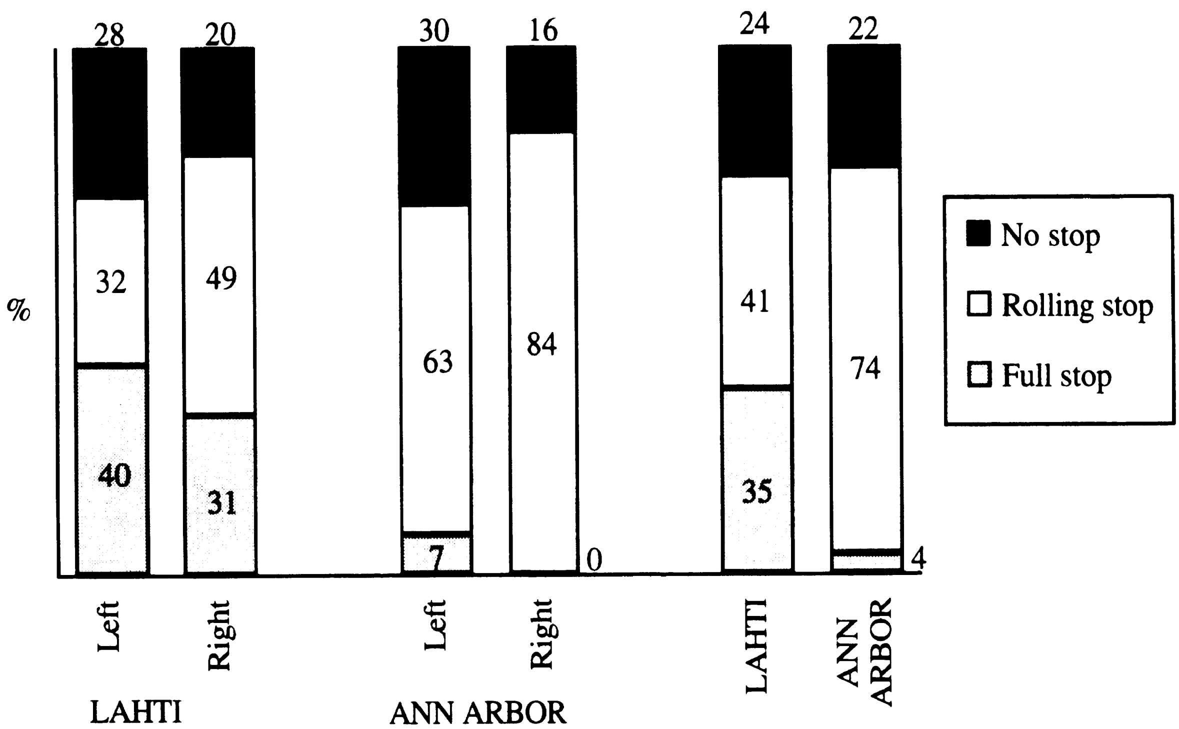

Figure 24. Stopping behavior at the second suburban intersections, by turn direction, and combined across turn directions.

Two following hypotheses were tested for each turn direction and between each pair of intersections.

Is there a cross-national difference in the proportion of full stops? This comparison shows the possible differences in the obeying of a formal traffic rule. A comparison of corresponding traffic streams (see Figures 22 through 24) showed that at each intersection, right-turning drivers in Lahti came to a full stop more frequently than those in Ann Arbor (for urban intersections, N = 55 vs. 55, $X^2(1) = 11.1$, $p < 0.001$; for the first suburban intersections, N = 56 vs. 63, $X^2(1) = 5.39$, $p < 0.03$; for the second suburban intersections, N = 75 vs. 64, $X^2(1) = 23.5$, $p < 0.00001$). The across-travelling drivers were investigated at urban intersections only. As in the case of the right-turning drivers, drivers in Lahti came to a full stop more frequently than those in Ann Arbor (N = 167 vs. 99, $X^2(1) = 13.6$, $p < 0.001$). Comparison of the left-turning drivers showed that at the second suburban intersections the difference was significant (N = 25 vs. 27, $X^2(1) = 7.77$, $p < 0.01$). (At the first suburban intersection, the test of significance was not performed because of the small number of left-turning drivers (N = 6 vs. 16).)

Is there a cross-national difference in the proportion of no stops? One could argue that this comparison shows the possible differences in the frequency of dangerous stopping behavior better than the previous one. The results showed that there was no clear difference between two cities. Only the difference of the across-travelling drivers at urban intersections was significant (N = 167 vs. 99, $X^2(1) = 4.26$, $p < 0.04$), with drivers in Lahti coming more frequently to no stops than those in Ann Arbor. A similar, but not statistically significant difference was found while comparing the right-turning drivers. The opposite (nonsignificant) tendency was found for the left-turning drivers.

As shown in Figures 22 through 24, the differences in the frequency of no stops were smaller between cities than between urban and suburban intersections (in both cities).

The stopping behavior in each city was also crosstabulated by driver's sex and by intersection. As earlier, the frequencies of full stops and no stops were analyzed. No difference was significant.

Finally, the stopping behavior of turning drivers in each city was crosstabulated by the use of turn signal and by intersection. There was no statistically significant difference in the frequency of full stops or no stops between signal users and nonusers. However, a slight tendency was found at both intersections in Lahti and at the urban intersection in Ann Arbor, with the signalling drivers tending to come to a full stop more infrequently than the other drivers (5-30% vs. 13-43%).

GAP ACCEPTANCE WHEN ENTERING A MAIN ROAD

Sites

The data for the comparison of gap acceptance when entering a main road were collected jointly with the data collection of the following, earlier presented, measures: (1) speed while approaching the intersection from the secondary road and (2) use of turn signal before turning (and stopping behavior) at the suburban intersection. Consequently, the sites are presented in Figures 8, 9, 17, and 18, and in Tables 10 and 13.

