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June, 1995; revised April, 1996

# Timing of Auditory Route-Guidance Instructions

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HUMAN FACTORS

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This experiment examined how far from an intersection an auditory route guidance system should present the final turn instructions ("Turn right"). In part 1, 48 drivers followed instructions from a simulated speech-based, in-vehicle navigation system ("In approximately 2 miles, turn right at the traffic signal."), responding "Is this it?" when they thought they had reached the desired intersection. In response, the computer gave the appropriate guidance ("no, continue..." or "turn..."). In part 2, they repeatedly approached two different intersections, with feedback from previous trials ("too far," "too close," "OK") being used to adjust when messages ("turn left") were given.

The method used in part 1 was much more efficient than the method used in part 2. Desired presentation distances in part 1 averaged 450 ft (when approached at 40 mi/h), approximately 50 ft greater than those obtained in part 2 (where intersections were more familiar). Desired presentation distances are best estimated from the part 1 data:

Distance (ft) = -389 + 119 (Age.code) - 113 (Sex.code) + 95 (Turn.code) +15 (Speed in mi/h) + 21 (# Vehicles Ahead).

where: Age.code 1= (18-30 years), 2 = (40-55), 3= (65-80)
Sex.code 1= women, 2 = men
Turn code 1= right, 2 = left

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University of Michigan, Ann Arbor, Michigan, USA

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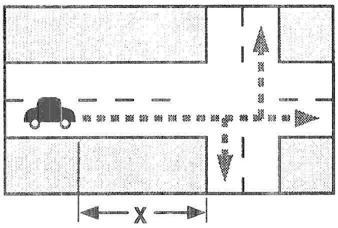
## 1 Issues

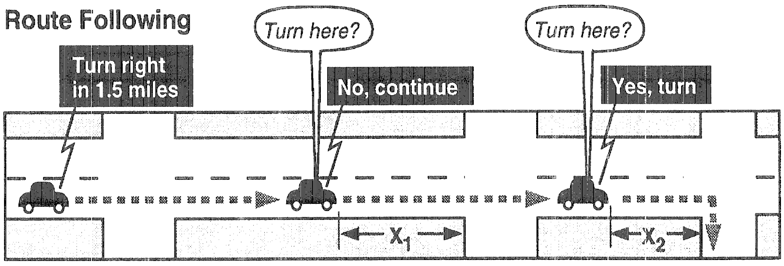



1. What is the best distance "X" for a navigation system to tell a driver to "turn right," "turn left," or "go straight?"
2. Will "X" be the same for different test methods?
3. How does "X" vary with:
   - driver age and sex,
   - traffic,
   - intersection geometry, and
   - traffic light state?

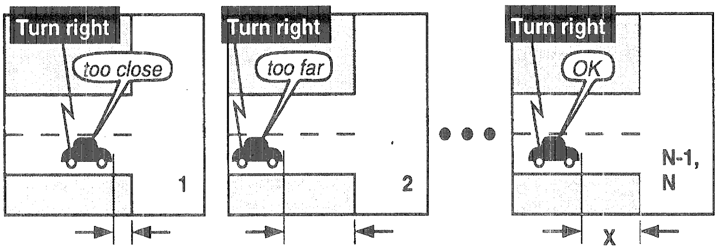
## 2 Two Methods Used to Find the Distance "X":

| | | Subjects | |
|---|---|---|---|
| | | men | women |
| Age | 18-30 | 8 | 8 |
| | 40-55 | 8 | 8 |
| | 65-80 | 8 | 8 |

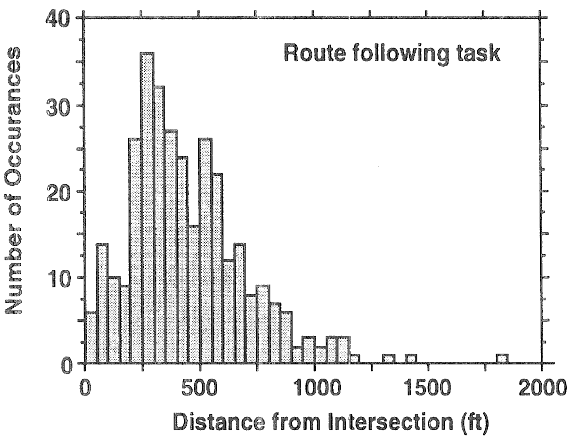
### Route Following

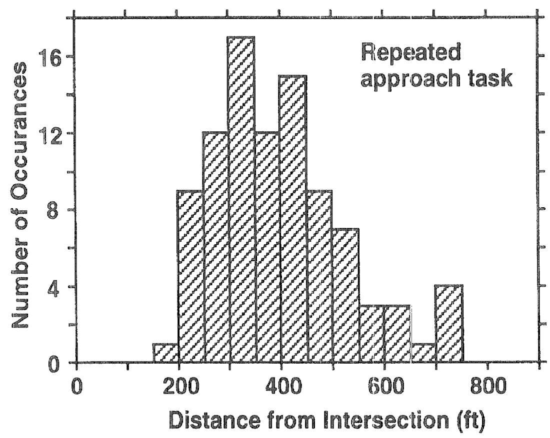



### Repeated Approach to Intersections




## 3 Results



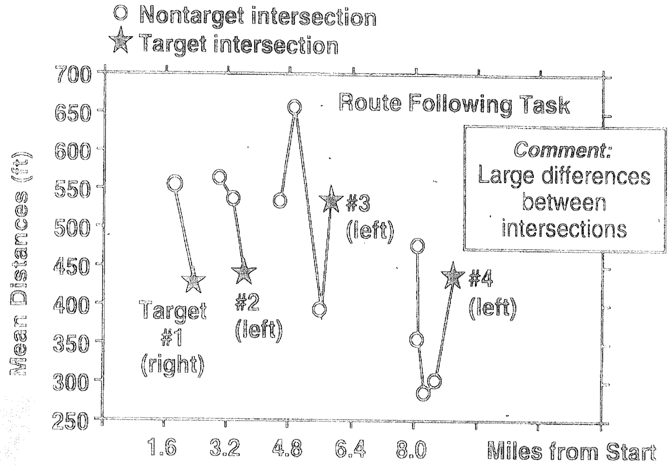




***Comment:*** Shapes of distributions are similar, but the mean in repeated approach is longer. Also, the data in route following is easier to collect.

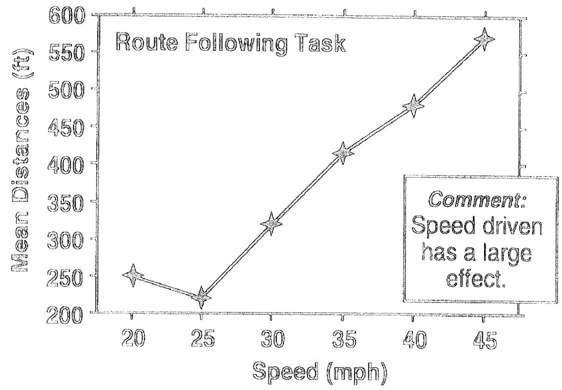
## 4 More Results

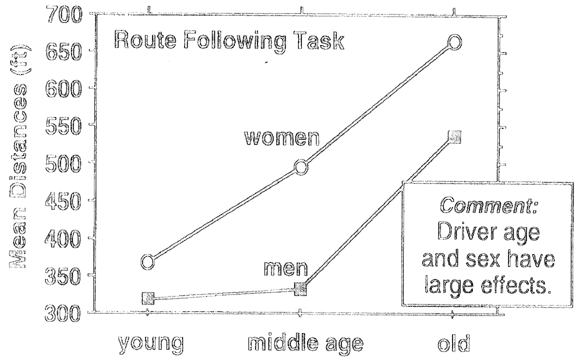
**Which factors mattered?**
ANOVA of Route Following Distances

| Factor | Significant? |
|---|---|
| Turn Direction | yes |
| Light Color | |
| When Approach Intersection | no |
| When Message Requested | no |
| Stop at Light | no |
| # Vehicles Ahead | yes |
| # Vehicles in Left Lane | yes |
| Time of Day | no |
| Speed | yes |
| Age | yes |
| Sex | yes |




Mean distances for "Is this it?" requests by intersection




## 5 Predictions

**Route Following Prediction**
Distance (ft) = - 389
+ 119 (Age code) 1 = young, 2 = middle, 3 old
- 113 (Sex code) 1 = women, 2 = men
+ 95 (Turn code) 1 = right, 2 = left
+ 15 (Speed)(mph)
+ 21 (Number of vehicles ahead)

**Repeated Approach Prediction**
Distance (ft) = -260
+ 14 (Speed)
+ 45 (Sex code)
+ 26 (Age code)

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## TABLE OF CONTENTS

# INTRODUCTION

## Why Are Auditory Guidance Systems of Interest?

There is a significant world-wide effort to apply computer and communications technologies to improve transportation, especially road transportation. This effort is conducted under many banners (IVHS or Intelligent Vehicle Highway Systems, and now ITS or Intelligent Transportation Systems in the United States; ATT or Advanced Transport Telematics in Europe; various names in Japan). The goals of these efforts are to enhance throughput, to improve safety, to satisfy user information needs, and to make driving more enjoyable.

There are many systems that may appear in future vehicles to help achieve these goals (Green, Serafin, Williams, and Paelke, 1991; Serafin, Williams, Paelke, and Green, 1991). Of those systems, navigation products will likely be one of the first sold widely in the United States. A navigation system shows a vehicle's current location, may give route guidance (either in real time or as a list of instructions), and potentially may provide instructions that are modified based on traffic updates. At the present time, several hundred thousand cars in Japan have navigation units, and field tests have been conducted examining such systems in Europe.

In the U.S., the first navigation product on the market (of which only a few thousand units were sold) was the ETAK navigator. This was a point-on-a-map product that had a 4-inch CRT showing a detailed map, a CD-ROM player for map data, and 12 buttons used to enter destinations and change the map scale. The product did not give route guidance. This product is now sold in Europe as the Blaupunkt Travelpilot. Recently, several organizations (GM, Ford, Amerigon) have announced navigation products for the U.S. market, and other products are likely. Most products have the same basic physical components as the ETAK product (small display screen, CD-ROM, push buttons for input). Both Hertz and Avis have announced offering a product developed by Zexel on selected vehicles in a few markets (Anonymous, 1994). Prototypes for the TravTek, FAST TRAC, and ADVANCE operational field tests all include interfaces with both visual navigation displays and voice guidance options.

How route-guidance information should be presented visually, auditorally, or some combination of these, is a central question affecting the design of navigation systems. For the visual modality, there are questions as to whether the information should be text, a simplified map showing turn arrows, turn arrows alone, or a detailed map. (See Green, 1992 for a review and Green, Hoekstra, and Williams, 1993; Green, Hoekstra, Williams, Wen, and George, 1993; Green, Williams, Hoekstra, George, and Wen, 1993 for recent research results.) Considerations include ambient lighting levels, physical display characteristics (size, contrast, resolution, colors and fonts available), driver characteristics (age, vision, and driving experience), features to be provided, and other factors. The preferred modality and format for guidance information may depend upon cost performance tradeoffs, as well as usability concerns. It is evident from the literature and product plans, that many future route-guidance products will use voice guidance to some degree, and that voice guidance has desirable usability properties.

Specifically, there is evidence from recent studies that indicates that using voice to supplement a turn display can be very beneficial to drivers by reducing glance durations and frequencies to visual displays, reducing workload, and reducing turn errors (Dingus, Perez, Fleischman, and Inman, 1994). In a second study, Kishi and Sugiura discovered that the use of voice reduced fixation frequency and mean heart rate (a measure of stress). (See Kishi and Sugiura, 1993 a,b.) In both studies, voice-only interfaces were not examined. Recent UMTRI research comparing single modality presentation found that navigation performance with a visual display by itself led to fewer navigation errors than an auditory interface by itself, but the auditory interfaces was rated as slightly easier to use (Green, Williams, Hoekstra, George, and Wen, 1993).

### How Has Message Timing Been Implemented?

The appropriate timing for the presentation of a particular voice message depends upon its purpose, length, and the content (and timing) of other messages in the set. Voice messages can be divided into four classes -- "early," "advance," "prepare," and "at turn" -- depending upon when they are presented The "early" maneuver message provides forewarning of upcoming maneuvers, occurring shortly after a preceding maneuver is completed. The "advance" message, is generally only presented on expressways and is timed to coincide with the appearance of signs several miles before an exit (e.g., "Plymouth Road, 2 miles"). The "prepare" message occurs shortly before a turn or exit and may include landmarks, location, distance away, etc. This message signals drivers to move to the appropriate lane and to begin searching for the street, landmark, or exit. The "at turn" or "approaching" message is the last minute reminder; it signals the driver to execute the maneuver.

Depending upon the number of these messages provided and their length, voice guidance interfaces (message sets) can be categorized as "brief," "expressive," and "chatty." Brief systems (e.g., Ali-Scout) generally only have one or two voice messages (the "at turn" message, and sometimes a "prepare" message) that serve to supplement a visually-based guidance system ("right," or "turn right ahead"). Expressive interfaces (Toyota, TravTek, UMTRI) provide three or four phrase "prepare" messages describing the turn direction, distance to the turn, street or route name, and possibly landmarks. Chatty systems (e.g., Back Seat Driver) add details concerning intersections that are difficult to maneuver.

To put the experiment reported here in context, it is useful to describe the voice message timing rules for each of the interfaces of interest (Back Seat Driver, the TravTek, UMTRI, Toyota, Ali-Scout). The Back Seat Driver interface emphasized driving on city streets (Davis, 1989; Davis and Schmandt, 1989). The interface provided for 10 basic actions (continue, forced turn, turn around, enter, exit, onto-rotary (traffic circle), exit rotary , fork, stop, and turn). Prepare messages in Back Seat Driver tended to be quite lengthy for complex decisions. ("Get in the left lane because you're going to take a left at the next set of lights. It's a complicated intersection because there are two streets on the left. You want the sharper of the two. It's also the better of them. After the turn, get into the right lane.") Back Seat Driver also provided an "at turn" message. ("Take a left here.") The distance to begin speaking was calculated as follows for this auditory navigation system:

distance = v * ( t.speak + t.react)

where:

t.speak = time to speak at 180 words/min, 3 words/sec
(the rate of the synthesizer)
t.react = driver's reaction time, assumed to be 2 sec
v = speed driven (ft/sec)

hence:

distance = v * ((#.words.in.message/3) + 2.0)

For a 10 word message heard by a driver traveling at 35 mi/h (56 km/h), the message should start 274 ft ( 0.08 km) before the intersection. At 60 mi/h (96 km/h), the same message should begin 469 ft (0.14 km) before the turnoff.

In the auditory portion of the TravTek interface, up to three voice messages were provided for each pending maneuver (Means, Fleischman, Carpenter, Szczublewski, Dingus and Krage, 1993). For city streets, special rules were also developed for successive turns in close proximity. For both city streets and expressways, there were at least two types of messages, "near turn" ("prepare") and "at turn." The "prepare" message, given at 0.4 mi (0.64 km) in advance of a turn on city streets, included the distance and turn information ("In 0.4 miles, bear right onto Main Street."). The "at turn" message was given 0.1 mi (0.16 km) from the intersection. In early versions of the interface, messages were presented 8 to 9 sec before the intersection, which was too far in advance (Fleischman, 1992, personal communication). In 8 sec, a vehicle will travel 410 ft (.13 km) at 35 mi/h (56 km/h) and 469 ft (.14 km) at 40 mi/h (64 km/h). Fleischman recommends considering the turn direction, road class, signalization, speed, and other factors in determining the time required.

In the UMTRI interface, three messages were provided when there was adequate time available. (See the following example, Table 1, and Green, Hoekstra, Williams, George, and Wen, 1993). Message timing was given less attention than other aspects of the auditory guidance interface. The recommendations for timing of the "prepare" and "approaching" messages were adopted from TravTek (Fleischman, 1992), although some thought has been given to the work of Eberhard (1968), Eberhard, Jones, Kolsrud, and Schoppert (undated), and Finnegan and Green (1990). While the TravTek timing recommendations concern only two speeds, experience from TravTek suggests three are desired (35 mi/h [56 km/h] or less, 40 to 50 mi/h [64 to 80 km/h] and 55 to 65 mi/h [88 to 104 km/h]). The UMTRI interface used times-to-travel to choice points (which included an allowance for the time to give the guidance message). Early messages were presented as soon as a driver was thought to have returned to normal driving speed after having completed a maneuver.

Example:

Early: *In 3.5 miles at Green Street, bear left.*
Prepare: *In 1 mile at the traffic light at Green Street, bear left.*
Approaching: *Approaching Green Street, at the traffic light at Green Street, bear left.*

Table 1. Message content and timing.

| Message | Information Provided | When Provided | |
|---|---|---|---|
| | | city | highway |
| Early *(always given)* | "In" {distance} "at" {location} {action} | 5 s ***before turn | 15 s ***before turn |
| Prepare *(only given if enough dist. after early message )* | {distance} {location} {action} - or - {distance} {landmark} {location} {action} | 1 mi (1.6 km) before turn | 1.9 mi (3.08 km) before turn |
| Approaching *(always given)* | "approaching" {location} {action} - or - "approaching" {landmark} {location} {action} | 0.1 mi (0.16 km) before turn | 0.3 mi (0.48 km) before turn |

In the Toyota interface, drivers are normally shown area maps, which are replaced by turn displays as the driver nears a turn point. For city streets, there are two primary turn messages (1. "About 700 meters ahead, turn to the right." and 2. "About 300 meters ahead, turn to the right at Hukeda town."). (See Kishi and Sugiura, 1993 a,b.) For expressways, there are two messages prior to the exit (1. "About 2 kilometers ahead, exit to Nagoya intersection." 2. "About 1 kilometer ahead, exit to Nagoya intersection."), and there may be a supplemental message closer to the exit. In Japan, the 1 and 2 km distances are associated with advance notice exit signs. Message content and timing was based on a thoughtful analysis of navigation information required by drivers. Kishi divides the execution of turning maneuvers into three phases: changing lanes, identifying the turn point, and executing the turn. The information required at each phase is not identical. A more detailed description of the interface appears in papers written by Ito and his colleagues (Ito, 1993; Ito, Watanabe, and Kishi, 1993; Ito, 1994), though the most detail appears in an SAE paper (Ito, Azuma, and Sumiya, 1993).

In the Ali-Scout interface, there are "prepare" ("left turn ahead") and "at turn" ("turn left") messages. "Prepare" messages are presented 1000 m (3281 ft) before expressway exits and, on average, 300 m (984 ft) before turns on city streets. The timing of "prepare" messages can be tailored (in 100 m [328 ft] increments) for each major intersection with 400 m (1312 ft) used for situations where lane changes may be needed (and many major roads), and 200 or 250 meters where streets are closely spaced or travel speed is low. "At turn" messages occur at 20 percent of the distance of the "prepare" messages, typically 200 m (656 ft) on expressways, and 60 m (197 ft) or 80 m (262 ft) on city streets, depending upon traffic.

Not all auditory navigation systems require timed messages. La Rue, Diller, and Tyebkhan (1994) describe AudioNav, a sensor-free voice-based navigation system. Since the AudioNav system does not know were the vehicle is located, all requests for information are initiated by voice commands from the driver ("next," "repeat," "previous"). As a consequence, system-initiated timing is not an issue for this interface.

Thus, current design practice is to provide at least one voice message close to the turn point and the experimental evidence is that providing supplement voice guidance is helpful to drivers (e.g., Kishi and Sugiura, 1993; Dingus, Perez, Fleischman, and Inman, 1994; Kimura, Marunaka, and Sugiura, 1994). Further, while there is agreement that the presentation of that message should depend upon the speed to travel, the distance from the intersection at which it is presented varies from interface to interface. Table 2 summarizes the interfaces described previously.

Table 2. Actual distance (ft, m) before turn of "at turn" messages.

| Interface | Street | | Expressway | |
|---|---|---|---|---|
| | (ft) | (m) | (ft) | (m) |
| Ali-Scout | 197/262 | 60/80 | 656 | 200 |
| Back Seat Driver | 274 | 84 | 469 | 143 |
| Toyota | 328 | 100 | 1640 | 500 |
| TravTek | 528 | 161 | 1528 | 466 |
| UMTRI | 528 | 161 | 1528 | 466 |

**When Should Messages Be Presented?**

Given the lack of agreement of the timing of the "at turn" message, how should the appropriate timing be determined? Timing of voice messages may depend upon the intended role of the message. Specifically, a voice message can be:

1. the primary source of guidance when there is no in-vehicle visual display
2. the primary source of guidance when signs cannot be seen (because they are missing, poorly illuminated or too small, or because the driver has poor vision)
3. an overload reducer (when the driver is too busy to look at an in-vehicle display)
4. a reminder to look for a visual message (because a long time has elapsed since the previous (possibly forgotten) message, or there has been a major change in the recommended route)
5. a backup if the visual message is missed.

In brief, these five cases are referred to as (1) no internal visual display, (2) no external visual display, (3) driver workload overload, (4) driver forgot, (5) backup. When a visual display is not available or missed (cases 1, 2, and 5), the auditory information should be presented at the optimal time for executing the maneuver, presumably the time when the visual information would have appeared. The case of forgotten input is very much like the case of no input; the information is not available.

The workload overload case deserves some discussion. Adding additional information in the form of a visual message could make matters worse, further overloading the driver. However, if properly implemented, voice guidance should reduce workload by overriding the need to process visual information, either from the in-vehicle display and possibly from signs outside the vehicle. In this case, the auditory information should be presented before or concurrently with visual information and should be effective. The rational behavior for drivers would be to attend to an auditory message when it is presented (since it is only available when it is presented), whereas the visual message remains and can be rescheduled for viewing later. This should be possible, since most input while driving is visual, minimizing competition for resources. If the message is well designed, drivers should not need to look at the visual display, thus reducing potential workload.

Hence, timing of auditory messages is largely determined by when information is presented by the in-vehicle display, which in turn is determined by the visibility of signs and other guidance in the real world. (On expressways, the TravTek, UMTRI, and Toyota interfaces all consider this notion by having voice messages coincide with advance exit signs.) Timing is also driven by the need to provide adequate time for drivers to plan maneuvers, to change lanes (as needed) to be in the proper lane to make a turn, to slow down prior to turning or stopping, and to execute the maneuver.

If sign placement is an important factor in determining the timing of associated auditory guidance, then it is important to know the rules for sign placement. The point at which drivers can read signs is influenced by both external workload demands associated with monitoring traffic, and internal demands from conversing with passengers and listening to the radio. However, the primary factors affecting legibility distance are related to the physical characteristics of the signs (character size, contrast), ambient lighting levels, and driver visual acuity.

In the United States, requirements for signs for national (Interstates, U.S. routes) and state roads are specified by the *Manual of Uniform Traffic Control Devices* or MUTCD (U.S. Department of Transportation, 1988). In the United States, national and state highways, while only accounting for a small portion of the total pavement-miles, carry a large share of the traffic (Teets, 1995). Signing practice for counties, cities, and other municipalities varies with local custom and funding.

Signing requirements vary by road class. On expressways, the standard practice is to have exit signs at 2 miles and 1 mile prior to an exit, along with a sign near the exit and at the exit gore. The exact location of the sign near the exit is not specified in the MUTCD, and its location depends on site-specific constraints. In urban areas where exits are closely spaced and not near exact mile increments, the distance of advanced notice signs varies prior to an exit. Placement may also depend on the posted speed of the road, typically 55 or 65 mi/h (88 to 105 km/h). Though, depending on the level of speed enforcement, weather, time of day, and traffic, free flow speeds may be as high as 80 mi/h (129 km/h).

Legibility distances for signs can be estimated using the 50 ft/inch rule for younger drivers, that is the reading distance increases 50 ft (15 m) for each inch of letter height (Olson, 1994). It is understood that at this distance, 85 percent of those drivers can begin to read the sign. The time to read the sign is not specified by the rule of thumb. Assuming a reading rate of 3 words/second (Levison and Cramer, 1993), a two-word exit gore sign would take 0.67 sec to read (on average). For a six-word advance sign, 2 sec would be required to read the sign. Spoken messages are presented at about the same rate.

As an example of MUTCD requirements and the implications for voice guidance interface design, expressway exit guide signs typically have lettering that is 15 to 18 in high depending on the situation. Letters of these signs should be legible at 750 to 900 ft (229 to 274 m) from the sign. Exit gore signs have 10-inch letters (500 foot (152 m) legibility distance). Given this large legibility distance, reading time should have a relatively small impact on the selection of the appropriate distance at which to present an auditory message. At 60 mi/h (96 km/h), about 10 percent of the distance is required to present a two-word message. For longer messages, the speaking duration is a significant factor. Having much larger effects are age-related differences, which can lead to 2:1 differences in sight distance of older versus younger individuals. Auditory messages are most valuable for the older drivers who cannot see the highway signs. One rationale, therefore, would be to present the message at the distance comparable to that at which younger drivers can read signs. (This assumes the driver has been forewarned of the exit and is in the appropriate lane.) This argument favors presenting auditory messages for an exit gore related message 500 ft (152 m) from an exit.

In contrast to the highly specific requirements for high speed roads, signing practice for residential and business districts varies with local custom, especially for street signs. As an example, street name signs in Ann Arbor tend to be fairly large. All signalized intersections in the city have oversized advance street signs (8-inch letters (20 cm)), 500 to 600 ft (152 to 183 m) before the intersection, suggesting a sign can first be read approximately 900 ft (274 m) before the intersection. (Note: 900 = (8 in * 50 ft/in) + 500 ft). In addition, the city is placing illuminated 10 to 12-inch (25 to 20 cm) signs on the mast arms of all traffic signals, replacing reflective signs. Ignoring illumination, this provides a legibility distance of 500 to 600 ft (152 to 183 m) from the intersection. Also, all street name signs will eventually be 9-inch (23 cm) signs, replacing the 6-inch (15 cm) signs. This increases the sign distance from 300 to 450 ft (91 to 137 m). In other jurisdictions, signs may even be less than 6 in (15 cm) high, old and lacking in contrast, and positioned so they will not be well illuminated by a vehicle's headlights or street lights.

For information concerning signing practice in other situations (rural roads, major highways), see Appendix A.

**For Which Decisions Is Auditory Support Most Necessary?**

While the legibility of street signs is relatively low, drivers need a significant amount of time to make route decisions and maneuver. When adequate time is not available, drivers will make incorrect turns or miss turns, or possibly even be involved in an accident. This suggests that of the various instances in which route choices are made, the timing of "at turn" messages is important. Because local practice is so variable and legibility distance in an urban environment depends on many context-dependent factors whose impact on navigation decisions has not been well documented, an experimental evaluation of this situation is desired.

**How Do Driver Reactions to "At Turn" Messages Influence the Types of Intersections and Speeds That Should Be Examined?**

Drivers respond to "at turn" messages by slowing down and turning. They may change lanes as well. Finnegan and Green (1990) indicate that the mean search time for preparing a lane change is 3.7 sec, but could be just over 6 sec, depending on traffic. The time to execute a lane change is about 1.5 sec on average, a brief time period. Changing a lane consists of three phases, turning the vehicle towards the other lane, moving to the other lane, and then realigning the vehicle. The duration of the first and last phases are unlikely to vary much with the speed driven. The duration of the middle phase is unlikely to change with posted speed. While higher posted speeds (e.g., 65 mi/h vs. 35 mi/h) lead to higher lateral speeds (the lateral velocity is equal to the driven speed times the cosine of the yaw angle), higher posted speeds are also associated with wider lanes (12 ft versus 10 ft).

For other than entering a turn lane (often for left turn), a lane change should not be required in response to an "at turn" message in a well-designed route-guidance system. Accordingly, this experiment was not designed to address preturn mispositioning (when the driver is in the right lane of a pair of lanes and needs to make a left turn).

How much drivers need to decelerate when approaching an intersection depends on the desired speed at the intersection, which in turn depends upon the traffic control device present (standard traffic signal, flashing yellow or red, stop sign, yield sign). Comprehensive data are lacking on the frequency of turns for various types of devices. Personal experience suggests most turns (in the U.S.) occur at cross intersections at which traffic control devices are present. When the driver does not have the right of way (approaching a stop or yield sign, approaching a flashing red, approaching a T intersection requiring a forced turn), behavior should be identical to approaching a red light (the driver must slow to a stop). When the driver has the right of way (the crossing street has a stop or yield sign, or a flashing red) behavior should be similar to approaching a green light. The specific intersection geometry (cross, T-left, T-right, etc.) is important only to the extent that it determines the right of way. Thus, driver needs for the timing of auditory guidance messages for most types of intersections can be inferred primarily from behavior at signalized, cross intersections.

Behavior at intersections will also depend on whether a turn lane is provided. If it is, then the driver needs to hear the message, decide to turn, and usually complete planning of the turn before the turn lane begins. If a center turn lane is provided for the entire road, not just the intersection, then the turn needs to begin within some reasonable distance close to the intersection. In some cases, the desired information may be provided by a "prepare" message.

Once the driver has moved into the proper lane and planned the approach, the approach needs to be executed. This will include moving the foot from the accelerator to the brake, and then braking smoothly to slow or stop. The time required to react ($T_r$) to the message prior to applying the brake may be included in the movement time. During this phase drivers will be traveling at a constant speed ($v_O$). In reality, the vehicle might coast, and in that case, there will be some slight deceleration. The distance traveled ($x_r$) is predicted by the following basic physics equation:

$$x_r = v_o * T_r$$

The relationship between speed, braking distance, and acceleration is expressed as:

$$v^2 = v_o^2 + (2 * a * x_b)$$

where: $v, v_o$ = current and initial velocities
a = acceleration
$x_b$ = braking distance

Rearranging this equation:

$$x_b = (v_o^2) / (-2 * a)$$

The total stopping distance is equal to the sum of the reaction and braking distances:

$$x = v_o * T_r + (v_o^2) / (-2 * a)$$

For a response time of approximately 2 sec (a nonpanic braking event), each 1 mi/h change in speed changes the stopping distance by approximately 2.9 ft. Depending on driving style (the desired duration of the coast phase prior to braking), this number could vary quite widely. For typical braking to zero speed (usually necessary for a left turn, but not always for a right turn), values close to 0.1 g are typical, but values can be as low as 0.06 g. In the 35 to 45 mi/h range (at 0.1 g), each 1 mi/h change in speed increases the distance required by 26.8 ft, for a total of 29.7 ft. Thus, the relationship between distance desired and speed is likely to be quadratic and is predominated by the braking event, not coasting prior to braking. If the range of the speeds examined is narrow (e.g. 10 mi/h), it may be difficult to distinguish linear from quadratic effects.

Thus, the speed driven should have an effect on the distance from intersections at which "at turn" messages are desired. It should be recorded in experiments when turn guidance is requested. In the U.S., most urban streets (from which the majority of turns occur) have speed limits of 35 or 40 mi/h (56 or 64 km/h), while major routes have speeds of 45 or 50 (72 or 80 km/h) when free flow occurs. Lightly traveled residential streets have speeds of 25 mi/h (40 km/h). The 35 to 40 mi/h (56 or 64 km/h) case is the most important one, with higher speed roads also being of interest. Given the rationale just described, it should be possible to scale data from the lower to higher speed roads by careful consideration of vehicle dynamics, road geometry (higher speed roads tend to have more traffic lanes and more turn lanes) and driver decision-making behavior.

In addition to the summary of the issues given here, there have been other attempts to determine the "information lead distance" for navigation displays. As an example, Tables 2 and 3 provide data for lane-change and speed-change maneuvers developed as part of the Experimental Route Guidance System (ERGS) project (Stephens, Rosen, Mammano, and Gibbs, 1968). As a footnote, ERGS had only a turn display.

Table 2. Information lead time and distance required for worst case-worst driver lane-change maneuver

| Function | Time (s) | Average Speed (mi/hr) | Distance (ft) |
|---|---|---|---|
| detect ERGS present | 2.5 | 40 | 147 |
| detect right lane required | 2.5 | 40 | 147 |
| detect need to change lanes | 1.9 | 40 | 112 |
| detect aft car | 5.5 | 40 | 323 |
| detect cars in right lane | 5.5 | 40 | 323 |
| wait for acceptable gap-initial acceleration | 1.63 | 35 | 84 |
| wait for acceptable gap-waiting speed | 25.5 | 30 | 1125 |
| change lanes | 4.5 | 30 | 198 |
| Total | | | 2459 |

Table 3. Information lead time and distance required for worst case-worst driver speed-change maneuver

| Function | Time (s) | Average Speed (mi/hr) | Distance (ft) |
|---|---|---|---|
| turn right guidance | 1.9 | 30 | 84 |
| red light ahead | 3.8 | 30 | 168 |
| rule out prior path(s) | 1.9 | 30 | 84 |
| slow down and stop | 4.9 | 15 | 147 |
| Total | | | 483 |

**What Level of Traffic Should Be Examined?**

The level of congestion could affect when messages should be presented. Typically, as congestion increases, speeds decrease, indicating that speed and congestion are linked. It is possible that in dense traffic, messages need to be presented sooner to provide the additional time required for maneuvering. This could be offset by the additional time available due to reduced speeds when congestion is present.

One consequence of performing driving experiments in traffic is that the risk to participants increases, suggesting testing should take place only in conditions of low to moderate traffic. The counterargument is that auditory navigation can make driving safer by reducing eyes-off-the-road time and will be of greatest benefit in heavy traffic; therefore, those are the conditions under which the system should be examined. For this initial effort, uncongested conditions are an appropriate starting point, with the investigation of congested situations being postponed until the risks to drivers are better understood. As a practical matter, the periods of local congestion are relatively brief, so the calendar time required to explore driving in congestion will be longer than for uncongested conditions.

## What Environmental Conditions Should Be Examined?

Poor weather conditions (rain, snow, fog, etc.) reduce the distance at which signs can be read and decrease the surface coefficient of friction, increasing stopping distance. Drivers compensate for this by driving more slowly. Darkness reduces the distance at which signs can be read and intersections identified, making auditory cues more useful. Again, drivers may compensate by slowing down. Thus, the effect of diminished visibility has a generally uncertain effect on preferences of auditory guidance message time. Unlike signs, traffic lights can be spotted more readily at night because of increased contrast. This could cause drivers to want auditory guidance at a greater distance from intersections. However, altering the timing for messages only for traffic lights, and only at night creates a driver interface which is inconsistent, and that inconsistency, potentially, could be detrimental to navigation performance. Because ambient lighting (day versus night) is such an important factor, its affects should be at least explored in pilot studies. Since weather cannot be controlled and its affects are uncertain, only good weather conditions were examined in this initial effort. Further, it is difficult to have equivalent levels of bad weather (e.g., the same rate of rainfall over several weeks).

## Who Should Serve As Subjects?

Clearly, participants should be drivers. While this experiment concerns auditory guidance, decisions are made in conjunction with visual information (highway signs and traffic lights), and hence driver vision is important. To get a sense of the range of variation, it is important to consider the extremes of the population, that is both young and mature drivers. For navigation products, the likely market would be those with the most disposable income, middle-aged drivers, should be included in the sample. As is described later, it was for these reasons that three age groups were explored in this experiment.

The differences due to gender are unknown, but since gender is an important driver descriptor, it should be included as a factor in selecting participants. Therefore, both men and women participated in the experiment described in this report.

Currently, there are no products on the U.S. market, so experienced users do not exist. Further, the initial application of these products will be in rental cars, so the time available for learning is short (as was the case in the experiment described later).

## How Might Message Timing Be Determined Experimentally?

### How should drivers indicate when messages should be presented?

Preferences for voice guidance timing could be obtained by presenting voice guidance only when requested (verbally or by pressing a button) and recording where or when requests occurred. An alternative is to present guidance at a variety of times and to have the drivers identify (for example, from ratings), the appropriateness of the timing. It was uncertain which approach was superior, so both were utilized in this research.

What should the response criterion be?

Also important to consider is the basis used by the driver to determine what is desired (earliest possible time, earliest time acceptable/comfortable, optimal time, latest time acceptable/comfortable, latest possible time). The latest time comfortable criterion was chosen to provide for greater acceptability in a situation not examined, closely spaced streets (often found in urban areas). (For the test course explored, streets were often 0.1 or more miles apart.) It seems reasonable that the final turn message should be presented when the next street available for a turn is the desired street. Knowing how late that can be is useful for handling situations of closely spaced streets.

What is unknown to the driver?

If a driver knows exactly when and where to turn, then presenting the final auditory message is of reduced use to the driver. Hence, in experimental evaluations some element of the turn should be uncertain (direction of turn or intended intersection) and should be clarified by the message of interest. Both situations are explored.

How should the driver respond?

Drivers could either indicate when they wanted a message by pressing a button or by saying something (e.g., "now," "is this it"). The manual response provides for cleaner timing since a computerized voice recognition system requires completion of the utterance and significant processing time thereafter before it can respond. However, a voice-based response minimizes interference with the primary visual-motor task of driving.

To minimize timing problems, a well-trained experimenter served as the voice recognition unit. Response delays were minimized by keeping verbal responses brief. Where messages were presented to drivers at their request and then presented on subsequent trials at different times based on driver input, it was easier to process verbal responses (too soon, a little/lot too soon, okay, a little/lot too late, too late) than use an array of buttons.

**Issues to Be Investigated**

Based on considerations of the literature and driver behavior, the following issues were selected to be explored in this research program.

1. What is the mean and distribution of distances to signalized intersections for which auditory "at turn" messages should be provided?

2. How does the distance vary with the method used to ask the question (drivers say when the want it, messages presented and drivers say how soon or late it was)?

3. How do driver preferences vary with their age?

4. Are there preference differences with gender?

5. Does the time of day or day/night differences affect preferences?

6. Do readily observed characteristics of traffic or intersection geometry affect preferences?

7. At traffic lights, does the color of the light (green, yellow, red) at the time decisions are made affect preferences?

## TEST PLAN

### Method Overview

Subjects participated in a two-part study focused on the timing of the "at turn" message given by an auditory route-guidance system. During the first part of the experiment, subjects were given turn instructions one to two miles in advance of the intended intersection by the simulated auditory route-guidance system using a female voice. ("In approximately two miles, turn right at the traffic signal.") The street name was not included, as would be the case if it was forgotten by the driver or the street signs are not legible. Ideally, well-timed auditory messages alone should be adequate to safely guide drivers to destinations.

Subjects were instructed to drive until they believed that they had reached the intended intersection and ask if it was the correct intersection, by saying "Is this it?." Both odometers (trip and total mileage), as well as the digital clock in the car were covered for the duration of the experiment, so the subject could not guess the intersection based on the mileage or time. Drivers complied with the experimenter-triggered, simulated, guidance system response ("Yes, turn <direction> at the traffic signal." or "No, continue through the traffic signal, when it is safe to do so."). The test route included portions of Ann Arbor and Ypsilanti, Michigan.

The second portion of the experiment involved two different intersections in Ann Arbor with different approach speeds. In this case, the intended intersection was known, but subjects did not know which way they would turn at that intersection. Upon approaching the intersection, drivers were told the turn direction. Once they reached the intersection, drivers classified the message timing (too late, too soon, or OK). On successive trials, the timing was adjusted, based on driver responses.

### Pilot Study

A small pilot study was performed to test the subject instructions and procedure and to study the effects of time of day on the subjects' responses. The pilot study involved 9 subjects, (8 men and 1 woman). Six of the men were in the young age group (18-30 years), one was in the middle age group (40-55 years), and one was in the mature age group (65-80 years). The woman was in the mature age group. Pilot subjects drove the test route, using the same methods as employed in the main experiment (described in the sections that follow and summarized above). The data from four of the men (3 young, 1 middle-aged) were used to determine if the time of day was a significant factor. All four of the men drove the same route, during the day and in the evening. Drivers requested the messages, on average, 349 ft from the intersection for the evening and 332 ft during the daytime. (Daytime refers to times between 9:00 a.m. and 4:30 p.m.; evening refers to the period between 9:00 p.m. and 11:30 p.m.) A sample mean t-test by speed revealed that there was no significant difference between the responses given during the day and those given at night ($p= 0.37$ for a two-tailed test). Elimination of time of day effects vastly simplified the execution of this experiment.

## Test Participants

A total of 48 licensed drivers participated in the experiment. They were either friends of the experimenters, recruited from a list of participants from previous studies, or individuals who worked at UMTRI (but not in the Human Factors Division). Most of the previous studies were unrelated to navigation. Sixteen subjects were selected from three age groups: young (18-30 years), middle-aged (40-55 years), and mature (65-80 years). The mean age in each group was 22, 46, and 72 years, respectively. Each age group contained an equal number of men and women. Their corrected visual acuities ranged from 20/13 to 20/70.

Participants reported that they drove between 1,000 and 40,000 mi per year (mean = 13,000). The annual mileage tended to less for the mature drivers and young drivers. Subjects were also asked to rate their familiarity with driving in the city of Ann Arbor on a scale from 1 to 4 (1 = Not at all familiar, 2 = Slightly familiar, 3 = Moderately familiar, and 4 = Very familiar). The mean subject response was slightly to moderately familiar.

## Test Materials and Equipment

The study was conducted on the road in a left-hand drive 1991 Ford Taurus station wagon with an automatic transmission. As the subjects drove the car, they were given auditory route-guidance instructions. The instructions were recorded and played back using a HyperCard program running on a Macintosh Power Book connected to a MAC Direct external hard drive and a Macintosh number Power Pad. The number pad had a message associated with numbers 0 through 9 and the " / " key. A drawing of the pad and the messages for each of the keys are shown in Figure 1 and Table 5. The guidance instructions were played using an amplifier and speaker mounted directly behind the front seat on the floor of the car.

All distances were determined by counting pulses from the vehicle speed signal sensor (four pulses per tire rotation, approximately 7990 pulses per mile). The number of pulses was recorded using a custom-made counter. The counter was manually controlled by the experimenter, and the output was recorded on a data sheet by the experimenter. The counter box had start, stop, and clear buttons and an LED display for the number of wheel pulses counted. A complete layout of the equipment arrangement inside of the car, including equipment model numbers is shown in Figure 2.

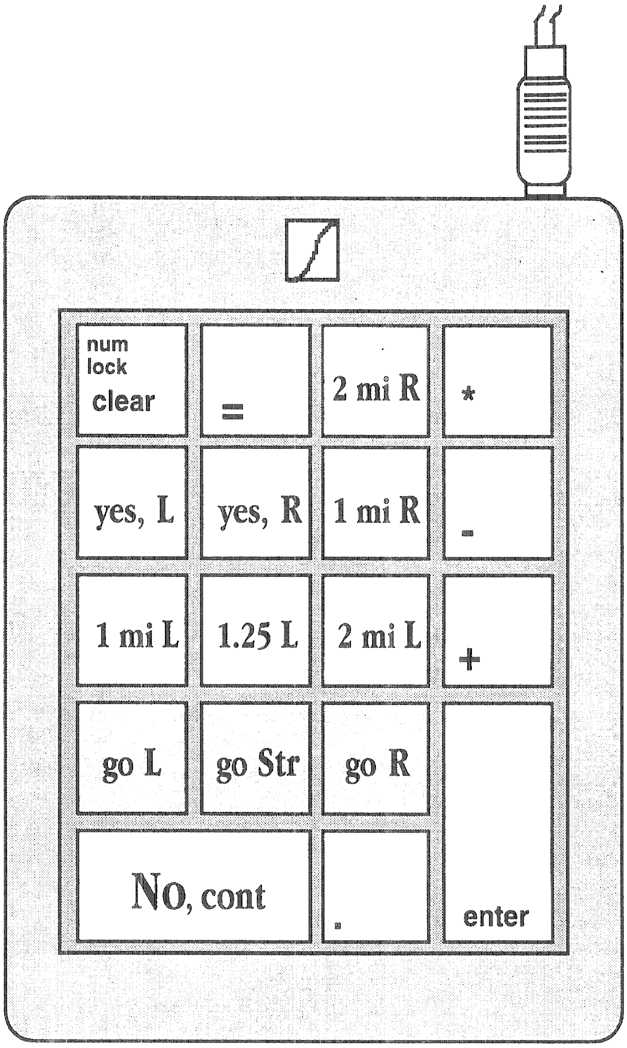



Figure 1. Number pad with associated messages.

Table 5. Messages associated with number pad abbreviations.

| Abbreviation on keypad | Associated message |
|---|---|
| 2 mi R | "In approximately 2 miles, turn right at the traffic signal." |
| yes, L | "Yes, go left at the traffic signal when it is safe to do so." |
| yes, R | "Yes, go right at the traffic signal when it is safe to do so." |
| 1 mi R | "In approximately 1 mile, turn right at the traffic signal." |
| 1 mi L | "In approximately 1 mile, turn left at the traffic signal." |
| 1.25 L | "In approximately 1 and a quarter miles, turn left at the traffic signal." |
| 2 mi L | "In approximately 2 miles, turn right at the traffic signal. |
| go L | "Go left." |
| go Str | "Go straight." |
| go R | "Go right." |
| No, cont | "No, continue through the traffic signal when it is safe to do so." |

*****Does the t in "No,cont "show up in drawing?***

## Test Route

The test route used for part 1 of the study, the route-following task, is shown in Figure 3. For clarity, a detailed insert of target intersection 4 is shown in Figure 4. The route contained a variety of nonurban business and residential main roads. The first part of the experiment began by turning left from Hogback Road, in Ann Arbor, onto Washtenaw Rd. towards Ypsilanti. The experiment ended at the intersection of Stadium and Packard Road, in Ann Arbor. There were two intersections used for the second part of the experiment: Ellsworth Road and Platt Road, in Pittsfield Township and Scio Church and Seventh Street, in Ann Arbor (The test route for part 2 is shown in Figure 5.). The first part of the experiment took approximately 25 to 35 minutes to complete, while the time for part 2 was between 1 and 1-3/4 hours. The specific (turn-by-turn) guidance instructions are given in the next section.