Design

This measure focused on the acceptance of gaps when entering the main road. In general, the acceptance of a small gap indicates risky driver behavior.

The data for every vehicle included the size of the accepted gap (i.e., the elapsed time between the time when the vehicle approaching from a secondary road entered a main road and the time when a vehicle travelling on the main road passed the conflict point). Drivers who did not accept the first gap also provided information about rejected gaps. However, only the duration of the first rejected gap was measured, because it was assumed that this gap was the most important one. The number or the durations of other rejected gaps were not measured. In addition, because of different approaching strategies of drivers, the starting time for the time measurement differed to some degree. Some drivers approached the intersection at relatively high speed, slowed down, and came to a full stop. In this case, the measurement of the duration of the rejected gap started immediately after the stop. However, some drivers slowed down much earlier when, presumably, they detected traffic on the main road. In these cases, the measurement of the duration of the rejected gap involved subjective estimation of the point of time when the driver would have been able to enter a main road.

This analysis included: (a) vehicles with a minimum headway of 20 sec in front of them and (b) vehicles that approached the stopping line in a situation when a gap (lag) on the main road was 10 sec or less. These limitations were imposed because it was felt appropriate to analyze the behavior of only those drivers who had to choose whether to accept or reject the first gap. The first limitation ensured that the driver could approach the intersection with a self-selected speed, and with no vehicle on the secondary road blocking the entry into the main road. The second limitation excluded drivers who did not have to choose whether or not to enter. As later will be shown, every rejected gap was 10 sec or less. Each gap more than 30 sec was classified into a category of 30 sec.

Results

The number and characteristics of the drivers are given in Table 16.

Table 16
Number and characteristics of drivers.

	Lahti		Ann Arbor	
	1	2	1	2
Number of drivers	89	117	127	164
Male drivers (%)	81.5	85.4	65.4	60.0
Estimated driver's age (%):				
<25	11.1	12.5	3.8	14.6
25-65	88.9	83.3	91.4	83.1
>65	0.0	4.2	4.8	2.3

At each intersection, there were more males in Lahti than in Ann Arbor (intersections 1:$X^2(1) = 5.91$, $p < 0.02$; intersections 2: $X^2(1) = 17.3$, $p < 0.0001$). The difference in the age distribution was significant only for the first intersection ($X^2(2) = 7.38$, $p < 0.03$).

The durations of the first gap (accepted or rejected) are given in Table 17. At the second intersections the difference was significant, with the gaps in Lahti shorter than in Ann Arbor ($F_{1,214} = 6.91$, $p < 0.01$). Overall, there was no significant difference between the cities. Furthermore, the differences were smaller than one might expect, because at the first intersection the difference of the traffic volume on the main road was substantial (see Table 10).

Table 17
Duration of the first gap by intersection.

	Lahti			Ann Arbor		
	1	2	Total	1	2	Total
Mean (sec)	4.5	3.0	3.7	3.8	4.0	3.9
Standard deviation (sec)	3.4	2.8	3.2	3.1	3.0	3.0
Number of drivers	77	90	167	107	126	233

Drivers who rejected the first gap. The results concerning mean duration of rejected and accepted gaps (see Table 18) show no systematic differences.

Table 18
Mean duration of rejected and accepted gaps (sec) in different traffic streams.
(Number of drivers in parenthesis.)

Turn direction - approaching direction of next vehicle on the main road	Driver reaction	Lahti		Ann Arbor	
		1	2	1	2
To right - from left	Rejected	4.5 (29)	2.6 (55)	3.5 (33)	2.9 (52)
	Accepted	19.9 (28)	21.9 (54)	21.9 (31)	16.6 (48)
To left - from right	Rejected	2.8 (21)	2.4 (9)	2.1 (28)	2.6 (25)
	Accepted	15.2 (13)	14.7 (3)	13.4 (27)	12.4 (23)
To left - from left	Rejected	2.1 (8)	1.5 (15)	1.2 (17)	2.9 (20)
	Accepted	12.7 (14)	14.1 (21)	13.3 (17)	11.3 (19)

A usual way to compare gap acceptance is to analyze critical gaps, i.e., to compute the number of accepted and rejected gaps by time separation. Then the proportion of accepted gaps for each gap duration will be computed. Finally, the gap size that 50% of drivers accept will also be defined.

However, the results showed that the number of left-turning drivers in each stream was too small to analyze them separately (see Table 18). Consequently, the critical gaps were computed for the right-turning drivers by intersection and for left-turning drivers as one group in each city. In addition, it was necessary to use time separations of 2 sec (initially 1 sec) because of the small number of cases (Figures 25 through 27).