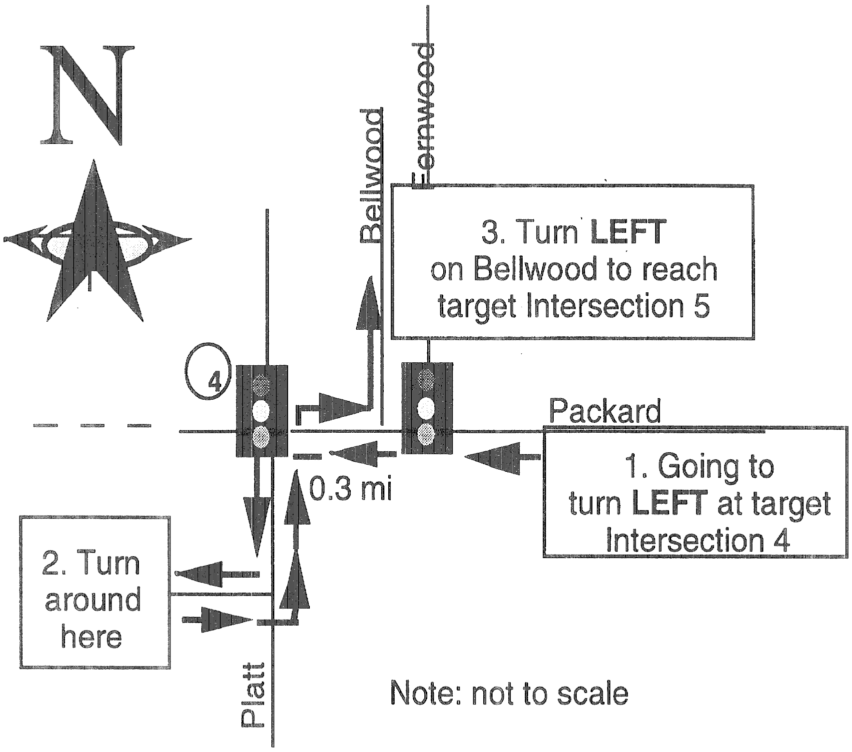



Figure 4. Insert to test route for part 1.

## Test Activities and Their Sequence

The experimenter met the subjects at UMTRI, where the introductions and paperwork were completed. Participants were told that the experiment would take approximately 2-1/2 hours and that they would be paid $25 for their time. (A copy of the instructions is found in Appendix C.) Subjects completed a biographical form and a consent form and then had their visual acuity measured using a Titmus Vision Tester. (A copy of both forms is found in Appendix B.) As they walked to the test vehicle, the experimenter gave the subject an overview of the two parts of the experiment.

While the subject adjusted the vehicle mirrors, seat, and temperature controls, the experimenter, seated on the passenger's side of the back seat, initialized the test equipment in the back seat of the car.

Subjects were told they would be driving for approximately 7 to 10 minutes before reaching the starting point for part 1 of the experiment. They were told to drive steadily at the posted speed and that all intersections of interest had traffic signals. (For exact wording of instructions, see Appendix C.)

Data was collected using the Wizard of Oz method in which a person (here, supported by a computer) simulated the behavior of a fully computerized system (Green and Wei-Haas, 1985). During the first part of the experiment, subjects heard messages from the simulated auditory route-guidance system (e.g., "In approximately 1 mile, turn right at the traffic signal,") for five different target intersections. The five messages, the intersections where the messages were given, and the intersections where the subject was to turn (target intersections) are given in Table 6. (Refer to Figures 4 and 5 for locations and distances.) (The first target intersection was used as a practice intersection.)

Table 6. Auditory route-guidance messages given during part 1 of the experiment.

| Intersection where message was given (street on/at) | Prepatory auditory route-guidance message | Destination Intersection (turn from/to) |
|---|---|---|
| Hogback/Washtenaw | "In approximately 1 mile, turn right at the traffic signal." | Washtenaw/Golfside |
| Golfside/Packard | "In approximately 1 mile, turn left at the traffic signal." | Packard/Mansfield |
| Mansfield/Washtenaw | "In approximately 1 and a quarter miles, turn left at the traffic signal." | Washtenaw/Golfside |
| Golfside/ Packard | "In approximately 2 miles, turn left at the traffic signal." | Packard/Platt |
| Pittsfield/Washtenaw | "In approximately 2 miles, turn right at the traffic signal." | Stadium/Packard |

After hearing the message, subjects continued driving what they perceived to be the specified distance, making any lane changes that were necessary during that time. (The odometer was covered, so the driver did not know the exact distance traveled.)

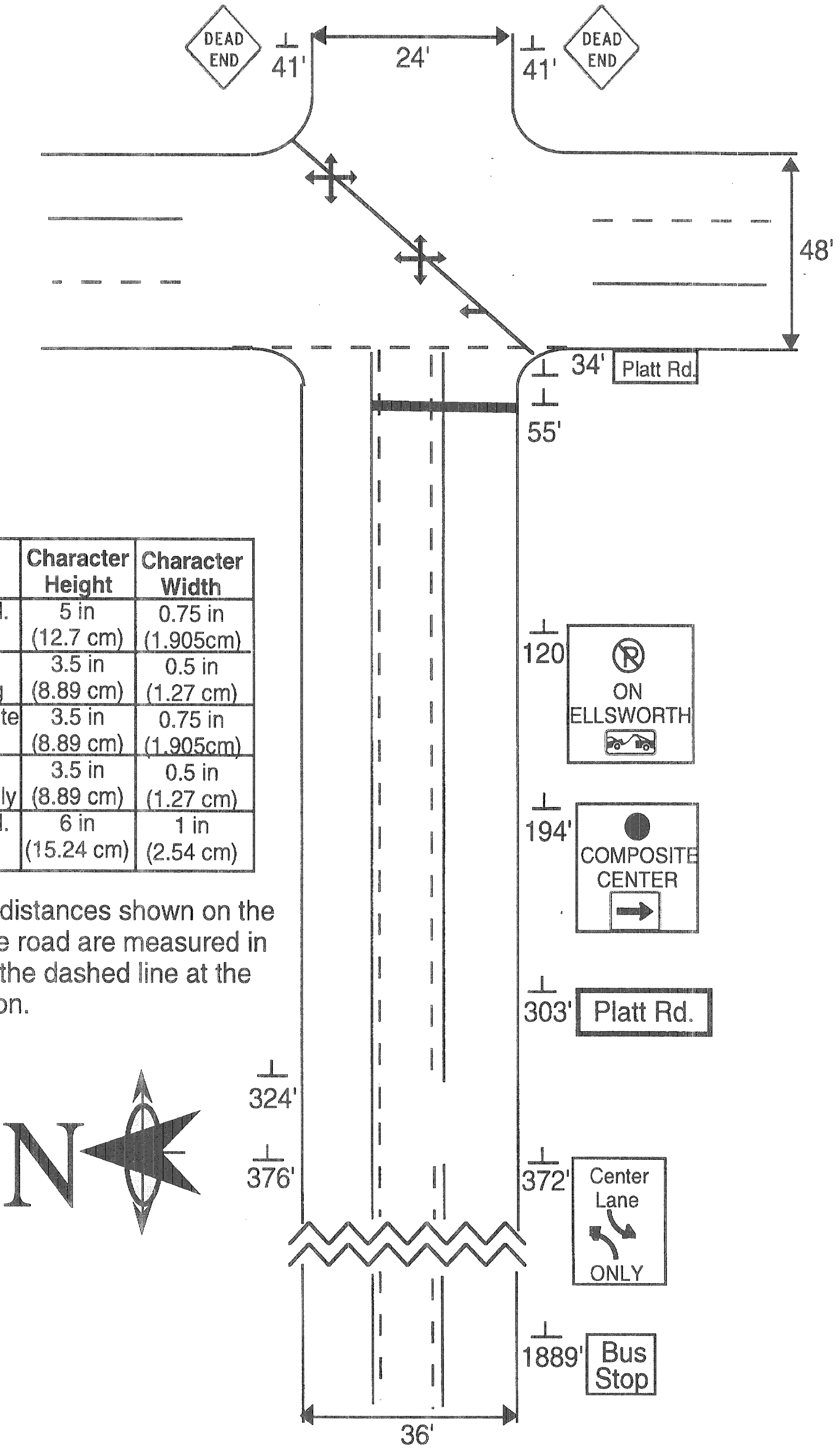
Before each target intersection, there were one to five preceding signalized intersections that the drivers might expect to be the target. When drivers believed they were approaching a target intersection, they asked the experimenter, "Is this it?" at the latest moment they felt comfortable hearing a confirming auditory instruction ("Yes, go left/right at the traffic signal, when it is safe to do so.") that would allow for a safe turn. The latest moment comfortable was defined as: the last moment that subjects felt comfortable finding out if they had reached the target intersection, while still feeling they could execute the turn safely and comfortably. It was emphasized throughout the experiment that the latest time comfortable was desired, not the time the subject wanted to or preferred to hear the message. Subjects were given an example to illustrate the difference between the two times.

In response to "Is this it?" queries, the experimenter immediately pressed the start button on the custom-made counter and one of three buttons to play the appropriate route-guidance voice message. See Table 7 for those messages. Based on the message, the subject either continued through the intersection or turned at the intersection. The counter was stopped by a second button press from the experimenter when the test vehicle reached the stop line marked on the pavement for that intersection. (The distance from the stopping line and the curb of the cross street varied between intersections. A table of those distances appears in Appendix F.)

Table 7. Verification scenarios.

| Scenario | Guidance system response | Action taken by subject |
|---|---|---|
| Subject asks at an intermediate intersection before the target intersection. | "No, continue through the traffic signal, when it is safe to do so." | Subject continues straight through intersection until reaches next intersection believed to be the target. |
| Subjects asks at the target intersection | "Yes, go left/right at the traffic signal, when it is safe to do so." | Subject turns at the target intersection. |
| Subject drives too far and misses the target intersection. | Experimenter asks subject to turn around at a convenient location. Missed intersection counted as an error in data. | Subject follows experimenter's instructions. |

After turning at a target intersection, the driver received spoken directions from the experimenter to reach to the beginning of the next trial. Upon turning at all five destination intersections of part 1, the subject pulled into a nearby parking lot and received instructions for part 2 of the experiment. Drivers were told that they would perform the same basic tasks at two separate intersections. The first intersection was located at Ellsworth and Platt in Pittsfield Township. Drivers always approached the intersection at Platt by driving east on Ellsworth. They were also instructed to drive toward the intersection while keeping their speed as close as possible to the posted speed limit, 45 mi/h. A sketch of the intersection is given in Figure 6. (Actual photographs and drawings of the target intersections are located in Appendices D and E.)




| Sign Name | Character Height | Character Width |
|---|---|---|
| Platt Rd. (20') | 5 in (12.7 cm) | 0.75 in (1.905cm) |
| No Parking | 3.5 in (8.89 cm) | 0.5 in (1.27 cm) |
| Composite Center | 3.5 in (8.89 cm) | 0.75 in (1.905cm) |
| Center Lane Only | 3.5 in (8.89 cm) | 0.5 in (1.27 cm) |
| Platt Rd. (303') | 6 in (15.24 cm) | 1 in (2.54 cm) |

Note: all distances shown on the side of the road are measured in feet from the dashed line at the intersection.

Figure 6. Platt and Ellsworth intersection.

Figure 7 shows the sequence of activities for each trial for part 2. Each time the test intersection was approached, the experimenter started the counter when the vehicle passed a pre-selected, fixed landmark on the side of the road 0.2 to 0.35 mi from the intersection. As the vehicle neared the intersection, drivers said "Now" at the latest moment they felt comfortable finding out the direction they were going to turn at that intersection. (The words "latest," "comfortable," and "safety" were emphasized throughout part 2.) In response, the experimenter simultaneously pressed the "stop" button on the counter and a key on the number pad to play the predetermined turn instruction from the auditory route-guidance system ("Go right," "Go straight," or "Go left."). Except when comfort or safety were compromised, drivers completed the maneuver at the traffic signal. Once drivers completed a turn at the intersection, they drove around the block and approached the same intersection again from the same direction. Drivers were told that they would approach each intersection a minimum of five times. The first two approaches to each intersection were for familiarization purposes.

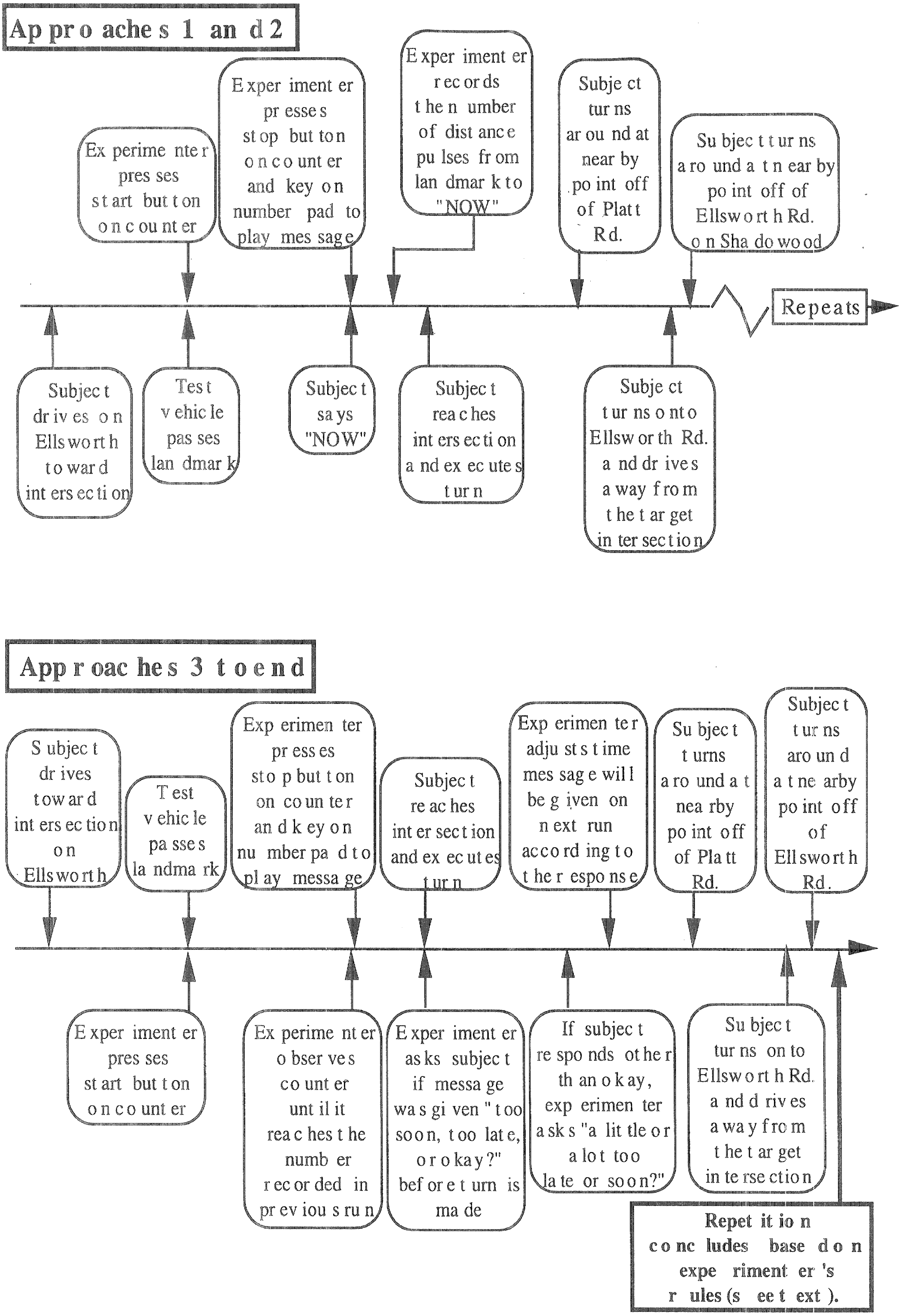



Figure 7. Flow chart for the sequence of events for part 2.

For all subsequent approaches, drivers waited for the turn direction to be given by the auditory route-guidance system. For the third approach, the experimenter pressed a key on the number pad to present an auditory turn instruction at the same distance (as indicated by the counter) as requested in the previous approach. As the driver reached the intersection, the experimenter asked, "Based on the latest moment you'd feel comfortable hearing the turn direction, was that message given too late, too soon, or OK?" If the driver answered "too late or too soon," the experimenter asked: "Was the message given a little or a lot too late/soon?" Based on the answers, the experimenter adjusted the distance at which the message was given on the next approach, presenting a message at the same distance, or changing the time by one or two sec. If the driver answered "OK" on the third approach, the distance used for the fourth approach was half the distance to the intersection on the third approach. This was in response to agreeable subjects who would answer "OK" to any distance at which the message was given. Most of the subjects who answered "OK" on approach 3 ended the experiment with distances closer to the intersection than they originally accepted. The complete rules for this staircase method are shown in Table 8.

Table 8. Distance adjustments for part 2 of the experiment.

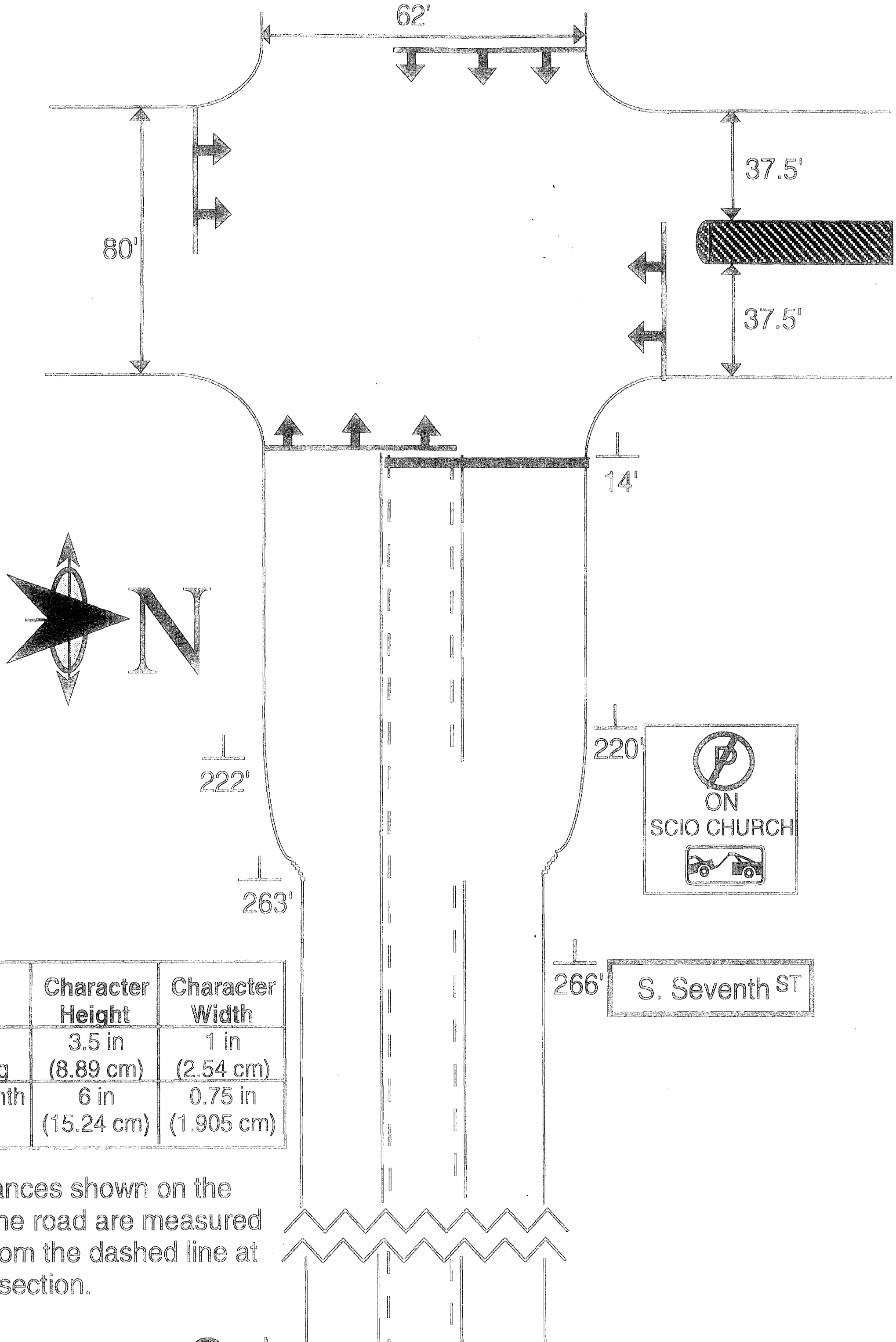
| Answer Combination | Distance Adjustment |
|---|---|
| OK | Message was given at same distance from intersection as previous approach. If this response occurred for the third approach, the distance at which the message was given on the fourth approach was half of the distance on the third. |
| Too late/little | Message was given the equivalent of 1 second sooner on the next approach. |
| Too late/lot | Message was given the equivalent of 2 sec sooner on the next approach. |
| Too soon/little | Message was given the equivalent of 1 second later on the next approach. |
| Too soon/lot | Message was given the equivalent of 2 sec later on the next approach. |

Normally, each intersection was repeatedly approached until the driver said "OK" to the same distance on two consecutive approaches. To prevent sessions from continuing indefinitely, or to handle situations where the response was apparent, other stopping rules were also established. (See Table 9.) The situations listed in Table 7 explain why the experiment was concluded with only one OK, as opposed to two consecutive, for the final approaches.

Table 9. Stopping rules.

| Answer combination on last approach for stopping the experiment | Criterion |
|---|---|
| OK | a previous response of OK was the same or +/- 13 pulses (8.4 ft) of the current response |
| OK | more than 8 approaches completed (two consecutive OKs not required) |
| a little too late (or soon) | the alternative sequence of too late/too soon for 2 successive approaches. The minimum change of 1 second was too large in a few cases. The distance used was halfway between the two alternatives. |
| a little too late (or soon) | the opposite answer was given on previous trial (e.g., a little too soon now, a little too late before), where one of the two distances was identified as "OK" previously |
| a lot too late (or soon) | the opposite answer given on previous trial (e.g., a lot too soon now, a lot too late before), end if distance 1 second between the two was called "OK" earlier |

Once this process was completed at the intersection of Ellsworth and Platt, drivers were directed by the experimenter to the second intersection of part 2, Scio Church and Seventh Street, approaching from the east. A drawing of the intersection is shown in Figure 8. The same process was repeated. Subsequently, participants drove back to UMTRI where they completed payment forms, were paid, and were thanked for their time.




| Sign Name | Character Height | Character Width |
|---|---|---|
| No Parking | 3.5 in (8.89 cm) | 1 in (2.54 cm) |
| S. Seventh St. | 6 in (15.24 cm) | 0.75 in (1.905 cm) |

*All distances shown on the side of the road are measured in feet from the dashed line at the intersection.

Figure 8. Scio Church and Seventh St. intersection.

# RESULTS

The data from the two conditions (route-following, repeated-approach) have been analyzed separately. Within each subsection, an overview of the means and differences between intersections, and factors that cause differences in the distances desired were considered separately.

## Part 1, Route-Following Condition

Prior to analysis of this data, the results associated with the practice intersection sequence (Washtenaw and Blockbuster Video, Washtenaw and Golfside) were discarded. Data from the intersections at Washtenaw and Sheridan and Stadium and Washtenaw were also not included in the main analysis. The two intersections coincided with a fork in the road, and some subjects asked "Is this it?" prematurely to clarify which direction they were to continue driving, even though they knew that they had not reached the destination intersection.

1. What is the mean and distribution of distances to signalized intersections for which auditory "at turn" messages should be provided?

With the practice and two unusual intersections removed, 321 responses remained in the data set. For those remaining data, the mean distance at which a message was desired was 450 ft (137 m) with a standard deviation of 261 ft (80 m). The mean approach speed was 38 mi/h. Distances ranged from 29 to 1813 ft (9 to 553 m). The very small distances represent two situations -- (1) the driver was almost in the intersection and was looking for a last moment confirmation and (2) the intersection light was red at approach and the driver stopped near the intersection before asking. Figure 9 shows the distribution of distances, which appears to be log normal.

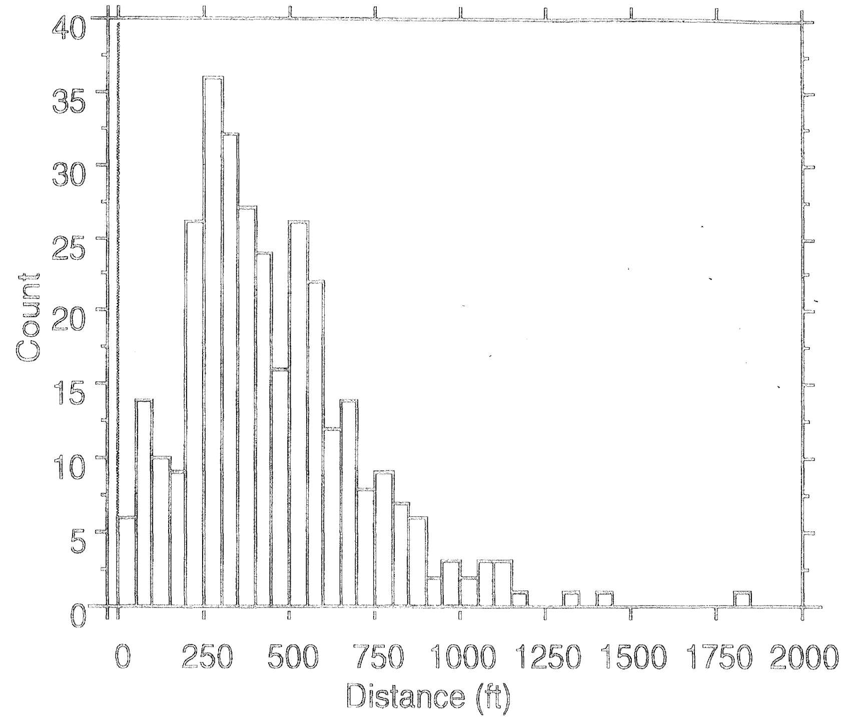



Figure 9. Distribution of distances for the route-following task.

Table 10 shows the mean and standard deviation of the distances for each intersection (including those which were not included in the main analysis), along with the number of responses. Again the number of responses per intersection differs, because drivers did not always request information while approaching each intersection. Differences among all test intersections were statistically significant ($F(11,309)=4.15$, $p<0.0001$). For six of the intersections, there were less than five responses, including two cases of only one response each. For intersections for which there were few responses, little faith should be given to the mean distances. Notice that distances by intersection vary quite widely, ranging from 285 ft (87 m) to 659 ft (201 m). While some of the differences are due to approach speed, there may be other reasons for between intersection differences.

Table 10. Distance statistics for each intersection in the route-following task.

| Intersection | | | | Mean | S.D. | Num | Min. | Max. |
|---|---|---|---|---|---|---|---|---|
| # | Name | Destination Intersection | Type | (ft) | (ft) | n | (ft) | (ft) |
| 1 | Washtenaw/ Blockbuster Video | Washtenaw/ Golfside | practice | 475 | 224 | 24 | 155 | 983 |
| 2 | Washtenaw/ Golfside | | | 420 | 266 | 46 | 35 | 1078 |
| 3 | Packard/Hewitt | Packard/ Mansfield | test | 557 | 206 | 30 | 219 | 1069 |
| 4 | Packard/ Mansfield | | | 430 | 254 | 47 | 29 | 1332 |
| 5 | Washtenaw/ Hewitt | Washtenaw/ Golfside | | 559 | 67 | 5 | 471 | 634 |
| 6 | Washtenaw/ Builders Square | | | 537 | 132 | 12 | 261 | 743 |
| 7 | Washtenaw/ Golfside | | | 441 | 188 | 42 | 209 | 892 |
| 8 | Packard/ Dalton | Packard/ Platt | | 534 | | 1 | 534 | 534 |
| 9 | Packard/ Carpenter | | | 659 | 292 | 14 | 311 | 1175 |
| 10 | Packard/ Fernwood | | | 394 | 226 | 26 | 50 | 1019 |
| 11 | Packard/ Platt | | | 534 | 268 | 45 | 196 | 1141 |
| 12 | Washtenaw/ Huron Parkway | Stadium/ Packard | | | | 0 | | |
| 13 | Washtenaw/ Sheridan | | test (drop) | 479 | 159 | 11 | 257 | 820 |
| 14 | Stadium/ Washtenaw | | | 356 | 120 | 11 | 182 | 500 |
| 15 | Stadium/ St. Francis | | test | 286 | 107 | 12 | 126 | 434 |
| 16 | Stadium/ Brockman | | | 302 | 127 | 42 | 41 | 588 |
| 17 | Stadium/ Packard | | | 438 | 390 | 45 | 34 | 1813 |

It was quite common for drivers in this experiment to request turn information ("Is this it?") at intersections prior to the target intersection (30, 12, 26, and 42 of the 48 drivers for each of the four intersections). This suggests that for some drivers, a message indicating they are nearing a planned turn may be desired.

In Figure 10, the y-axis shows the distance from the intersection at which information was requested. The x-axis shows the intersection sequence number and the location of the intersections with respect to one another and to the beginning of the route-following experiment. (The origin of the x-axis corresponds to the start of the part 1.) The last intersection of each sequence is the destination, at which the driver is to turn. There are no patterns evident. For example, nondestinations were not different from destinations, and distances did not increase or decrease as destination intersections were approached. In fact, for the purpose of this analysis, it does not matter if the street was one onto which a drivers was supposed to turn or not turn. In both cases, their response indicated how far in advance of a street a final turn message was desired. It should be noted that there were no requests made at the first intersection in sequence 4; therefore, only intersections 2 through 6 are shown in the figure. In examining this figure, recall that the geometry for intersections 2 and 3 of sequence 4 were quite different from that of other intersections in this experiment.

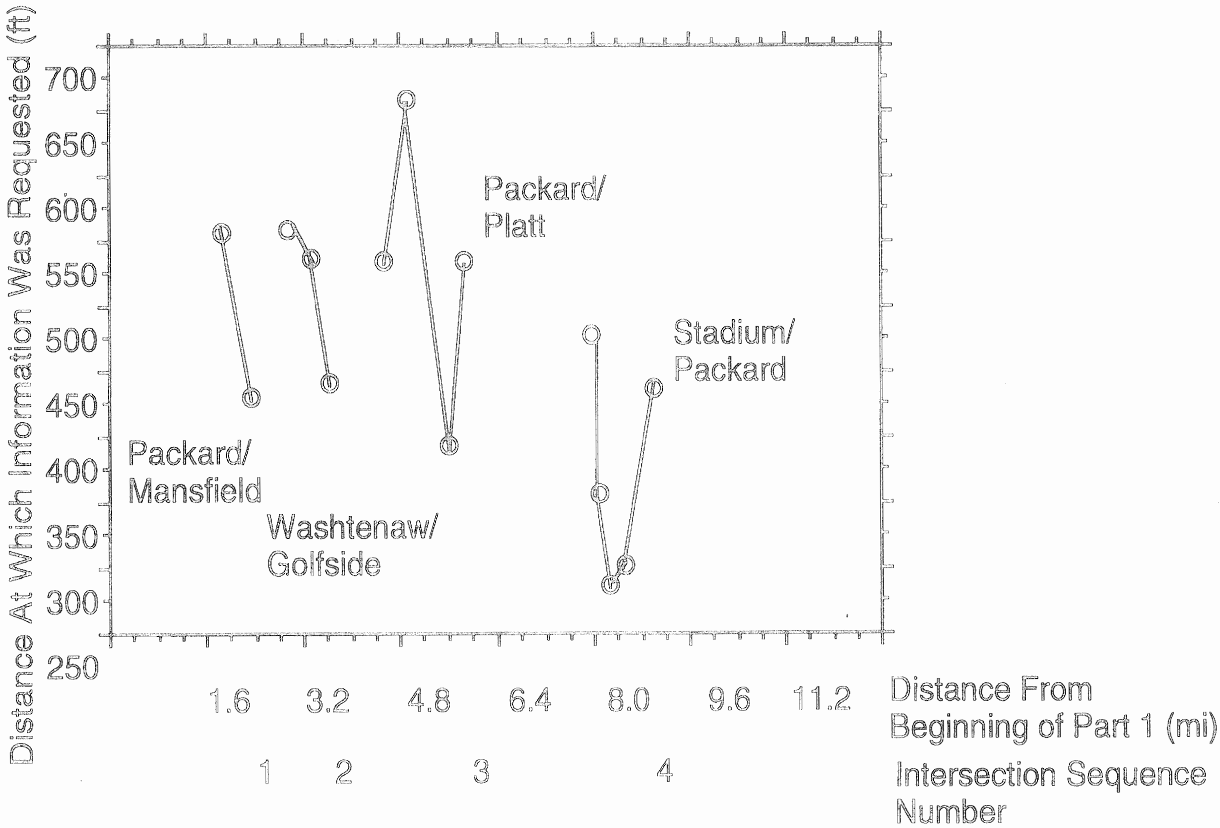



Figure 10. Distances for requests for test intersections.

2. How do driver differences, traffic, the state of traffic lights, and other factors affect the distances at which requests are made?

The approach followed was to examine factors of interest using a one-way ANOVA for each effect. Factors that were significant (along with interactions of factors) were then examined in a combined model. Factors of interest included:

- intersection differences (turn vs. nonturn, turn direction)
- approach speed
- state (color) of intersection signal (at approach, when message requested, at intersection)

- state of the left turn traffic signal
- number of cars ahead and in left turn lane
- time of day (morning, afternoon, evening)
- driver differences (age group (young, middle, mature), sex)

To examine differences other than those due to intersections, an Analysis of Variance (ANOVA) was used. As a first step, a one-way ANOVA was computed to examine the effect of the state of the left turn light. It was not significant ($F(1,132)=0.23$, $p=0.63$) and thus was not included in the main analysis. Adding the state of the left turn light (collected for only left turns) to the model substantially reduced the data set size by eliminating right-turn data. The light state was correlated with the number of cars in the left-turn lane, which remained in the analysis.

Also excluded from the main analysis were between-intersection differences. When included in the main analysis, between intersection differences were significant (here $F(10,184)=1.97$, $p=0.03$). However, including them in the model made it impossible to examine turn direction effects, because each intersection was either a right turn or a left turn. While between-intersection differences could have been treated as a nested effect, the varying cell sizes and unbalanced design (resulting from the naturalistic data collection method) made such an analysis extremely unwieldy, so it was not pursued.

Interaction effects were also excluded from the main analysis. (In fact, subsequent analysis of only statistically significant main effects showed that there were no significant pairwise interactions.)

Table 11 shows the results of the initial step of the analysis after the preliminary steps just described. Notice that none of the factors associated with the state of traffic lights were statistically significant. However, there were slight differences with drivers wanting greater warning distances for approaches when the traffic light at the intersection was red than for approaches when it was green. The state of the light was recorded at three different occasions during the experiment: the approach, when the message was requested, and when the vehicle was at the light. The mean distance across subjects was calculated for the three instances. In each case, the distance when the light was red was greater than when the state of the light was green (509 vs. 428 ft for the approach, 502 versus 433 ft when the message was requested, 477 versus 440 when the vehicle reached the light). This was not due to a difference in speeds, as participants tended to be driving more quickly when the light was green than red. Also not statistically significant were time of day differences (morning: 489 ft, afternoon: 474 ft, early evening: 353 ft). The slight time-of-day differences probably reflect differences in the driver samples. Relatively more young and middle-aged drivers participated in the early evening sessions, and they tended to prefer shorter distances. Mean speeds as a function of time of day differed by a fraction of a mile per hour, too little to matter. The failure of the number of cars in the left lane to be significant is not surprising because all turns were considered, not just left turns.

Table 11. Initial ANOVA of route-following data.

| Factor | df | F-Value | P-Value |
|---|---|---|---|
| Turn Direction | 1 | 4.75 | .03 |
| State of Light When Approaching Intersection | 2 | 1.48 | .23 |
| State of Light When Message Requested | 2 | 0.27 | .76 |
| Stop at Light | 1 | 0.05 | .83 |
| Number of Vehicles Ahead | 1 | 4.74 | .03 |
| Number of Vehicles in Left Lane | 1 | 0.64 | .43 |
| Time of Day | 2 | 1.91 | .15 |
| Speed | 1 | 17.10 | .0001 |
| Age | 2 | 22.09 | .0001 |
| Sex | 1 | 13.63 | .0003 |
| Residual | 74 | | |

Subsequently, nonsignificant factors were eliminated stepwise (using $p<0.1$ as the cut), with each effect being pooled into the error term of the ANOVA. In some cases, reducing constraints on main effects increased the sample size. Table 12 shows the factors remaining in the analysis (age, sex, intended turn direction (left or right), speed driven (to the nearest 5 mi/h), and the number of cars ahead).

Table 12. Factors significant at $p<0.1$.

| Factor | df | F-Value | P-Value |
|---|---|---|---|
| Turn | 1 | 14.35 | .0002 |
| Number of Vehicles Ahead | 1 | 1.75 | .07 |
| Speed | 1 | 27.28 | .0001 |
| Age | 2 | 34.62 | .0001 |
| Sex | 1 | 22.71 | .0001 |
| Residual | 284 | | |

Figure 11 shows the combined effects of driver sex and age. On average, men wanted less advance warning than women (502 versus 393 ft), and older drivers wanted more distance than middle-aged or young drivers (597 versus 422 versus 339 ft). Within age and sex categories, there were major differences in driving style. Some drivers would rapidly approach an intersection and then request guidance, while others were extremely concerned they were going to miss a turn and asked much sooner. Readers interested in additional statistics on sex and age will find them in the appendix.

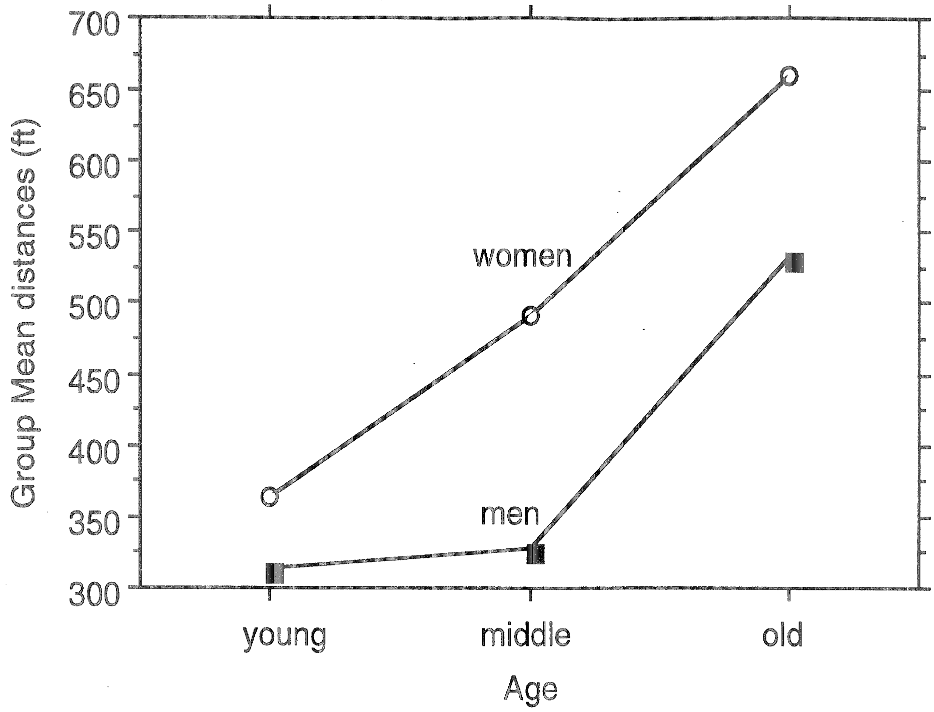



Figure 11. Effects of driver age and sex.

Also significant was the effect of turn direction, with drivers wanting more distance for left turns (486 ft) than rights (366 ft).

Figure 12 shows all the distance data as a function of the number of vehicles ahead. Figure 13 shows the trends using an expanded scale. Minimal faith should be placed on the distances for more than seven vehicles ahead, as those situations only occurred a maximum of three times each in this experiment.

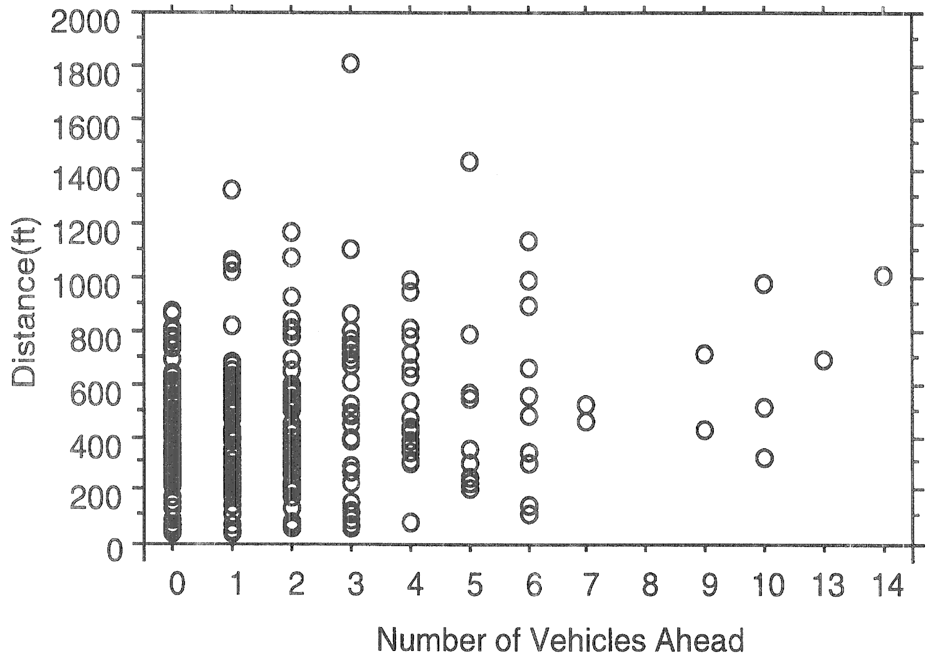


Figure 12. Number of vehicles ahead versus the desired distance.

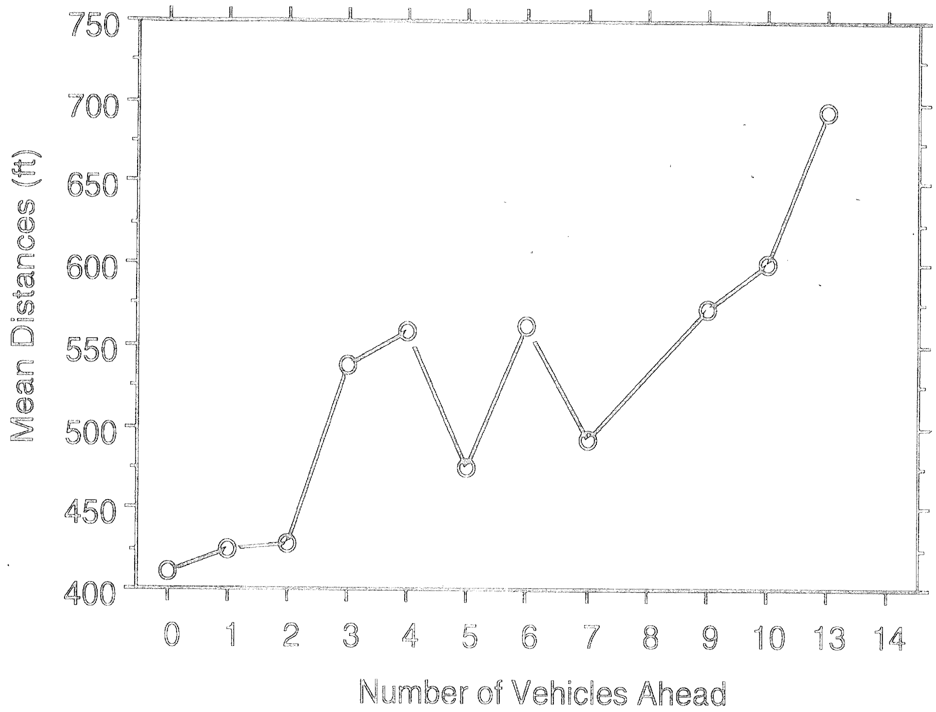



Figure 13. Mean number of vehicles ahead versus the desired distance.

Speed effects were quite pronounced, with drivers wanting more distance as speed increased. (See Figures 14 and 15 for the full data set and the trend line. Note that the y-axis values for Figure 15 cover a larger range of values those in Figure 14.) The departure from linearity at 20 mi/h represents only one response.