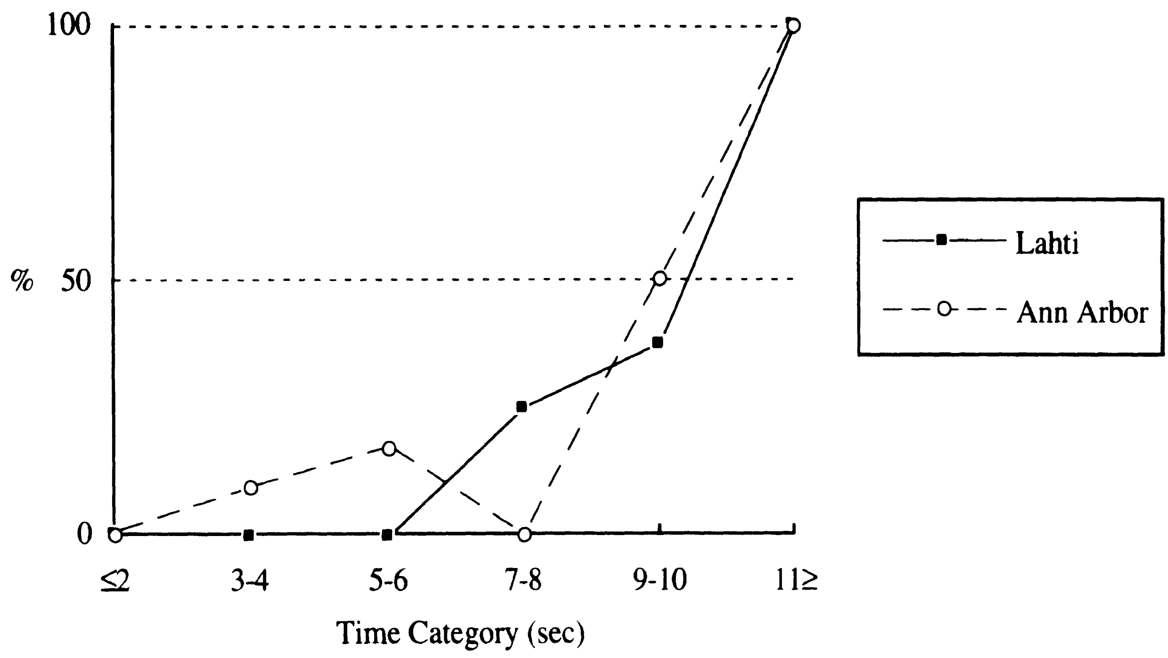

Figure 25. Critical gaps for right-turning drivers at the first intersections.

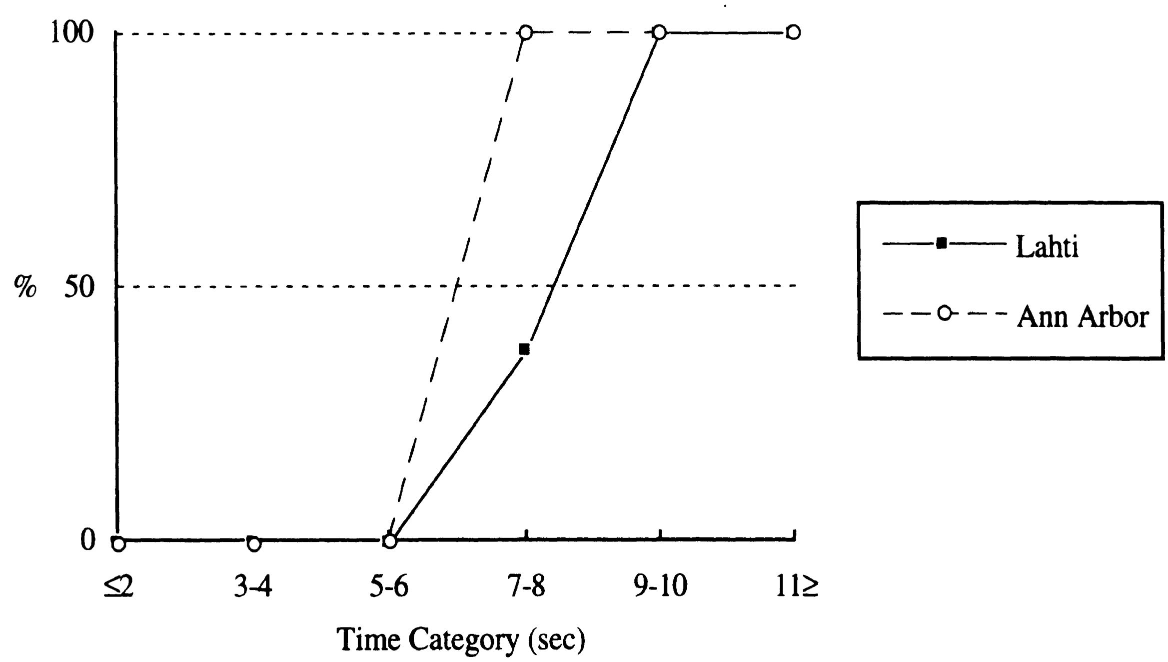

Figure 26. Critical gaps for right-turning drivers at the second intersections.