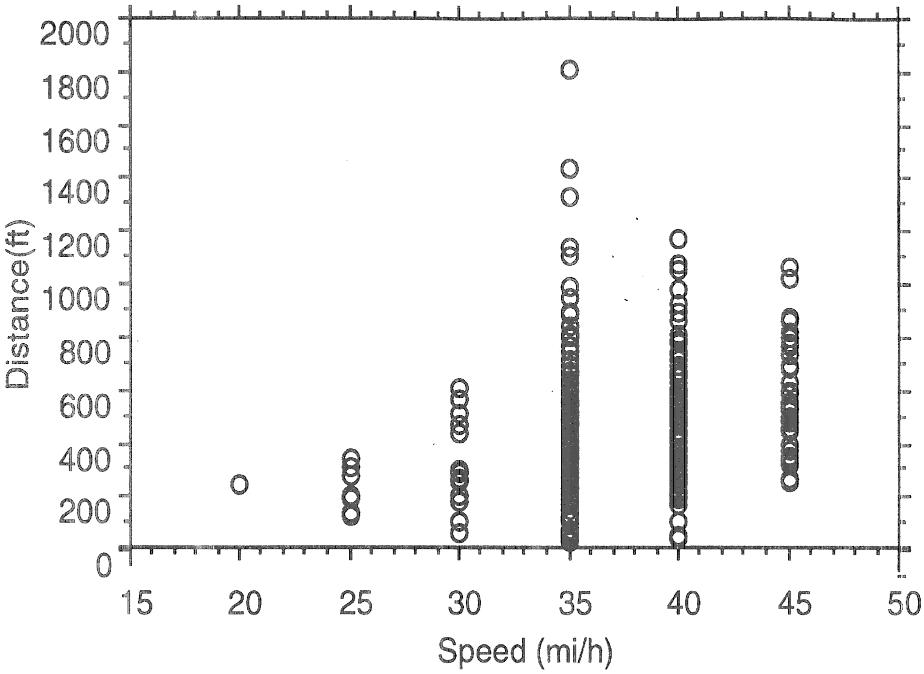



Figure 14. Speed versus the desired distance.

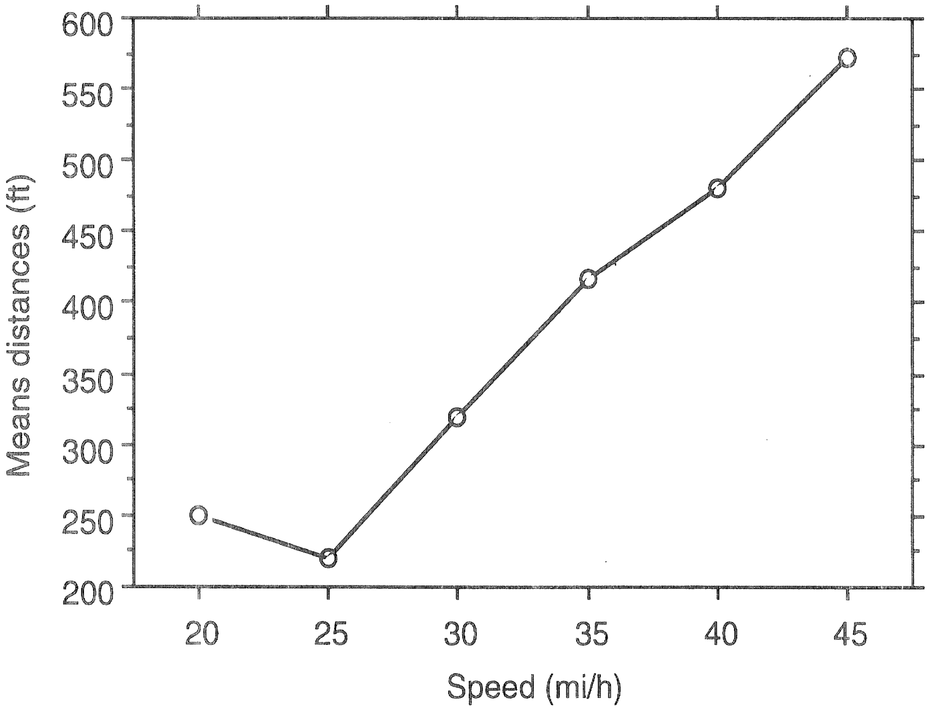



Figure 15. Mean speed versus the desired distance.

Using multiple linear regression, a prediction for the desired warning distance was developed. While other models might be appropriate, a linear model was chosen because most of the variables were binary or represented a limited number of categories (making higher order models difficult to test). Other variables, in particular speed, had a limited range. One notion (proposed in the Introduction) is that driver requests are based on allowing sufficient distance ahead so that they can brake comfortably and just stop at the intersection prior to a turn. The distance required depends on their current speed, their reaction time, and an acceptable g braking level. If there are vehicles ahead of them, then additional distance will be required (equal to the distance occupied by the vehicles ahead of them plus the intervehicle gaps).

The following expression accounts for 34 percent of the variance in the distance estimates, a moderately low amount.

$$\text{Distance (ft)} = -389 + 119\,(\text{Age.code}) - 113\,(\text{Sex.code}) + 95\,(\text{Turn.code}) + 15\,(\text{Speed}) + 21\,(\text{Number of Vehicles}).$$

where:

Age.code 1= young, 2 = middle-aged, 3= older
Sex.code 1= women, 2= men
Turn.code 1= right, 2= left
Speed (mi/h)
Number of Vehicles (vehicles ahead)

The speed coefficient is somewhat less than predicted by theory. As noted in the introduction, each mile per hour increase in speed is associated with an increase of almost 30 ft in stopping distance (assuming a deceleration of 0.1 g) For this g value, a relatively small increase in the absolute g level can lead to a large percentage change in stopping distance. Further, it may be that increasing speed is also associated with other increases (traffic, workload, etc.) for which additional processing time is needed. Better estimates of the effects of speed could come from an examination of a wider range of speeds.

If the driver is calculating how far in advance turn information is needed based on the space occupied by cars in front, the 21 ft per car is reasonable. A typical U.S. car in the area where the experiment took place is about 180 in long (15 ft) . (As a benchmark, a Honda Accord is approximately 184 in long. A Ford Taurus is about 194 in. Both are considered midsize to large cars.) If one looks at cars stopped at a traffic light in the area where the test was conducted, the gap is about 3 ft. Hence, the space required per car is approximately 18 ft (15 + 3). This is quite close to 21 ft from the regression expression based on the route-following data. Where trucks are a large part of the traffic mix, a larger coefficient is to be expected.

In some situations, data on the number of vehicles might not be available (from short range on board transmitters or video sensors at traffic lights). Assuming the number of cars is distributed as it was in this experiment, distance can be predicted as shown below. This expression accounts for 31 percent of the variance.

Distance (ft) = -306 + 125 (Age.code) - 118 (Sex.code) + 106 (Turn.code) +13 (Speed)

where codes are as above.

If data on only drivers and speed were available, then the prediction is:

Distance (ft) = -179 + 15 (Speed) + 127 (Age.code) - 116 (Sex.code).

This expression accounts for 27 percent of the variance. A plot of the residuals follows in Figure 16.

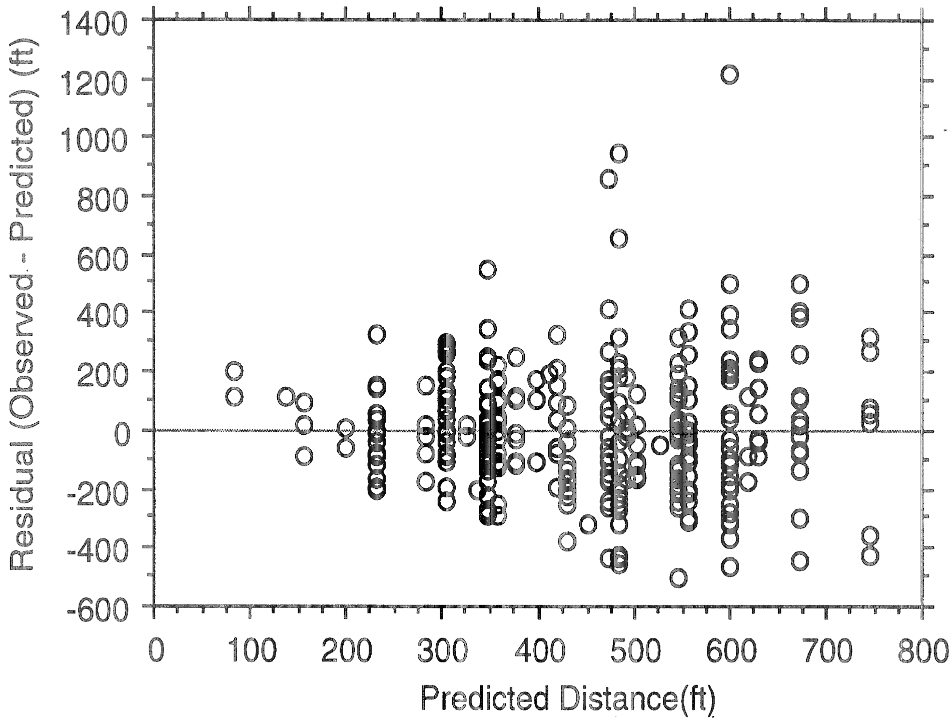



Figure 16. Residuals versus predicted distance for route-following task.

In the worst case, information on drivers might not be available (if, for example, settings were not provided for such in the navigation system preferences). In that case, assuming drivers match the age distribution here (equal number in the three age groups, an equal number of men and women), then the expression given below should be used. This expression accounts for only 10 percent of the variance. For real products, it might be preferred to estimate the distribution of drivers among the three age groups and two genders using target customer demographics, and utilize the four component models above to develop estimates.

Distance (ft) = -249 + 14 (Speed) + 109 (Turn.code)

An alternative approach to analyzing the data is to consider left and right turns separately, since only left turns should be affected by the state of the left turn light and the number of cars in the left turn lane. For left turns, with all variables of interest in the expression, 42 percent of the variance is accounted for by the following equation.

Distance (ft) = -103 - 134 (Sex.code) +126 (Age.code) +14 (Speed)
- 14 (Left.light.code) +11 (# Vehicles Ahead) +13 (# Vehicles in Left Turn Lane).

When a stepwise regression approach is used, only three variables appear in the equation, and the percentage of the variance accounted for is almost identical. The resulting equation is:

Distance (ft) = -137 (Sex.code) +137(Age.code) + 12 (Speed).

For right turns, the variance accounted for is 33 percent, and all variables remain in the equation when a stepwise analysis is performed, resulting in the expression given below. Notice that for the right-turn case, the coefficients for the number of cars ahead and speed are much larger than in the left-turn case.

Distance (ft) = -792 - 124 (Sex.code) +151 (Age.code)
+ 47 (# Vehicles Ahead) +26 (Speed)

**Part 2, Repeated-Approach Condition**

1. What is the mean and distribution of distances to signalized intersections for which auditory "at turn" messages should be provided?

In part 2 of the experiment, the focus of the analysis is on the distances associated with the final approaches (94 of the 594 approaches) that represent driver preferences. Of the 96 possible final approaches (48 drivers x 2 intersections per driver), two data points were lost (one for each of two drivers) due to equipment failures. Excluding those two approach sequences, the number of approaches per driver for both intersections varied from 5 to 9 with a mean of 6.4. Figure 17 shows the distribution of the number of approaches.

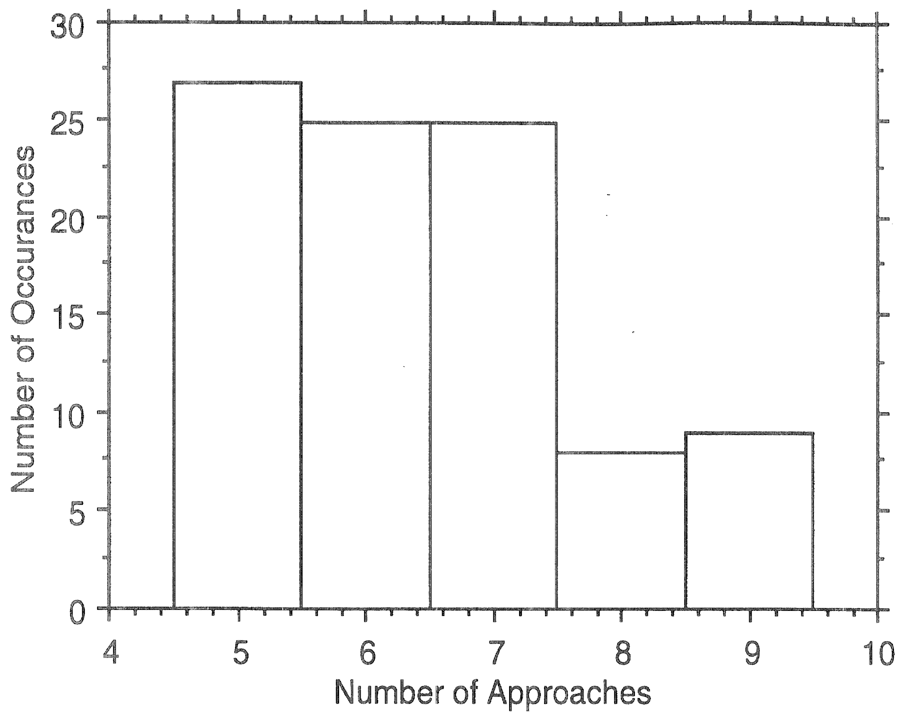



Figure 17. Number of approaches in the repeated-approach task.

Approaches where messages were given at a distance where drivers desired them occurred frequently. As shown in Figure 18, the distance at which messages were presented was "OK" for 417 of the 594 approaches for which data were available. (Data from 16 additional trials were lost due to equipment failure.) Almost half of the 417 (2 repetitions * 2 intersections/subject * 48 subjects) corresponded to the last two trials (generally required to be OK for the sequence to end).

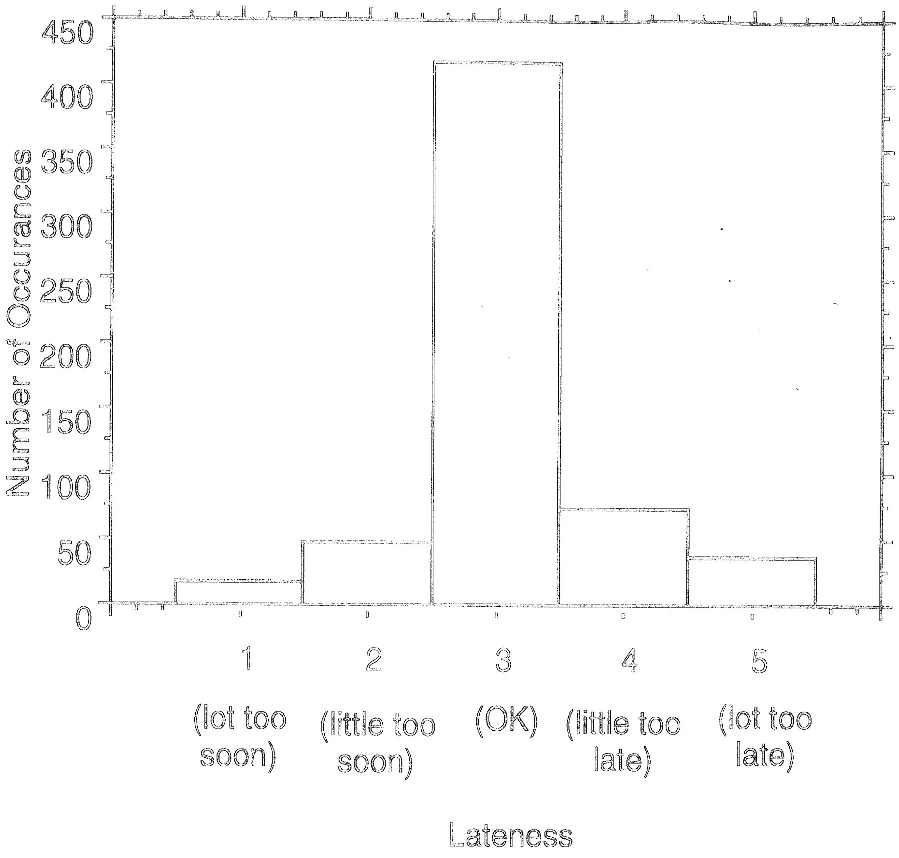



Figure 18. Responses to message timing.

For these final responses, the mean distance from the intersection ranged from 195 (59 m) to 736 ft (224 m) (mean=397 ft [121 m], standard deviation=121 ft [39 m]). This mean distance is 53 ft less that the mean distance from part 1, route-following. Since the mean approach speeds were identical (38 mi/h), most likely, the repeated-approach task led to familiarity with the intersection, and less need for advance warning of turns. Although both parts of this experiment considered the latest moment at which drivers would be comfortable hearing a message, the repeated nature of part 2 may have biased drivers towards a shorter distance.

Figure 19 shows the distribution of responses. Notice they are skewed toward the shorter distances

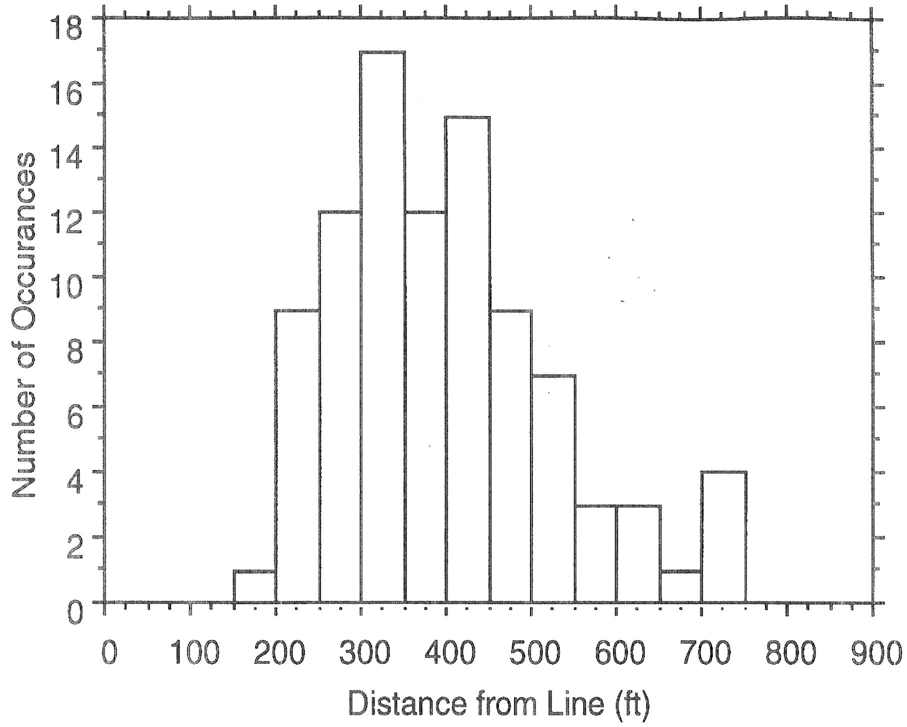



Figure 19. Distribution of distances in the repeated-approach task.

Table 13 shows the summary statistics for the two intersections examined in the Repeated-Approach condition. The means were quite different, primary because of differences in the approach speed. (This is discussed in greater detail in the following section.)

Table 13. Distance statistics for each intersection in the repeated-approach task.

| **Intersection** | | **Mean** | **S.D.** | **n** | **Min.** | **Max.** |
|---|---|---|---|---|---|---|
| **#** | **Name** | (ft) | (ft) | | (ft) | (ft) |
| 1 | Ellsworth and Platt | 467 | 124 | 47 | 245 | 736 |
| 2 | Scio Church and Seventh St. | 326 | 90 | 46 | 195 | 591 |

2. How do driver differences, traffic, the state of traffic lights, and other factors affect the distances at which requests are made?

Initially, all measures were included in an 11-factor ANOVA with no interactions. (See Table 14.) Notice that initially only the intersection and the number of vehicles ahead approached significance.

Table 14. List of factors initially considered.

| Factor | df | F-Value | P-Value |
|---|---|---|---|
| Intersection | 1 | 7.53 | .008 |
| Turn Direction | 1 | 2.16 | .146 |
| State of Light When Approaching Intersection | 1 | 0.37 | .545 |
| State of Light When Message Requested | 1 | 1.84 | .180 |
| Stop at Light | 1 | 0.09 | .762 |
| Number of Vehicles Ahead | 1 | 2.95 | .090 |
| Number of Vehicles in Left Lane | 1 | 0.39 | .533 |
| Time of Day | 1 | 0.30 | .584 |
| Speed | 1 | 2.33 | .131 |
| Age | 1 | 0.22 | .638 |
| Sex | 1 | 1.81 | .182 |
| Residual | 74 | | |

In a stepwise manner similar to part 1, factors of least significance were individually removed from the analysis and significance levels were recomputed after each step. In the final step, only those factors with significance levels below 0.1 were retained in the analysis. One exception to this process concerned intersection differences. As shown in Figure 20 , the mean approach speed to the Ellsworth and Platt intersection was considerably greater than for the Scio Church and Seventh St. intersection (43 versus 35 mi/h). (These two intersections were chosen so speed could be explored.) Eliminating the intersection effect from the analysis led to the speed effect being highly significant, so it was retained in the analysis.

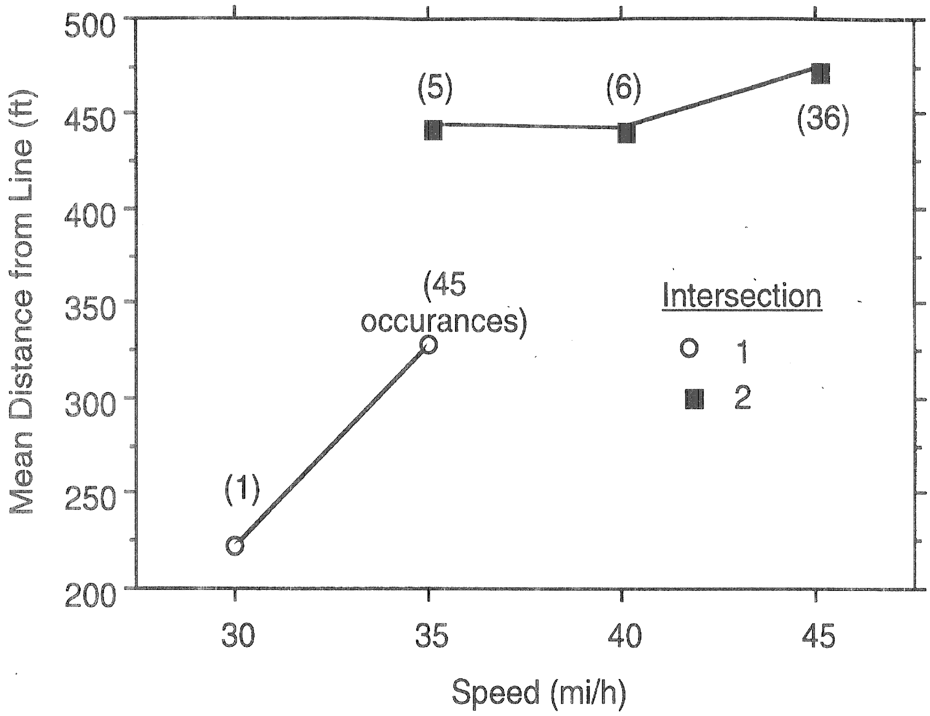



Figure 20. Number of times each speed was chosen for final approaches.

Table 15 shows the mean distances and speeds for the nonsignificant categorical factors. For this data set, the mean distance for when the light was red tended to be greater than for the green state for both the approach phase and when the message was requested. This may be in part due to the slightly greater approach speed when the light was red. One would expect the distance to be greater for a green light than a red. When the light is red, the driver must slow down (and possibly stop), and hence can be provided with the message closer to the intersection.

Table 15. Categorical factors removed from the model.

| Factor | Case 1 | Speed | n | Case 2 | Speed | n | Case 3 | Speed | n |
|---|---|---|---|---|---|---|---|---|---|
| | | mi/h | | | mi/h | | | mi/h | |
| intersection | intersection 1<br>326 ft | 35 | 46 | intersection 2<br>467 ft | 43 | 47 | | | |
| light at approach | red<br>417 ft | 40 | 60 | green<br>362 ft | 38 | 33 | | | |
| light at message | red<br>415 ft | 40 | 44 | green<br>382 ft | 39 | 45 | yellow<br>328 ft | 38 | 3 |
| stop at light | yes<br>384 ft | 39 | 52 | no<br>408 ft | 40 | 39 | | | |
| time of day | morning<br>408 ft | 39 | 33 | afternoon<br>416 ft | 39 | 34 | early evening<br>359 ft | 39 | 26 |
| turn | right<br>353 ft | 38 | 31 | straight<br>382 ft | 39 | 26 | left<br>446 ft | 40 | 36 |

Also among these nonsignificant factors were time of day effects. The approach speeds for all times were identical. The slightly reduced distance in the early evening is probably due to less traffic being present, along with the relatively fewer number of drivers who were tested then. Relatively fewer older drivers (who desired greater distances) served as subjects in the early evening, so this difference may be partially confounded with driver age.

The greater distance desired for left turns (though not significantly so) is logical. When making a left turn, a majority of the time the driver must come to a complete stop at the traffic light. A right turn simply requires the driver to slow down at the intersection. On city streets, right turns are typically made at speeds close to 15 to 20 mi/h. The distance required to decelerate from those speeds to zero mi/h (the difference between the left and right turns, computed using $v^2 = 2ax$) is 74 to 132 ft, spanning the value 93 ft (446 - 353) based on the experimental data. If the driver is continuing straight through the intersection, no change in speed is necessary.

Also not to be found significant were the effects of the number of vehicles ahead and the number of vehicles in the left-turn lane. Figure 21 shows the results for the number of vehicles ahead. For the most part, what differences may be in the data (greater distances when no vehicles were ahead versus one vehicle) reflect differences in approach speed (less when one vehicle was ahead). For two vehicles or more vehicles, there are too few data points on which to base an inference.

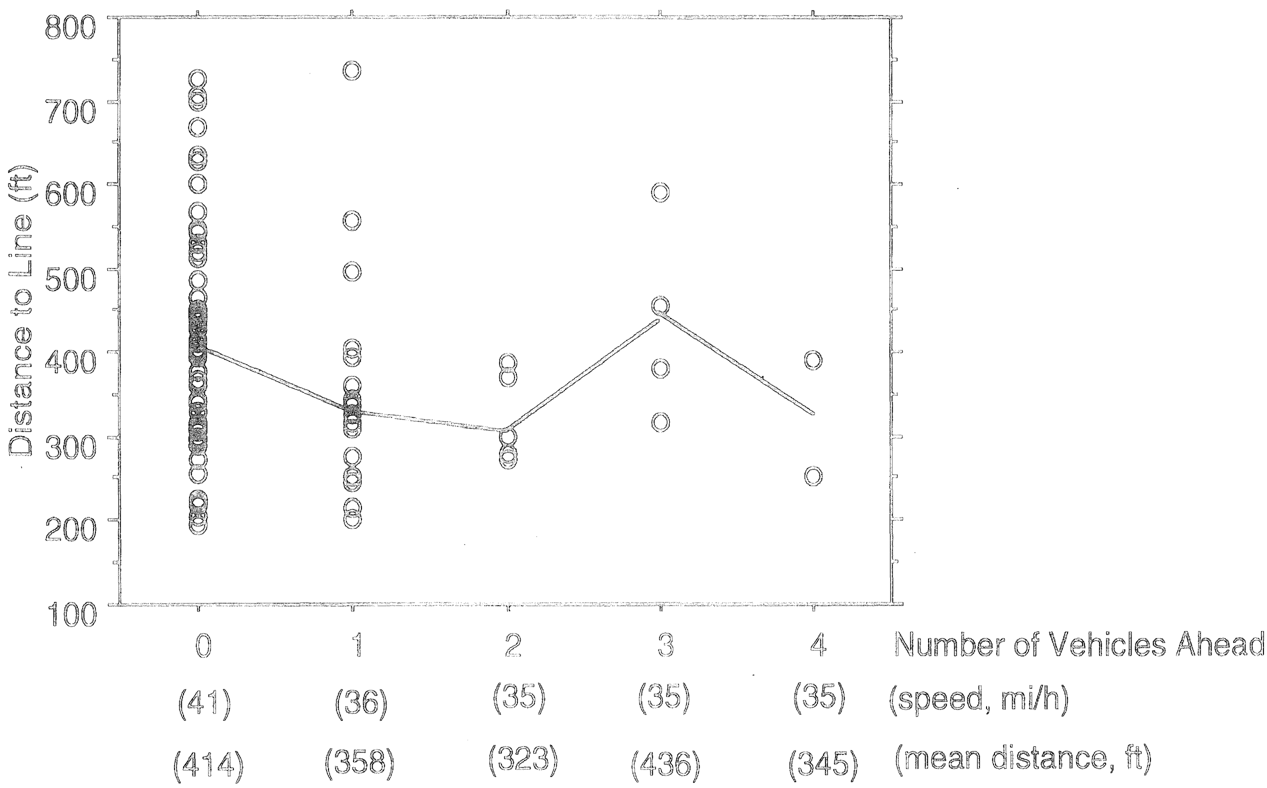



Figure 21. Number of vehicles ahead versus desired distance.

Figure 22 shows the relationship between the number of vehicles in the left-turn lane and the desired distance. As that number increases, greater distance is desired to achieve the same braking deceleration as when no vehicles are present. Also, distance is required to move into the left turn lane. The correlation between the two, the number of vehicles in the left lane and distance, was 0.29, fairly low. Consideration of only left turns resulted in virtually no change in the correlation coefficient (r=0.26). This makes sense, because drivers did not know which way they were going to turn prior to their request.

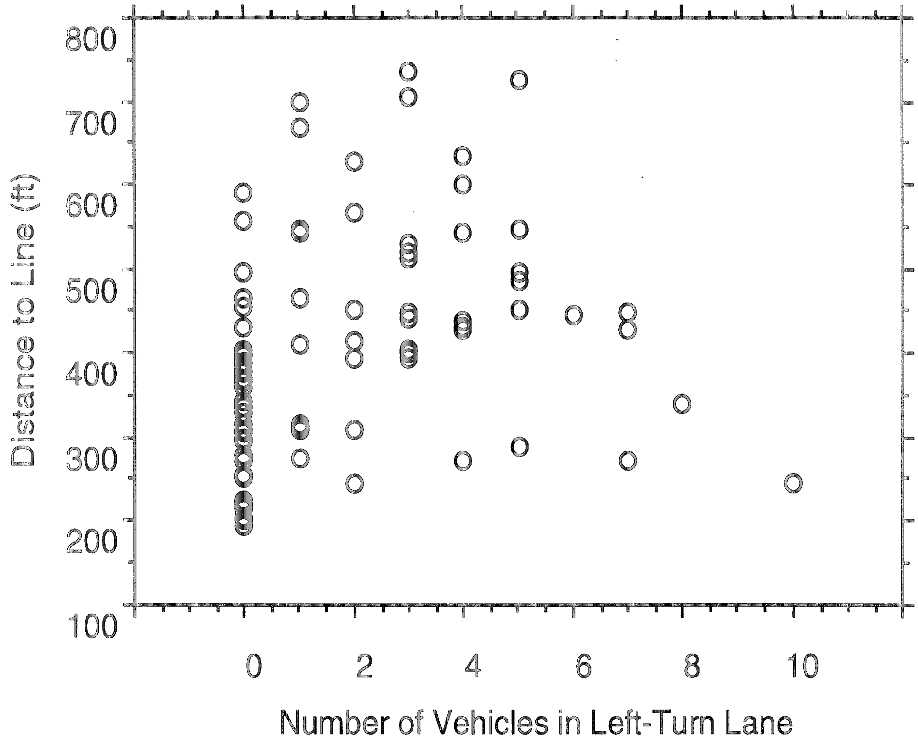



Figure 22. Desired distance versus number of vehicles in the left turn lane.

Table 16 is the resulting ANOVA table when factors with significance p>0.10 are removed. Remaining are speed, driver age, and driver sex.

Table 16. Factors with significance levels below 0.10.

| Factor | df | F-Value | P-Value |
|---|---|---|---|
| Speed | 1 | 36.30 | .0001 |
| Age | 2 | 3.20 | .046 |
| Sex | 1 | 4.03 | .048 |
| Residual | 88 | | |

Figure 23 shows the relationship between speed and desired distance of the intersection. There are too few data points to determine if the relationship is curvilinear. (For 35, 40, and 45 mi/h the means are 339, 443, and 474 ft.)

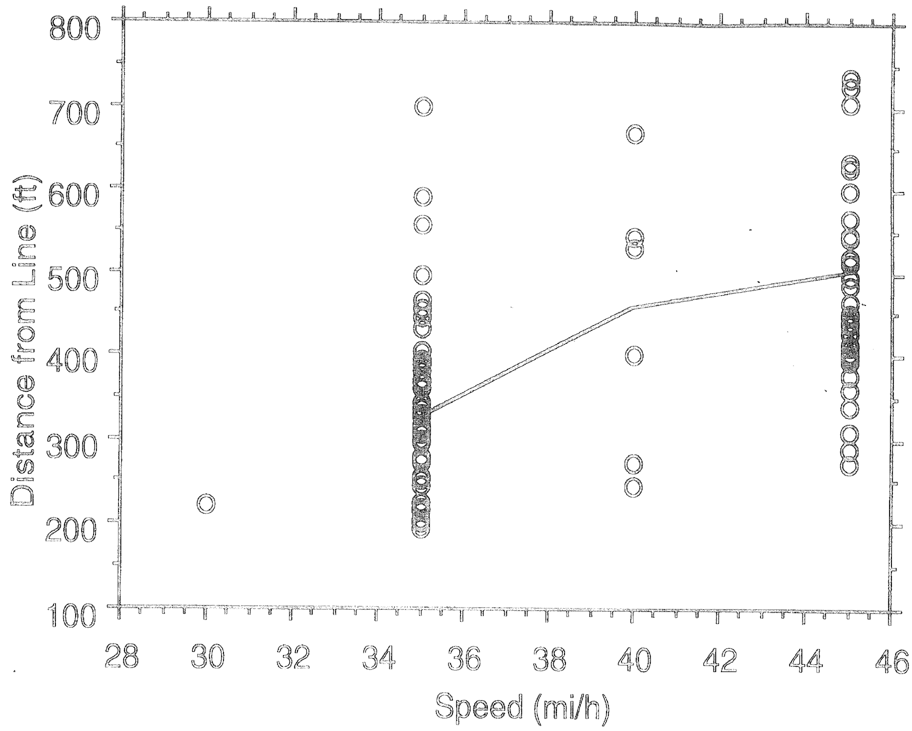



Figure 23. Relationship between speed and desired distance.

Figure 24 shows the differences due to subjects. Notice that the primary differences due to age are between the older drivers and the other groups. The interaction between sex and age was not significant ($p=0.87$). The pattern is similar to that found in the route-following task. (See Figure 11.)

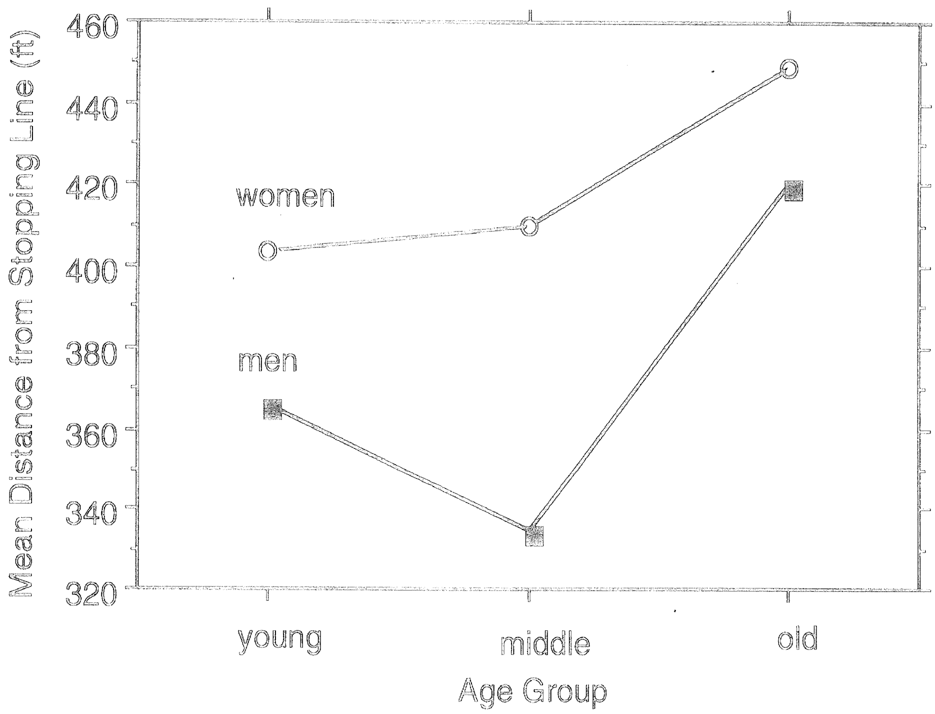



Figure 24. Effects of driver age and sex.

Using these results, a regression analysis was computed for this data set as shown below. This equation accounts for 33 percent of the variance, not an extremely large value. On average, women tend to want approximately 45 ft of additional warning; older subjects want 52 ft more than younger drivers; and 14 ft should be allowed for each mile per hour. The large negative intercept is partially due to the positive coding given to all sex and age values.

$$\text{Distance (ft)} = -260 + 14(\text{Speed}) + 45(\text{Sex.code}) + 26(\text{Age.code})$$

where Sex.code =1 (male) or 2 (female)
Age.code = 1 (young), 2 (middle aged), 3 (old)
Speed in mi/h

Figure 25 shows the residuals from the computation. It is most likely that the variability unaccounted for is due to individual differences. In comparing these results with Figure 16, bear in mind that a slightly expanded y-scale has been used here.

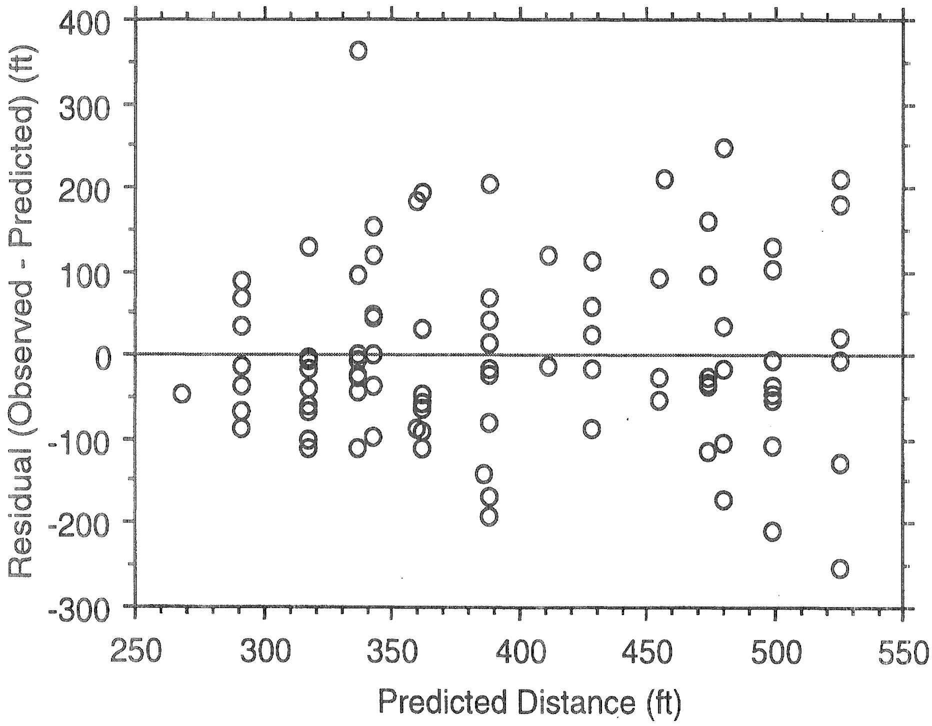



Figure 25. Residuals versus predicted values.

## CONCLUSIONS AND RECOMMENDATIONS

1. What are the mean and distribution of distances to signalized intersections for which auditory "at turn" messages were desired?

The mean distance for the presentation of messages was 450 ft (137 m) with a standard deviation of 261 ft (80 m) in the route-following task and 397 ft (121 m) with a standard deviation of 139 ft (39 m) in the repeated-approach task. (Note: The distances given were measured from the stopping line, not from the intersection edge.) The smaller value in the repeated-approach case most likely reflects familiarity with the intersections.

2. What factors significantly affect the distance at which messages were desired?

For the route-following data, the distance at which messages were desired were affected by the sex and age of the driver, the turn direction, the number of cars ahead, and the speed driven. For left turns, the number of cars in the left turn lane had a small influence. In particular, desired warning distances in the route-following task were greater for women than men (by about 113 ft) and increased with age (119 ft for each step-young to middle, middle to old). For the repeated-approach task, gender differences were 26 ft and 45 ft per age group. Although differences should be smaller in the repeated-approach task (because the overall mean distance at which information was desired was about 20 percent less), the reduction in the size of the age and gender differences is much more than 20 percent. One explanation is that women were more affected by familiarity than men.

For left turns versus right turns, approximately 95 more feet were desired in the route-following task, 93 ft for the repeated-approach condition. When making left turns, drivers must usually come to a complete stop and wait for a traffic light to change. For right turns, coming to a full stop may not be required. The 95 foot difference is consistent with the assumption that right turns are made at 15 to 20 mi/h, while the vehicle comes to a stop before making a left turn.

For the route-following task, distance also increased 15 ft for each mile per hour in speed and 21 ft for each vehicle ahead in the route-following condition (versus 14 mi/h in speed and an unknown value for each vehicle in the repeated-approach condition). The speed coefficient is somewhat less than predicted by theory, but it may be that the assumed braking deceleration (.1 g) is low. The 21 foot estimate is reasonably consistent with a theory that assumes drivers need additional distance to compensate for vehicles ahead and gaps between them.

3. What factors did not significantly affect the distance at which messages were desired?

The distance at which messages were desired was unaffected by the state of the traffic lights (for example, on approach, when the message was presented). Relatively minor were the effects of time of day, which may have been reflecting differences in speed driven and traffic (which in this experiment was measured as the number of cars ahead of the test vehicle). In the pilot experiment, the day-night difference was examined and a statistically significant difference was not found. However, the sample was quite small and, therefore, the test was not robust.

4. At what distance should messages be presented?

Because the actual driving situation more closely reflects the route-following task (not knowing at which intersection to turn rather than which way), it is recommended that navigation interfaces use the message timing developed from that task.

Distance (ft) = -389 + 119 (Age.code) - 113 (Sex.code) + 95 (Turn.code) +15 (Speed) + 21 (# Vehicles).

where

Age.code 1 = young, 2 = middle-aged, 3 = older
Sex.code 1 = women, 2 = men
Turn code 1 = right, 2= left
Speed (mi/h)
# Vehicles (vehicles ahead)

For situations where the specific driver age and sex is unknown, customer demographics should be used to determine likely percentages, and the distance setting should be weighted accordingly. There may also be merit in providing a setting that would allow drivers to adjust the overall timing. The drawback of this is that it complicates the driver interface, and should drivers err, allows them to set a time that could pose a hazard if it is too brief.

If data on the number of cars ahead are not available in real time, it may be possible to estimate a mean value from historical data on traffic flow, and enter it into the expression.

A common situation will be minimal traffic with the vehicle being driven by a middle-aged driver. When driving at 35 mi/h, the recommended distance is 356 ft for women and 243 ft for men. When driving at 45 mi/h the distances are 506 ft for women and 393 ft for men. These four distances are consistent with those in current practice (as described in the introduction).

Beyond the data provided here, designers need to consider the penalties of providing a message too late (missing a turn or stopping sharply to make a turn) and too early (turn onto the wrong street, forgetting the street and missing the turn, stopping sharply to turn onto the wrong street, etc.) and the probabilities of each outcome.

5. How does the distance vary with the method used to ask the question ?

The mean distance in the route-following condition (drivers say when they want the message) was 53 ft (16 m) less than in the repeated-approach condition (where they said if particular distance was OK or not). This probably occurred because drivers were more familiar with the intersection in the later condition.

6. How should data be collected in future studies?

The data collection methods used in this experiment were inexpensive and realistic. Participants had little difficulty in identifying when they wanted a message. Messages presented by the PowerBook using the Wizard of Oz method were readily understood, and the overall protocol worked well, so the general test method and instructions should be retained.

Prior to the experiment, the authors believed that the repeated-approach method might be preferred because of the popularity of similar methods in psychophysics research for determining thresholds. However, the route-following method was much more efficient with 321 responses obtained in 30 minutes (per subject) versus only 94 usable data points in approximately 80 minutes (per subject) in the repeated-approach method. Although the data collected using the repeated-approach method may have been slightly higher quality, the more rapid data collection rate in the route-following approach (a factor of nine) far outweighs the quality advantage. Further, the route-following task more closely resembles real driving experience. The route-following method is therefore recommended.

Because the effects were significant, samples in future studies should include both men and women and three age groups, as was the case here. Utilizing the same age distributions facilitates comparison with this data set. Also, data should be collected on the number of cars ahead and the number of cars in the left turn lane. So speed can be measured more precisely, a digital speedometer should be provided. In this experiment, speed was read to the nearest 5 mi/h using the instrument panel speedometer, a method less accurate than desired.

In future studies, it is apparent that it will not be necessary to collect data on the state of traffic lights as they did not significantly affect the distance at which messages were desired. This should simplify the data-collection protocol.