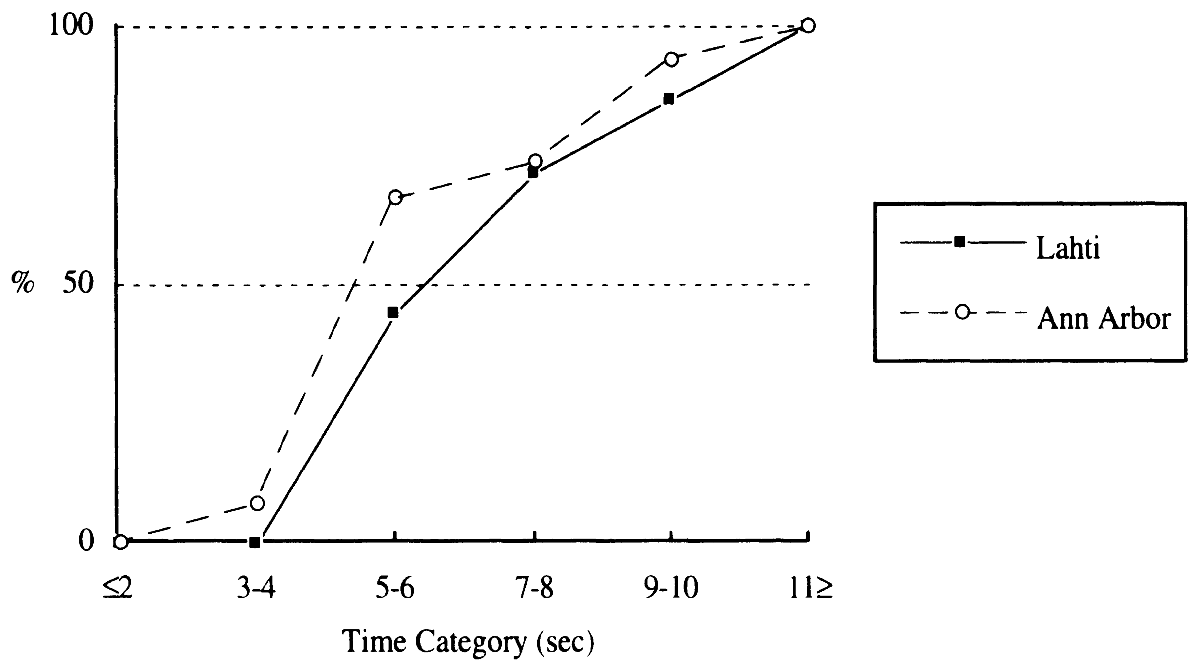

Figure 27. Critical gaps for left-turning drivers at both intersections.

Figures 25 through 27 show that differences in critical gaps were small. In each case, however, the critical gap was slightly longer in Lahti than in Ann Arbor. Given this order, the analysis for the left-turning drivers as a one group is justified. The underlying logic for that conclusion is as follows. The left-turning drivers rejected relatively similar gaps in both cities. Specifically, 57% of drivers in Lahti and 59% in Ann Arbor rejected the gaps involving the first vehicle from the right (see Table 18). While accepting a gap, the corresponding proportions were 31% and 58%. In other words, the drivers in Ann Arbor accepted a larger proportion of gaps involving the next vehicle from the right when a longer gap would be necessary than in the case of the next vehicle approaching from the left. Consequently, it is possible to conclude that the critical gap was systematically longer in Lahti than Ann Arbor. Unfortunately, the results based on the long time separations allow us to define only the order of the critical gaps, but not their absolute values.

Drivers who accepted the first gap. The durations of the first accepted gaps are summarized in Table 19. These gaps were submitted to an analysis of variance using city and turn direction as factors. The two main effects and their interaction were not statistically significant.

Table 19
Duration of the first accepted gap by intersection.

	Lahti			Ann Arbor		
	Right turn	Left turn	Total	Right turn	Left turn	Total
Mean (sec)	7.4	7.8	7.6	8.0	6.9	7.6
Standard deviation (sec)	1.7	2.0	1.8	1.8	1.7	1.9
Number of vehicles	17	12	29	38	20	58

The distributions of the first accepted gaps are shown in Figure 28. The proportions of the shortest gaps (3-4 sec) indicated no difference between the two cities.

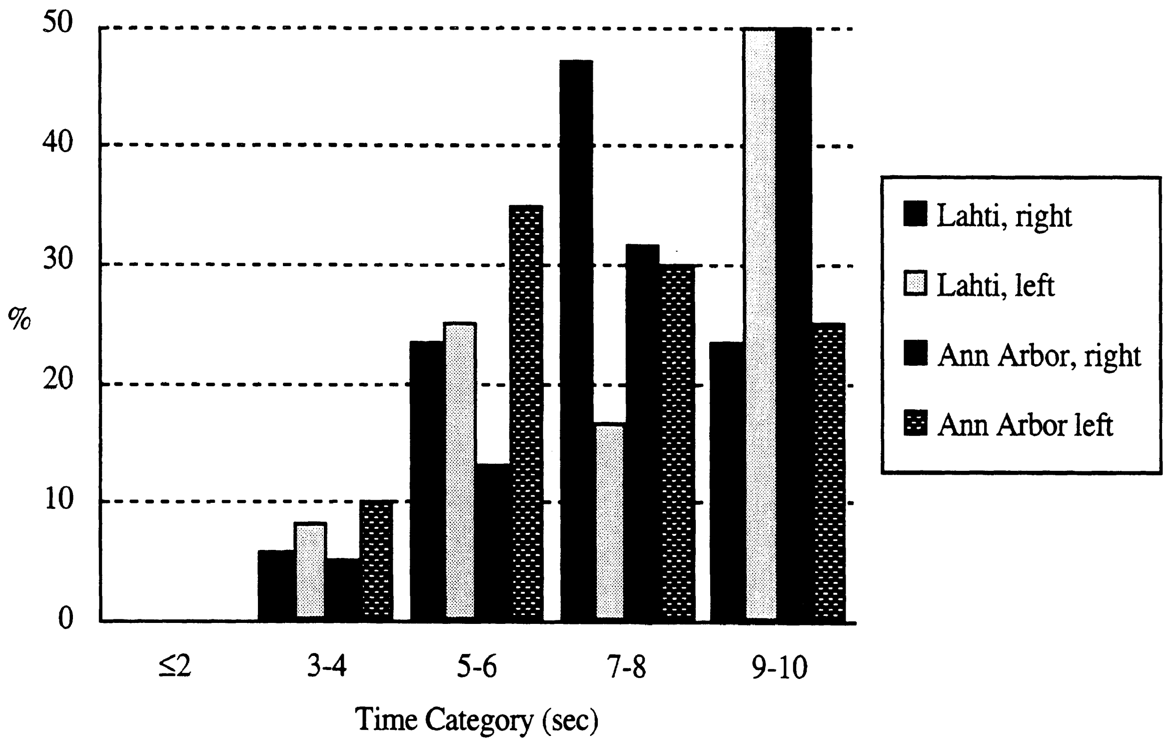

Figure 28. Duration of the first accepted gap.