Future research should consider the four factors on timing of the final turn message: (1) day versus night, (2) a greater range of speeds, (3) geographic differences, and (4) vehicle type. In addition, the frequency of requests for turn reminders/continuation messages as a function of the distance between turns should be examined.

Although this experiment did not reveal a day versus night difference, the test of such was not robust. Examinations of day versus night differences are generally straightforward to plan and design, though scheduling drivers is not simple. Time of day is unlikely to interact with speed, so only one speed needs to be examined.

As shown in this experiment, speed is an important factor. Driving at 55 mi/h is common on major roads in the U.S., and that speed, along with selected data at lower speeds (for comparison with this data set), should be examined. Increasing the speed range should permit the quadratic model proposed in the introduction to be tested.

It is well known that there are both regional and international differences in driving behavior. (For example, drivers in Boston are likely to be more aggressive than drivers in the Midwest.) However, collecting such data can be challenging because of the need to transport test equipment and support experimenters. International studies are particularly difficult to fund and manage, but for global manufacturers, are most needed and should be supported.

It also may be that driving behavior (and distances for guidance messages) depends on the type of car being driven, with cars with greater performance capability (and shorter stopping distances) being driven more aggressively. It is uncertain if this is purely due to type of vehicle driven or a selection process in which more aggressive drivers select higher performance vehicles. Examining this factor will require obtaining and instrumenting multiple vehicles, which adds significantly to the project cost. Some thought should be given to the types of vehicles in which navigation systems will initially be offered.

Finally, in this experiment the distance between turns in the route-following experiment was one to two miles. For larger distances, some increase in the warning distance may be needed. More important, however, will be occasional reminders that the driver is on the correct route. In this experiment, it was not unusual for half of the subjects to ask for turn information for the intersection prior to the destination. The challenge in examining this factor is that increasing the distances between turns will increase the time required to test each driver.

## Summary

Thus, the experiment reported here examined two alternative methods for identifying when auditory messages should be presented to drivers. The results from the two methods were consistent, though the route-following method was clearly superior and should be used in future studies.

Using these methods, equations to predict how far from intersections drivers want the final turn message in nonexpressway driving were developed. Typically messages should be presented between 250 and 500 ft from the intersection, with the distance being modified based on the speed driven, the traffic, and driver characteristics. This value is in reasonable agreement with current design recommendations for experimental and production navigation systems. Further, the adjustments are consistent with a theory based on the physics of rectilinear motion in which drivers alter when the request should be made based on the distance required to stop.

These results should be extremely useful to both those developing auditory in-vehicle navigation products and those interested in collecting more refined data on when auditory guidance messages should be presented.

## ADDENDUM

After this report was initially completed, the authors received a copy of Ross, Nicolle, and Brade (1994). This HUSAT report describes an experiment very similar to the research described here, both in terms of approach and results, carried out as part of the HARDIE project. Readers interested in the topic of guidance message timing are encouraged to obtain a copy after it is accepted by the Transport Telematics Office and becomes available for public distribution.

Those seeking a summary of this UMTRI effort should examine Green and George (1995). This Human Factors and Ergonomics Society paper was written and delivered after the initial report was completed.

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## APPENDIX A - CURRENT U.S. SIGNING PRACTICE

In addition to the specifications for exit gore signs and street signs given in the introduction, detailed requirements for other situations exist in the MUTCD. For state and national roads that are not limited-access highways (either two lane or four lane), signing practice may vary with the posted speed of the road, and the extent to which the route is urban. For rural roads, junction signs (e.g., JCT 18) may serve as a trigger. Practice is to place them at least 400 ft from the intersection. These signs typically have 12-in high characters (corresponding to a 600 foot sight distance, assuming a clear line of sight).

For both state and local roads (and national roads in a few cases), warning signs may alert drivers to upcoming intersections. They may indicate the geometry of an upcoming intersection (cross, T, Y) or the presence of a traffic control device (light) or sign (stop or yield). An upcoming intersection may be associated with a change in route. The MUTCD specifies the distance the warning sign should be from the intersection, which depends upon the posted or 85 percentile speed of the road being driven, and the speed to which the driver must decelerate. For turns from major roads (55 mi/h), turn speeds on the intersecting roads tend to be large (30 mi/h), and therefore distances of warning signs from intersections (400 ft) must be substantial. (See Table 17.) Warning signs typically have letters 12 in high, though the 10 in and 15 in sizes are sometimes used. Legibility distances are typically 600 ft and total lead distances are 1000 ft, suggesting that in those situations auditory messages should be presented at about that distance from intersections.

Table 17. Distances (ft) of warning signs from intersections for "high judgment" situations.

| posted or 85 percent | | | decelerate to (mi/h) | | | | |
|---|---|---|---|---|---|---|---|
| speed (mi/h) | | 0 (stop) | 10 | 20 | 30 | 40 | 50 |
| 20 | 175 | | | | | | |
| 25 | 250 | | 100 | | | | |
| 30 | 325 | 100 | 150 | 100 | | | |
| 35 | 400 | 150 | 200 | 175 | | | |
| 40 | 475 | 225 | 275 | 250 | 175 | | |
| 45 | 550 | 300 | 350 | 300 | 250 | | |
| 50 | 625 | 375 | 425 | 400 | 325 | 225 | |
| 55 | 700 | 450 | 500 | 475 | 400 | 300 | |
| 60 | 775 | 550 | 575 | 550 | 500 | 400 | 300 |
| 65 | 850 | 650 | 650 | 625 | 575 | 500 | 375 |

Note:
"High judgment" refers to situations where the decision is very difficult (10 second PIEV, where PIEV = Time required for Perception, Identification/understanding, Emotion/decision making, Volition/execution of decision

For business districts (45 mi/h, 72 km/h) where turn speeds are moderate (30 mi/h, 48 km/h), warning signs should be a minimum of 175 ft (53 m) from the intersection. In these cases, the warning signs have 12 in (30 cm) high letters designed for a 600 foot (183 m) sight distance. Together, this data suggests turn messages should initiate 775 ft (175 ft + 600 ft, 236 m) from most intersections.

For residential streets (speed limit = 35 mi/h, turn speed 20 mi/h), the minimum placement distance is the same as the same for business districts, 175 ft (53 m).

## APPENDIX B - BIOGRAPHICAL AND CONSENT FORMS

**University of Michigan Transportation Research Institute**
**Human Factors Division**
**Biographical Form**

Subject: [ ]

Date: [ ]

**Name:** ______________________

**Male** **Female** (circle one) **Age:** ________

**Occupation:** ______________________

**Retired or student:** Note your former occupation or major______________

**Education** (circle highest level completed):

| | |
|---|---|
| some high school | high school degree |
| some trade/tech school | trade/tech school degree |
| some college | college degree |
| some graduate school | graduate school degree |

**What kind of car do you drive the most?**

Year:________ Make:______________ Model:______________

**Approximate annual mileage:** ______________

**Have you ever driven a vehicle with an in-vehicle navigation system?**

No  Yes, in an experiment  Yes, elsewhere

**How familiar are you with driving in the city of Ann Arbor?**

Not at all familiar  Slightly familiar  Moderately familiar  Very familiar

**In the last 6 months, how many times have you used a map?**

0  1-2  3-4  5-6  7-8  9 or more

**How often do you use a computer?**

Daily  A few times a week  A few times a month  Once in awhile  Never

TITMUS VISION: (Landolt Rings)

| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | Vision correctors? Y / N |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| T | R | R | L | T | B | L | R | L | B | R | B | T | R | ________ |
| 20/200 | 20/100 | 20/70 | 20/50 | 20/40 | 20/35 | 20/30 | 20/25 | 20/22 | 20/20 | 20/18 | 20/17 | 20/15 | 20/13 | which? |

Subject: ____________ Date: __________

**AUDITORY ROUTE GUIDANCE TIMING**
**PARTICIPANT CONSENT FORM**

The purpose of this experiment is to identify the timing of auditory route-guidance instructions that tell drivers where to turn at intersections. In this experiment, you will be driving at fixed speeds through several intersections, repeatedly, and will be asked about your preferences for the timing of these messages. You will be driving in Ypsilanti and Ann Arbor.

The study consists of two parts. In part 1, you will be asked to perform a task at 5 different intersections. In part 2, you will approach two intersections, repeatedly, for at least four times.

This experiment is not a test of your driving skills. Your priority is always to drive **safely**. You are expected to **obey all traffic and speed laws**. If you are not driving safely, you will be given one warning, after which the experiment can be stopped. Please tell the experimenter at any time if you feel you are unable to complete the study. Thank you for your participation.

**The complete experiment consists of one on-the-road test. You will be paid $25. The experiment will take approximately 2-1/2 hours.**

**I HAVE READ AND UNDERSTAND THIS DOCUMENT.**

| | |
|---|---|
| ____________________ | ____________________ |
| Print your name | Date |
| ____________________ | ____________________ |
| Sign your name | Witness (experimenter) |

# APPENDIX C - INSTRUCTIONS TO SUBJECTS

**Hi, are you** (participant's name)? **I'm** (experimenter's name). **Thank you for coming today. Let's go down to the conference room and get started.**

Overview

**This study will consist of an on-the-road session and will take about 2-1/2 hours. You will be paid $25 for your time. You will be driving an automatic transmission Ford Taurus station wagon on public roads in Ann Arbor and Ypsilanti. At certain times, you will be asked to drive at the posted speed limit, if it is safe to do so.**

**This experiment concerns navigation systems that give spoken instructions on how to get to a destination. A system like this might tell you where to turn as you approach an intersection, by saying, "Turn RIGHT at the traffic signal." We're interested in the timing of these types of messages. If they are presented too early, a driver may turn at the wrong intersection or may forget the turn direction. If the message is given too late, the driver could be forced to make a sudden maneuver and possibly cause an accident.**

**For this study, you will be asked about your preferences for the timing of the auditory route-guidance messages. First, I'll have you fill out some forms, and then, we'll go down to the car and I'll finish explaining the experiment.**

Consent and Bio Forms

**First, please read and sign this consent form, and then turn the page and fill out the biographical form. If you have any questions at any time, feel free to ask them at any time.**

Provide consent and biographical forms. Check that it is legible and complete.

**I also need to see your driver's license.** Check license.

Vision Test

**Next, I'll be testing your vision wearing any corrective eyewear you drive with.** Subject puts face up to vision tester. **Can you see in the first diamond that the top circle is complete but that the other three are broken? In each diamond, tell me the location of the solid circle - top, left, bottom, or right.** Continue until two in a row are wrong. Take the last one that they got correct to determine visual acuity.

Driving Rules and Cautions

**Let me reiterate a few important points from the consent form. First of all, driving safely is your main priority. If you feel unsafe or are unable to make any turn, please don't. Second, if you are uncomfortable or wish to stop at any time,**

**please let me know right away. You are expected to obey all speed limits and driving laws.**

**This is how we'll get to the beginning of the experiment.** Show subject map with roads highlighted to beginning of test route. **You will be following this highlighted route to get to the beginning of the test route at the intersection of Washtenaw and Carpenter roads.** Go down to the test vehicle

At the test vehicle

**Please fasten your seatbelt, adjust the seat, mirrors, steering wheel height, as you feel necessary.**

- Adjust car seat, steering wheel height, and side- and rear-view mirrors.
- Fasten seatbelt.
- Point out climate controls, no cruise control, odometer and clock will be covered during the experiment.
- Remind about following speed limit.

**The study today will consist of two parts. In the first part, you will be told several miles in advance to make a turn ahead, but will be unsure of the exact location. You will be given an instruction by the navigation system, similar to the following:**

Press button on key pad to play sample message.

**"In approximately 2 miles, turn RIGHT at the traffic signal."**

**As you approach the intersection you think may be the target intersection, your task is to ask me, "Is this it?" at the latest time you feel comfortable knowing if it is the target intersection. If you are correct, you will hear an instruction similar to the following message.** Press button on key pad to play sample message.

**"Yes, turn RIGHT at the traffic signal, when it is safe to do so."**

**You should then go to the intersection and complete the turn. If this is not the target intersection, you will hear this message instead.** Press button on key pad to play message.

**"No, continue through the intersection, when it is safe to do so."**

**You should continue driving until you come to another intersection that you feel is the target. Keep in mind that you should ask at the latest moment you feel comfortable finding out if the intersection you are approaching is the target intersection.**

**We'll repeat this process for 5 target intersections. All of the intersections you will be turning at will have traffic signals. While we're doing this part of the experiment, I'd like you to drive as close to the speed limit as you are able to, when it's safe, of course. I'll remind you periodically about this task. Do you**

**have any questions about part 1 of the experiment?** Experimenter answers any questions the subject has.

**OK! Let's get started....**

Follow Huron Parkway to Huron River Dr. Turn LEFT on Huron River Dr. Go to Hogback Rd. Turn RIGHT. Go to Washtenaw. Turn left. Begin part 1 of the experiment.

Part 1 of the experiment continues. Subject turns right onto Packard. **Please pull into the Food Mart parking lot on your left.** Subject pulls in and parks car.

**You've finished part 1 of the experiment. For part 2, you will drive to a specific intersection and approach it repeatedly. For the first two times, you won't know the direction of your turn until you ask for it. To hear the turn direction, your task is to say "Now" at the latest time you feel comfortable hearing your turn direction for that intersection. For approach 3, 4, 5, etc., you won't have to ask for the turn direction. The auditory navigation system will give you your turn instructions. You should complete the turn that the system gives you, if you feel safe doing so. Once you reach the intersection, I will ask whether the time that the system gave you the message was "too soon," "too late," or "okay." If you say "too soon" or "too late," I will ask you if the message was a little too late/soon or a lot too late/soon. Again, keep in mind that I'm interested in the latest time you feel comfortable hearing the instruction. Your answer should be based on the same criteria on each approach. We will approach each intersection at least 4 times.**

**After we've completed part 2 at this intersection, we'll drive to a different intersection and repeat the same process.**

**During part 2 of the experiment, I will ask you to drive at the posted speed limit, when possible. If at any time during this experiment, you have questions or feel that you can not finish, please let me know. Do you have any questions?**

**Once we finish with the second intersection, we'll head back to UMTRI.** Drive to first intersection. Test vehicle nears Ellsworth and Platt intersection.

**The speed limit at the first intersection** (Ellsworth and Platt) **is 45 mi/h. Try to keep your speed at 45 mi/h, when it's safe to do so.** Target intersection comes into sight. **Your task is to say "Now" at the latest time you feel comfortable hearing your turn direction.** Experimenter starts counter as vehicle passes landmark (bus stop). Subject says "Now." Experimenter presses a key to play the message, stops the counter, and records the number displayed on the counter. **Now, we'll just circle back around the block to the same starting point. The next approach will be just like the first one.** Give subject instructions how to get back to starting point. Approach intersection again. Experimenter starts counter as vehicle passes landmark. Subject says "Now." Experimenter presses a key to play the message, stops the counter, and records the number displayed on the counter.

On third approach, when subject reaches intersection: **We want to know the latest time you feel comfortable hearing the direction you're going to turn at the intersection. Was that message given "too late," "too soon," or "okay?"** If "too soon," or "too late," ask **Was it a little or a lot too soon/late?** Repeat process until subject has responded OK on two consecutive approaches. Process may also stop according to various stopping rules, mentioned in the text.

**OK, we're finished with this intersection. Now, you'll drive to the second intersection** (Scio Church and Seventh St.) **for this part of the experiment and repeat the process. The geometry of the intersection is basically the same, except the speed limit will be 35 mi/h instead of 45.**

Experimenter gives subject instructions to the second intersection. Subject turns left onto Scio Church. Experimenter gives the same instructions as she did at the previous intersection. Repeat process until subject has responded OK on two consecutive approaches. Process may also stop according to various stopping rules, mentioned in the text.

**OK. We're finished. Now, we'll head back to UMTRI and fill out a payment form, then we're all set.** Experimenter gives subject directions back to UMTRI.

At UMTRI, the experimenter provides the subject with a payment form and a pen. Subject completes the form, and the experimenter pays them and thanks them for their time. Experimenter escorts subject to the front door.

## APPENDIX D - PHOTOGRAPHS OF TARGET INTERSECTIONS

### Part 1, Route-Following Condition

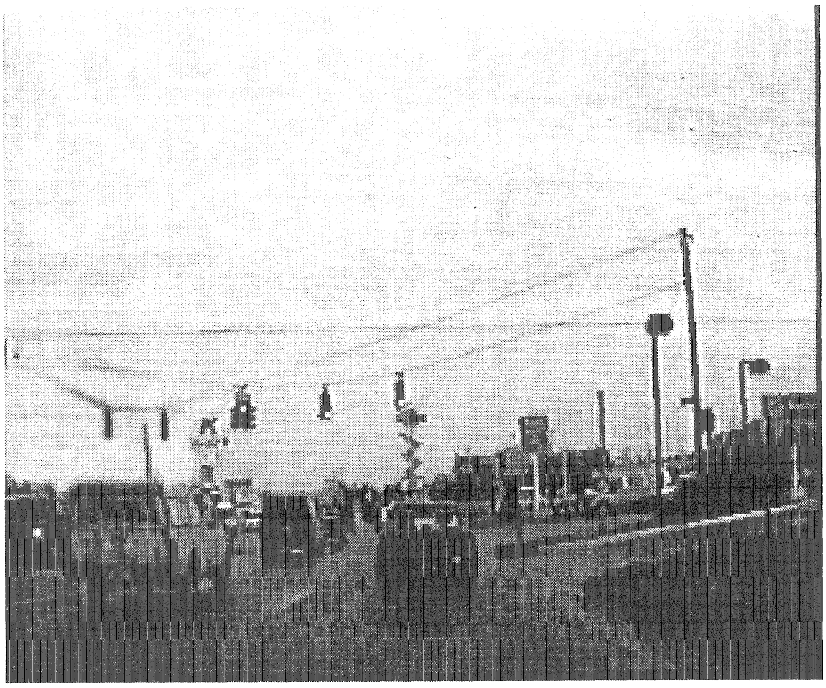


Figure 26. Washtenaw and Golfside intersection (practice intersection).

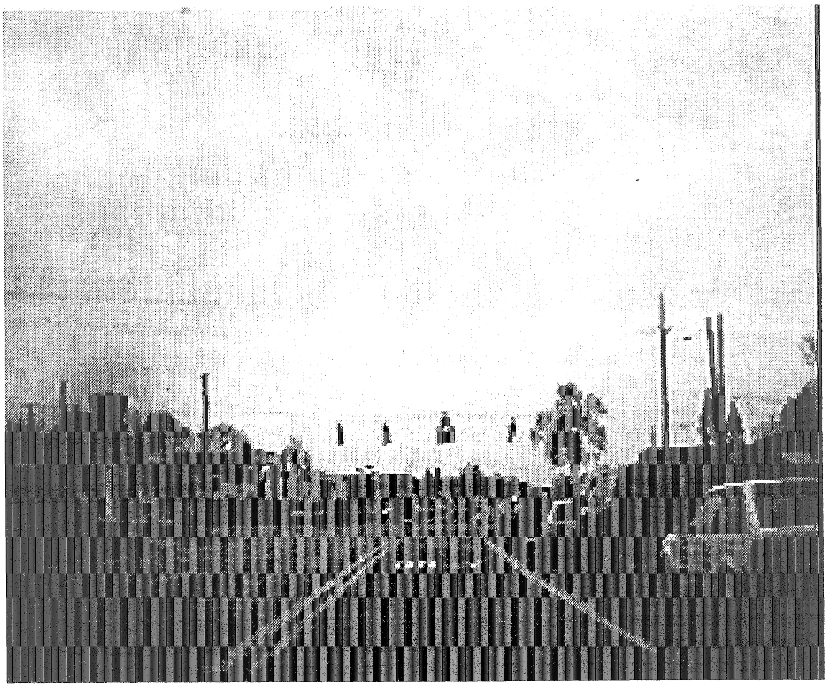


Figure 27. Washtenaw and Golfside intersection.

Figure 28. Packard and Mansfield intersection.

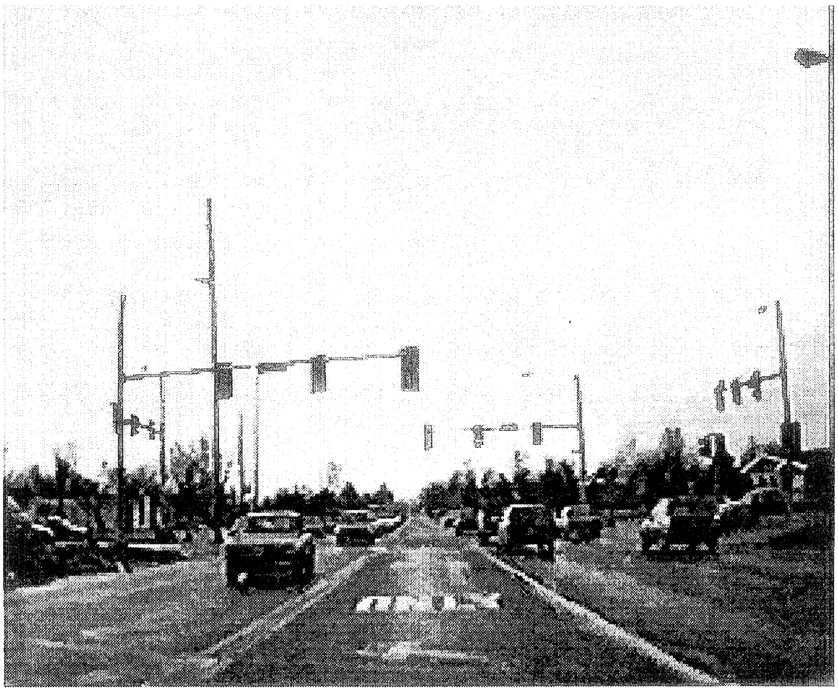


Figure 29. Packard and Platt intersection.

Figure 30. Stadium and Packard intersection.

## Part 2, Repeated-Approaches Condition

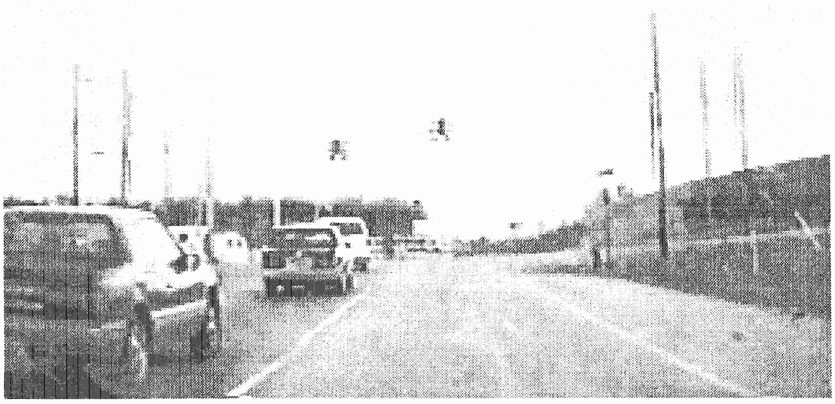


Figure 31. Ellsworth and Platt intersection.