YIELDING TO PEDESTRIANS AT INTERSECTIONS

Sites

Yielding to pedestrians was studied at two controlled intersections in each city (Figures 29 and 30). Table 20 shows the road and traffic conditions at each intersection.

Table 20
Road and traffic conditions.

	Lahti		Ann Arbor	
	1	2	1	2
Environment	downtown			
Speed limit (kph):	50		48 (30 mph)	
Number of lanes for left-turning cars	one			
Lane width (m)				
road to turn from	3.5	3.5	3.0	3.3
road to turn to	5.1	4.0	6.0	3.6
Distance from the stop line to the pedestrian crossing (m)†	31	28	21	21
Pedestrian island	yes		no	
Traffic control cycle (sec)	100	100	80	70
Green phase (sec)				
left turning vehicles	35	30	27	30
pedestrians	41	37	17	20
Traffic volumes per hour*:				
left turning vehicles	80	140	100	60
oncoming vehicles	100	0	100	80
pedestrians	150	200	80	180
Number of vehicles per one second of green phase*	0.06	0.13	0.08	0.04
Number of pedestrians per one second of green phase*	0.10	0.15	0.10	0.17

† A theoretical distance for a vehicle travelling straight ahead at first and then following along the largest possible circular arc.

* Road users running red lights were excluded.

(1)

(2)

Figure 29. The sites of the measure of yielding to pedestrians in Lahti: (1) the intersection of Kauppakatu and Kirkkokatu (the pedestrian crossing on the left), (2) the intersection of Vapaudenkatu to Vesijärvenkatu (the pedestrian crossing on the right).

(1)

(2)

Figure 30. The sites of the measure of yielding to pedestrians in Ann Arbor: (1) the intersection of East Washington Street and South State Street (the pedestrian crossing on the right), (2) the intersection of South University Avenue and Forest Avenue (the pedestrian crossing on the right).

Design

The observation focused on the interactions of left-turning drivers and pedestrians who had a green phase at the same time. In this situation, driver should yield the right-of-way to pedestrians (as well as to coming vehicles). Although the main focus is in driver behavior, the interaction of the road users is important. Only interactions that did not involve oncoming vehicles or bicycles on a pedestrian crossing were included in the analysis.

Results

The number of interactions, drivers, and pedestrians is presented in Table 21.

Table 21
Number of registered interactions, drivers and their characteristics, and number of pedestrians.

	Lahti		Ann Arbor	
	1	2	1	2
Number of interactions	72	82	87	78
Male drivers (%) *	70.5		69.5	
Estimated driver's age (%)*:				
<25	17.9		25.0	
25-65	76.9		73.5	
>65	5.1		1.5	
Number of pedestrians in interactions (%):				
1	49.3	30.5	54.0	35.9
2	28.2	31.7	26.4	24.4
3	12.7	23.2	13.8	20.5
4	7.0	8.5	4.6	11.5
5	1.4	2.4	1.1	5.1
6	1.4	3.7	0.0	2.6

* In Lahti, information on sex and age was collected at the second intersection only.

The proportions of male and female drivers were not significantly different from each other.

Initially, driver behavior in interaction was classified into four categories, adopted mostly from Himanen and Kulmala (1988): (a) drove on, (b) braked and/or weaved slightly, (c) braked and/or weaved clearly, and (d) stopped. Correspondingly, pedestrian behavior was classified into four categories: (a) walked on, (b) slowed down or stopped, (c) ran, and (d) retreated. However, the interaction with a stopping driver was very infrequent, particularly in Ann Arbor. Proportions of slight brakes/weaves and clear brakes/weaves were about the same at each intersection. Furthermore, pedestrians ran or retreated infrequently. Consequently, the categories of both road-user groups were combined to two categories: continues (driving or walking) and reacts.

The results indicated no significant difference in the proportions of the interactions between cities or between intersections in each city (Figure 31). Driver's sex had no significant effect on driver behavior in either city.

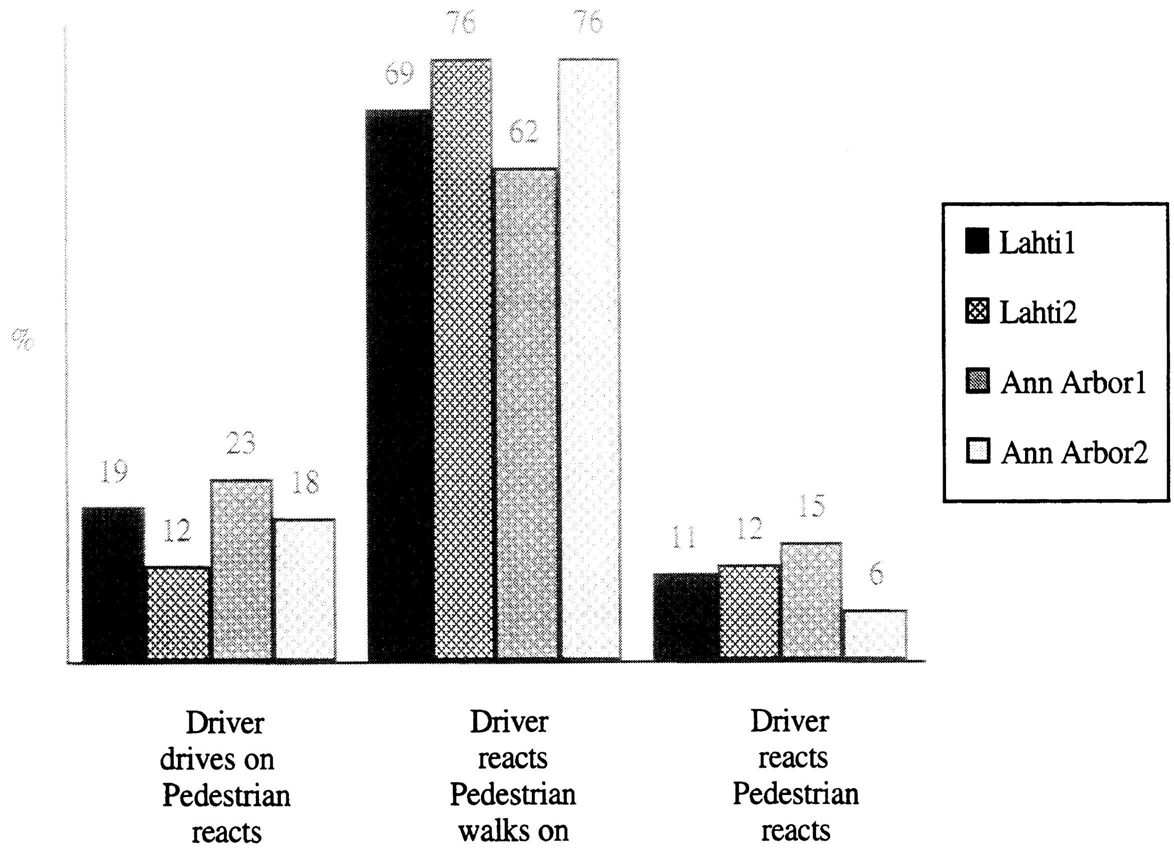

Figure 31. Proportions of different type of interactions.

Driver behavior, crosstabulated by the number of pedestrians in interaction, is presented in Figure 32. The results showed that only if there were one to two pedestrians in interaction, some drivers in Lahti did not yield to pedestrians while in Ann Arbor that happened also when there were three to four pedestrians. The difference between the two cities was not significant for one to two pedestrians but was significant for 3 to 4 pedestrians ($X^2(1) = 8.66$, $p < 0.01$).

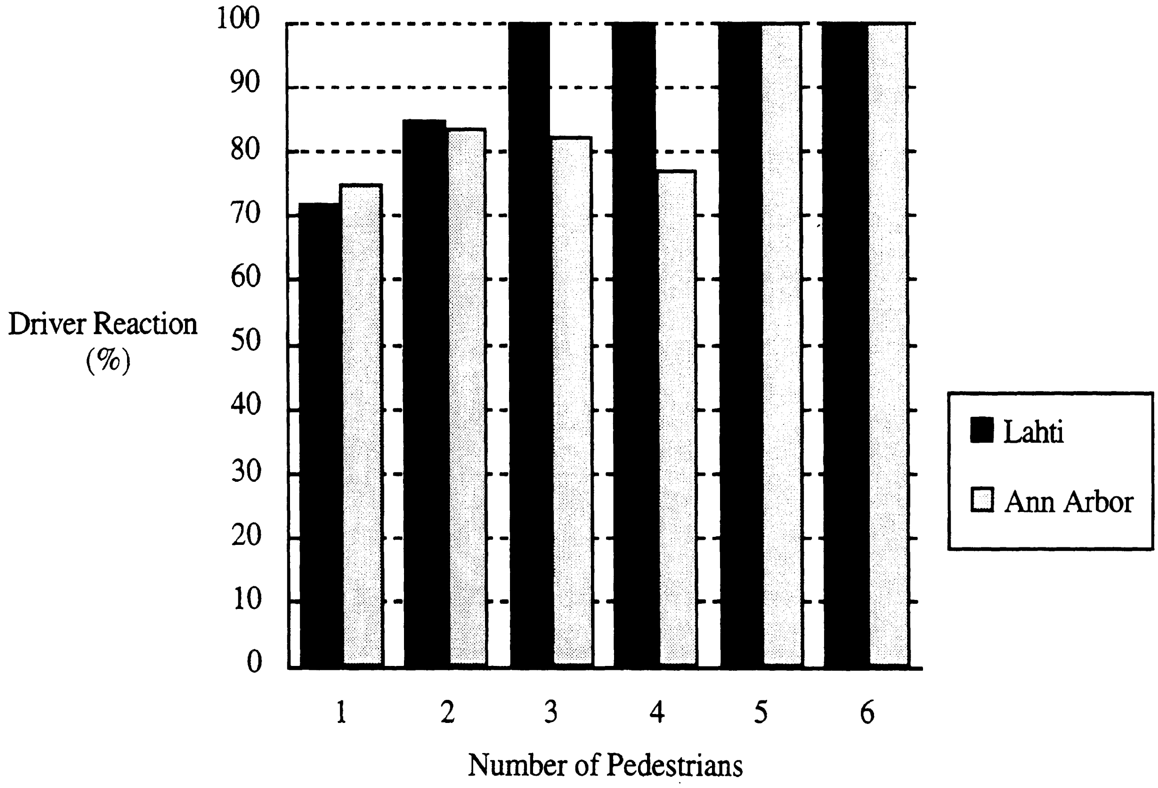

Figure 32. Driver behavior by the number of pedestrians in interaction.

USE OF SAFETY BELTS

Design

No new data were collected because relatively comparable data from other researchers are available. We used data from a study performed by Heino (1994) in Finland, and Streff, Eby, Molnar, Joksch, and Wallace (1993) in Michigan.

Data for both studies were collected by field observations in 1993. The Finnish data were collected in May and the Michigan data in September. Only the use of the shoulder belt of front occupants (outboard in Michigan) was observed.

The following major differences existed in data collection. The Finnish data were collected at 10 am and 3 pm on all days of week, except for Sundays. The Michigan data were collected between 7 am and 7 pm on all days of week. In Finland, the sampling was designed for urban and rural areas at 32 locations. The rate for the whole country was calculated by weighting the regional data by the population of the counties. In Michigan, the data collection was based on a sample design that intended to represent all passenger vehicle motorists in the state. The study estimated belt use for the state based on vehicle miles of travel. Because of these differences, no test of significance was performed.

Results

Results of the use of safety belts in Finland and Michigan are given in Table 22.

Table 22
Use of safety belts on front seat in passenger cars in Finland and Michigan. The Finnish data are weighted by population of a county, while the Michigan study estimated belt use for the state based on vehicle miles of travel (adapted from Heino, 1994 and Streff, Eby, Molnar, Joksch, and Wallace, 1993)

	Finland		Michigan
	urban	rural	statewide
Front (outboard) shoulder belt use (%)	77	92	64
Number of observed occupants	19,700	17,489	17,719

The Finnish rate was higher than the Michigan rate. However, the difference between Finnish urban and rural areas was also substantial. The Michigan (unweighted) data crosstabulated by site revealed that the use of seat belts at freeway exits was slightly higher (66%) than at intersections (64%), indicating the same tendency. The Finnish data crosstabulated by occupants revealed that the difference of use rate of drivers and passengers was only 1 to 2%. The Michigan (unweighted) data crosstabulated by day of week and time of day did not show systematic trends.

In addition, Streff, et al. (1993) reported that the Michigan rate has increased considerably from previous measures, for example being 13% greater than 15 months earlier. In contrast, the Finnish rates have been relatively constant for last the 12 years (Heino, 1994). One possible reason for the increased rate in Michigan is that all 1990 model year and newer passenger vehicles must have automatic restraint systems installed (airbag or safety belts) (Streff, et al., 1993).

DISCUSSION

This study was designed (1) to develop an initial set of measures to observe driver behavior in different countries, different parts of a country, or in longitudinal studies, and (2) to compare driver behavior in Finland and Michigan. The results of the study will be discussed in terms of the two goals. First, development of the set of measures will be addressed. Second, the results concerning the comparison of driver behavior in Finland and Michigan will be discussed.

Development of the set of measures

The following measures were developed:

(1) Speed behavior in free-flow traffic
(2) Headways while following other vehicles
(3) Use of turn signals before a lane change
(4) Speed while approaching an intersection from a secondary road
(5) Speed after turning onto a secondary road
(6) Use of turn signals before turning
(7) Stopping behavior at intersections with a stop sign
(8) Gap acceptance when entering a main road
(9) Yielding to pedestrians at intersections
(10) Use of safety belts

The comparison made between Finland and Michigan showed that each of those measures was usable. Given that, the essential questions are: How reliable and valuable results do these measures provide? The problem of reliability includes three broad areas: (1) techniques of data collection and interpretation of the data, (2) matching of environmental factors and specific rules, and (3) number of drivers.

Techniques of data collection and interpretation of the data. Data collection by video technique provides a possibility to examine every event carefully and to replay it, if necessary. However, the recorded data have room for interpretations. The most evident interpretation problem of the present study was the separation of rolling and no stops at intersections with a stop sign. The separation was based on the comparison of walking and driving speeds, but perhaps this is not the best way. It may involve systematic bias if several people estimate the speed. In this study, however, one person interpreted all the data.

If data are collected by note keeping only, the reliability may decrease (Heino, 1993). In addition, the video technique provides a possibility to count actual traffic volumes.

Heino (1993) estimated that errors of data collected by the traffic counter, DSL-1, are minimal because the counter excludes vehicles that are changing lanes, for example. Furthermore, a lag caused by the data transfer is minimal. The speed data collected by the photocell pairs proved to be reliable.

Matching of the environmental factors and specific rules. The long lists of selections and definitions show the limited scope of this study. However, it is emphasized that these selections, limitations, and definitions have to be explicit to show how cautious we have to be while generalizing the results. On the other hand, the limitations of the study do not invalidate the results because the goal of the study is to collect basic information on driver behavior. The task of future studies will be to show the possible effects of environment, lighting conditions, roadway conditions, etc.

If we estimate how well the match succeeded in the performed comparison, we may see some shortcomings. First, while comparing the proportions of drivers exceeding speed limit, the second site in Ann Arbor seemed to be different in two ways: the speed limit was relatively high for a suburban highway and there was intersections for left-turning vehicles. While selecting the sites, too little attention was paid to these factors. The second major concern was that the traffic volumes on the main road were substantially different in measures of speed behavior while approaching the intersection from the secondary road, and gap acceptance when entering a main road (on the first intersection). However, presumably this did not influence the comparisons harmfully because the results showed that drivers who accepted or rejected the first gap decreased speed similarly in both cities. Comparing gap acceptance was based on critical gaps, ruling out a major influence of different volumes on the main road.

Matching of the rules was not always an easy task. Many differences exist between Europe and North America: the existence of stop sign is much more frequent in North America than in Europe, and the following traffic controls are used in North America only: 4-way stops and all-way stops, center turn lane, and right turn on red. In addition, many European countries (including Finland) use a more hierarchical street network than the U.S. does.

In general, some of the factors were rather easy to match, including width of the road and roadway conditions. In contrast, the sight distances were impossible to match completely. Further, given the limited number of sites in each city, several problems emerged while combining all the factors.

Number of drivers. In studies like this, the question about the number of drivers is always connected to the amount of time that is allowed for data collection. Especially in the case of measures such as speed while approaching an intersection and gap-acceptance, attention should be paid to this question, because only a small amount of data is usable for further analysis. Perhaps it would be possible to collect these data also by loop detectors, providing possibilities for collecting a substantial amount of data.

This study was not based on data collection at a random sample of sites in two cities, because the goal was to develop and test the set of measures. If the goal is to get a general picture from one or two countries, special attention must be paid to the selection of the sites in order to cover the target area without any bias (see, for example, Streff et al., 1993).

Finally, the question of the value of the comparison of driver behavior is difficult to answer on the basis of this individual comparison. However, the question is worth discussing.

It was assumed that the measures would show different aspects of driver behavior that have potential safety effects. As indicated earlier, we do not know whether it is the case. Hopefully, further research will show the possible connections by comparisons of driver behavior and traffic accidents. The main difficulty of this approach has been the lack of a sound methodology for investigating driver behavior. Therefore, the study produced a research tool. Of course, it is possible to add other measures to this set of measures. As mentioned earlier, the use of motorcycle and bicycle helmets and the proportion of drunk drivers, for example, have been observed already in longitudinal or countrywide comparisons (Heino, 1993, 1994; Streff, 1994). Also, this kind of tool may be necessary when similar technical applications are intended for use in different countries or in a large country, such as the U.S. This may happen more frequently in the future when high-tech applications like IVHS, PROMETHEUS, and DRIVE (Transport Telematics) are involved.

Comparison of driver behavior in Finland and Michigan

The main findings of the cross-national comparison performed in Lahti and Ann Arbor are as follows:

(1) While studying vehicle speed in free-flow traffic, no difference was found in the variance of the speed. On suburban highways, the proportion of drivers exceeding the speed limit was smaller in Ann Arbor (84.0% and 63.2%) than in Lahti (88.3% and 84.5%), but no difference was found in the proportion of drivers exceeding the speed limit more than 15 kph. However, as indicated earlier, matching of the second sites was far from perfect. The third comparison of speed (while approaching the intersection) showed no difference in the proportion of drivers exceeding of the speed limit (82.9% and 81.4%). Further, the fourth comparison (speed after turning onto a secondary road) showed the difference: 69.3% of drivers in Lahti and 56.5% of drivers in Ann Arbor exceeded the speed limit. In summary, the results suggest that the proportion of the drivers exceeding the speed limit is high in both cities, and drivers in Lahti tended to exceed the speed limit more frequently.

(2) There were no systematic difference in the proportion of short headways in car-following situations.

(3) Before a lane change, drivers in Lahti signalled more frequently than those in Ann Arbor (63.7% vs. 50.4%).

(4) While approaching an intersection from a secondary road, speed change was more substantial in Lahti than in Ann Arbor at the distances 90 m and 30 m from the intersection (but not at 60 m), although the initial speed was higher in Ann Arbor. These results suggest that drivers in Lahti approached the intersection from the secondary road somewhat more cautiously than drivers in Ann Arbor.

(5) After turning onto the secondary road, drivers in Lahti tended to accelerate more slowly than those in Ann Arbor. However, there were slight differences in the gradients of the roadways and the posted speed limits.

(6) Before turning at intersections, drivers in Lahti signalled more frequently than those in Ann Arbor, both at urban intersections (84% vs. 43%) and at suburban intersections (75% vs. 59). Consequently, this result, along with the result of the use of turn signals before a lane change, suggests that the use of turn signals is generally more frequent in Lahti than in Ann Arbor.

(7) Drivers in Lahti came to a full stop at intersections with a stop sign more frequently than those in Ann Arbor. Perhaps this difference is, at least partially, explained by the more frequent use of stop signs in the U.S. than Europe. However, there was no clear difference between the cities in the frequency of no stops compared to rolling and full stops. The difference in the frequency of no stops was much smaller between cities than between urban and suburban intersections.

(8) Differences in the size of critical gaps for gap acceptance were small. However, the critical gaps tended to be slightly longer in Lahti than in Ann Arbor. There was no difference in the duration of the first gap that was accepted.

(9) The results showed no general differences in yielding to pedestrians at intersections. However, if there were one or two pedestrians in interaction, some drivers in Lahti did not yield pedestrians, while in Ann Arbor that happened also when there were three or four pedestrians.

(10) Safety belts were more frequently used in Finland (92% in rural areas and 77% in urban areas) than in Michigan (64% statewide).

CONCLUSIONS

Results suggest that, overall, driver behavior is rather similar in Lahti and Ann Arbor (as was assumed at the beginning of this study). In addition, most of the differences were minor.

However, there were substantial differences in the frequency of using turn signals before turning, full stops at intersections with a stop sign, and using safety belts. These differences are in agreement with the second hypothesis assuming that Finnish drivers obey specific traffic rules better than Michigan drivers, presumably because of the more substantial driver training in Finland. On the other hand, this conclusion can not be generalized to all specific rules because drivers in Lahti tended to exceed the speed limit more frequently and yielding to pedestrians indicated no difference. In addition, the higher safety belt rate in Finland might be affected by the law permitting primary enforcement.

It was assumed that some positive indication of the longer history of motorized transportation in the U.S. would be detected. However, the present results did not support this assumption. In contrast, compared to drivers in Lahti, the drivers in Ann Arbor tended to decrease speed later while approaching the intersection from a secondary road, to accelerate more rapidly after turning onto the secondary road, and to accept smaller gaps while entering the road. The last effect may indicate an adaptation to heavier traffic volumes in the U.S.

The similarity of driver behavior patterns indicates that subjective observations of foreigners overestimate the frequency and magnitude of differences, and that the similarities may not be detected (Nortamo, 1991).

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