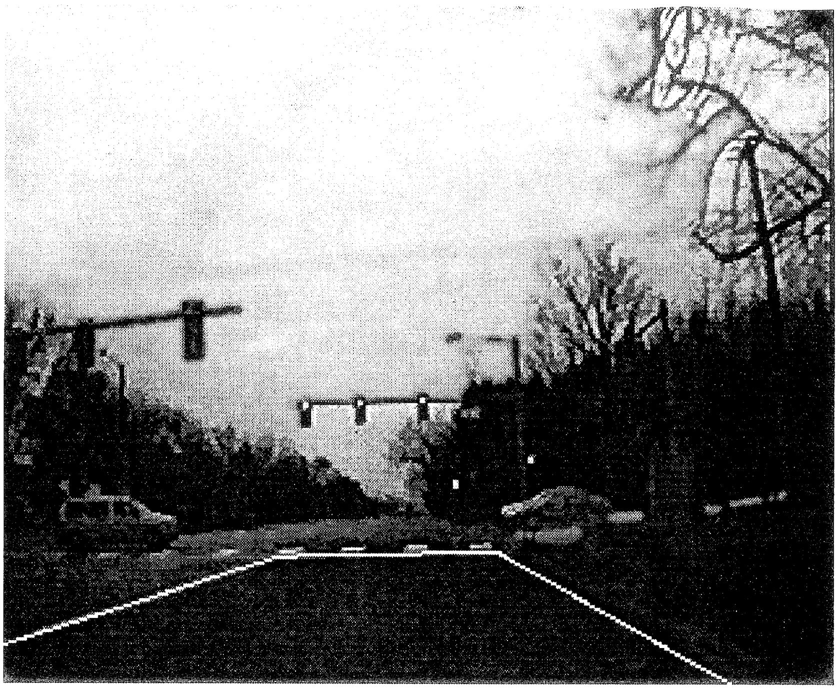
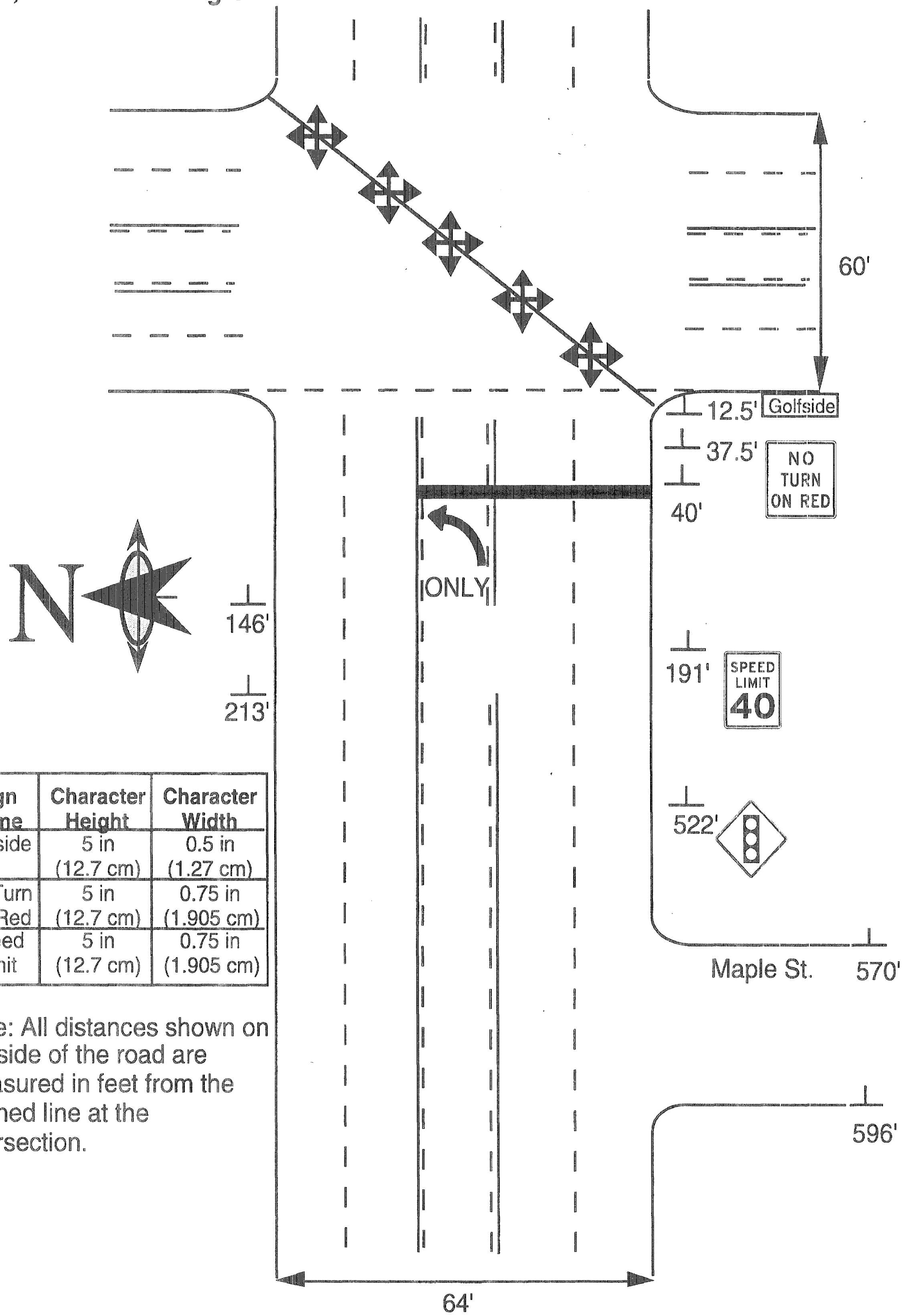


Figure 32. Scio Church and Seventh St. intersection.

# APPENDIX E - DRAWINGS OF TARGET INTERSECTIONS

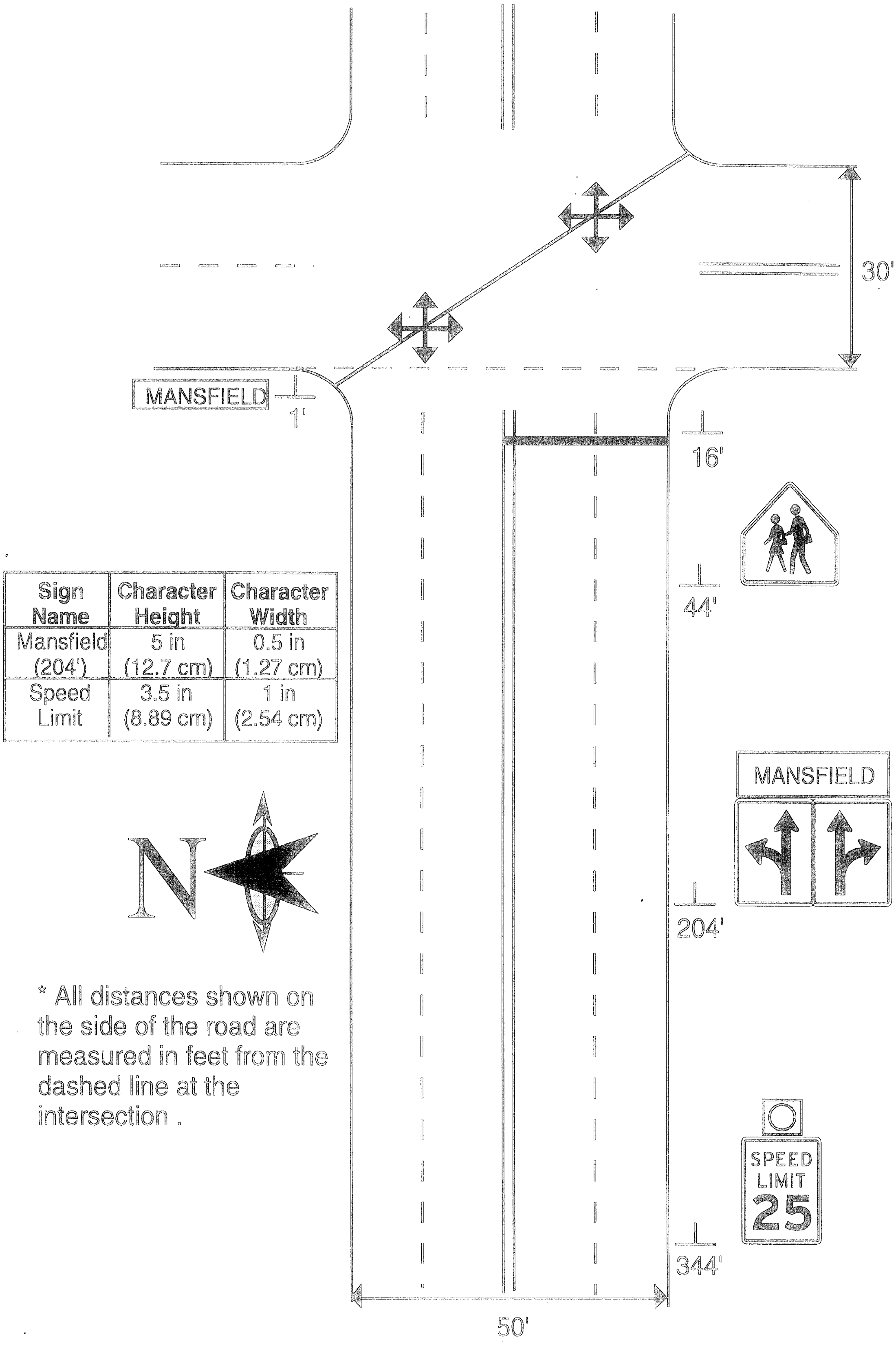
## Part 1, Route-Following Condition




| Sign Name | Character Height | Character Width |
|---|---|---|
| Golfside | 5 in (12.7 cm) | 0.5 in (1.27 cm) |
| No Turn On Red | 5 in (12.7 cm) | 0.75 in (1.905 cm) |
| Speed Limit | 5 in (12.7 cm) | 0.75 in (1.905 cm) |

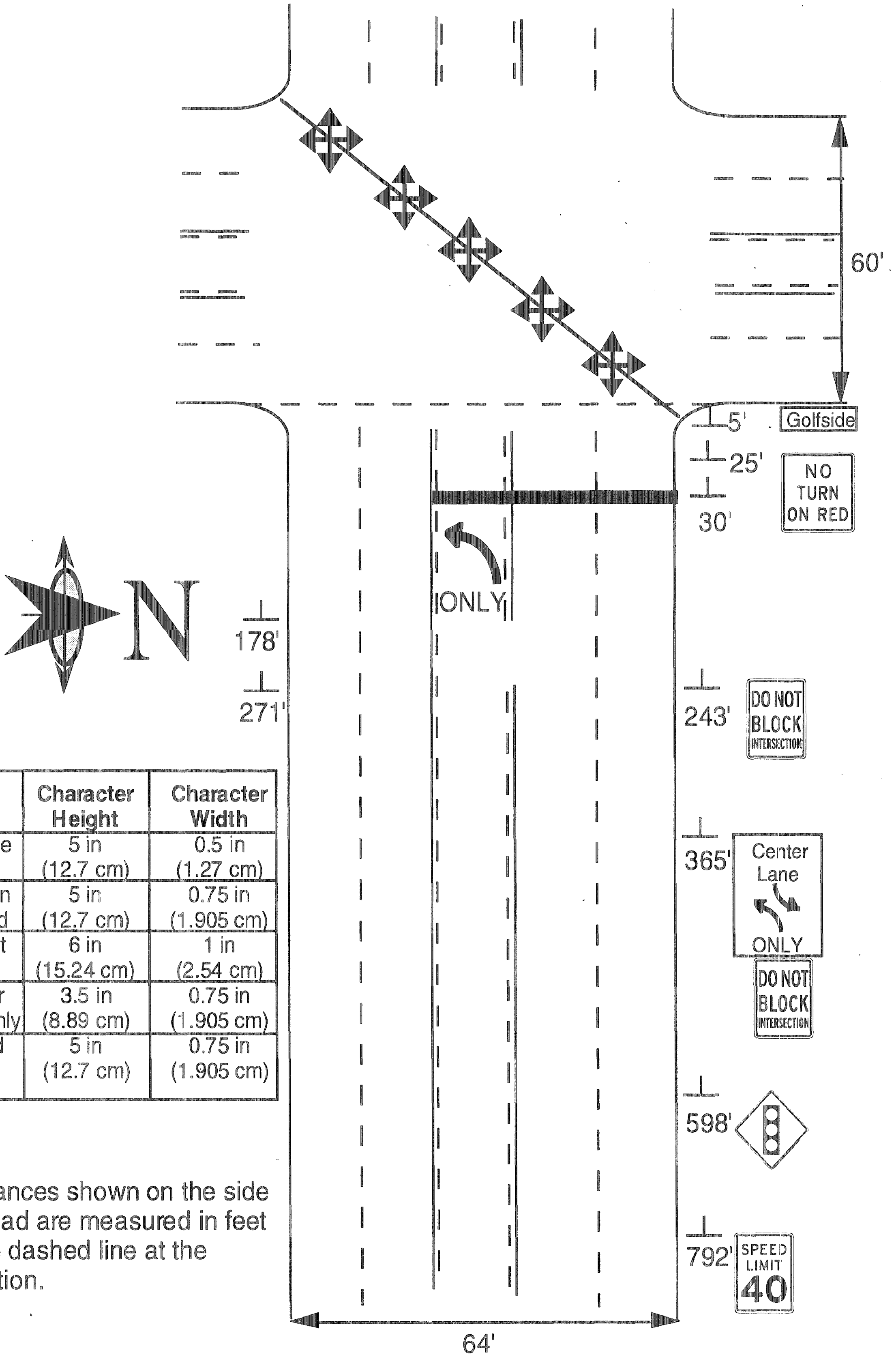
Note: All distances shown on the side of the road are measured in feet from the dashed line at the intersection.

Figure 33. Washtenaw and Golfside intersection (practice intersection).




| Sign Name | Character Height | Character Width |
|---|---|---|
| Mansfield (204') | 5 in (12.7 cm) | 0.5 in (1.27 cm) |
| Speed Limit | 3.5 in (8.89 cm) | 1 in (2.54 cm) |

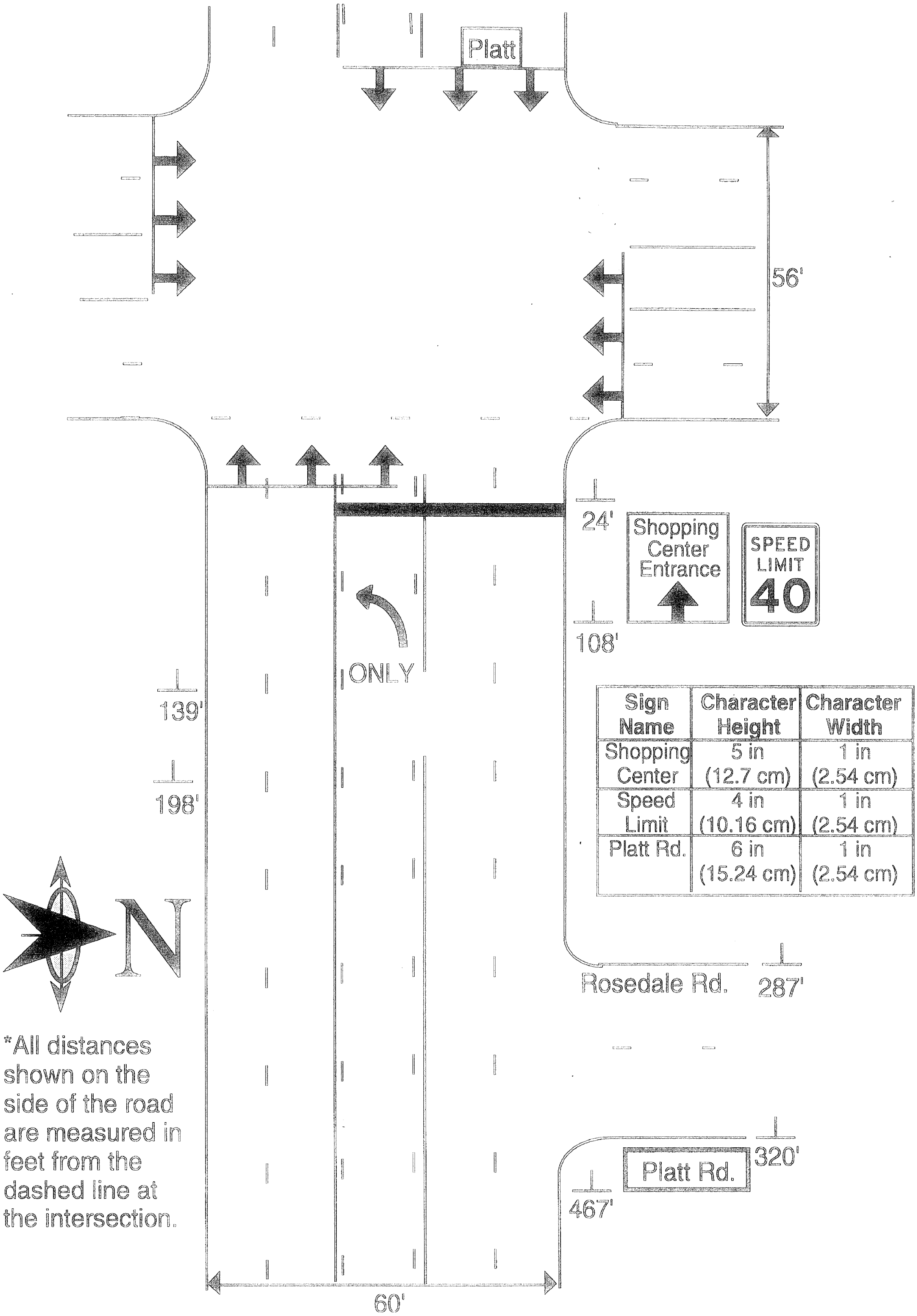
Figure 34. Packard and Mansfield intersection.




| Sign Name | Character Height | Character Width |
|---|---|---|
| Golfside | 5 in (12.7 cm) | 0.5 in (1.27 cm) |
| No Turn On Red | 5 in (12.7 cm) | 0.75 in (1.905 cm) |
| Do Not Block | 6 in (15.24 cm) | 1 in (2.54 cm) |
| Center Lane Only | 3.5 in (8.89 cm) | 0.75 in (1.905 cm) |
| Speed Limit | 5 in (12.7 cm) | 0.75 in (1.905 cm) |

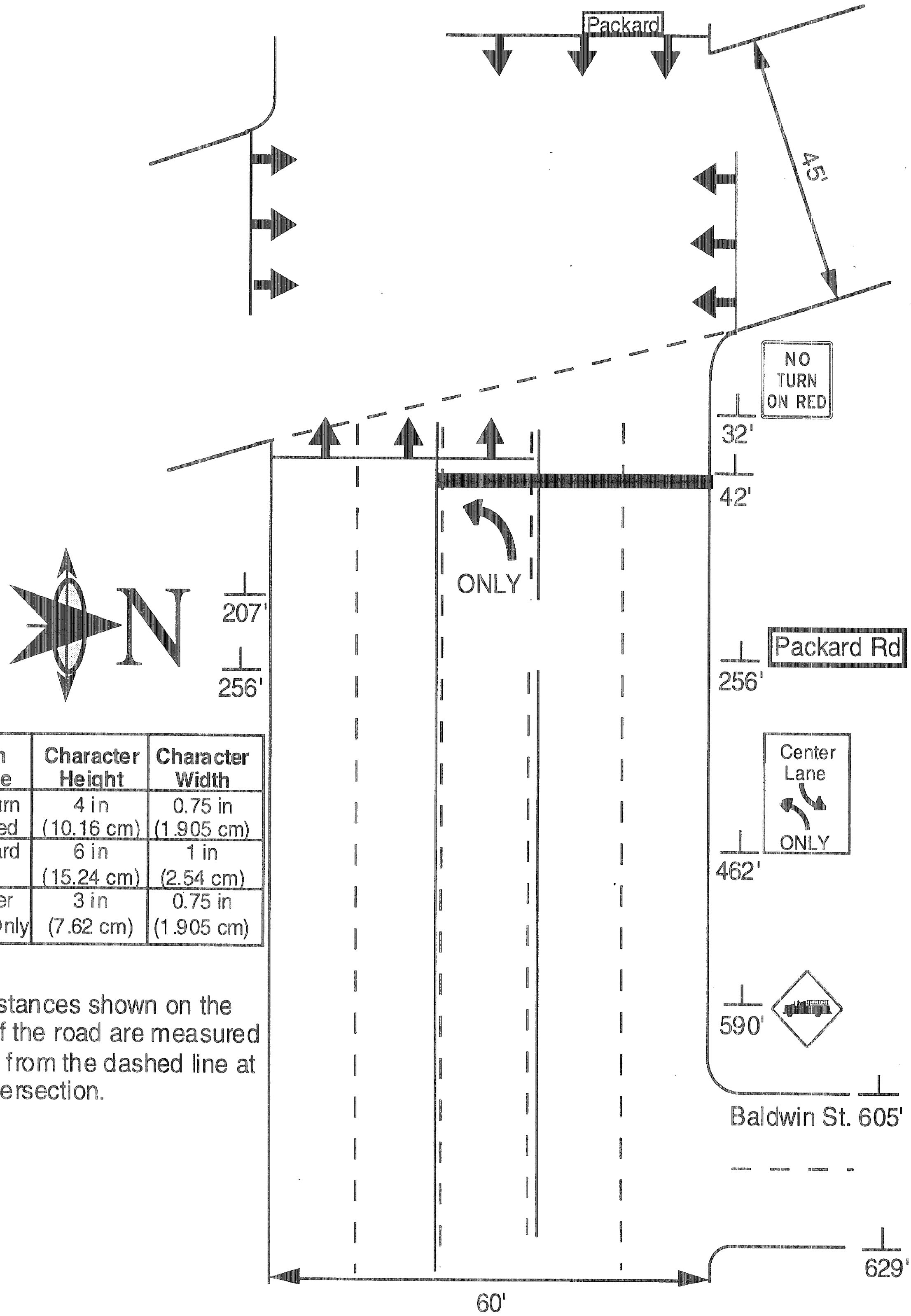
*All distances shown on the side of the road are measured in feet from the dashed line at the intersection.

Figure 35. Washtenaw and Golfside intersection.




| Sign Name | Character Height | Character Width |
|---|---|---|
| Shopping Center | 5 in (12.7 cm) | 1 in (2.54 cm) |
| Speed Limit | 4 in (10.16 cm) | 1 in (2.54 cm) |
| Platt Rd. | 6 in (15.24 cm) | 1 in (2.54 cm) |

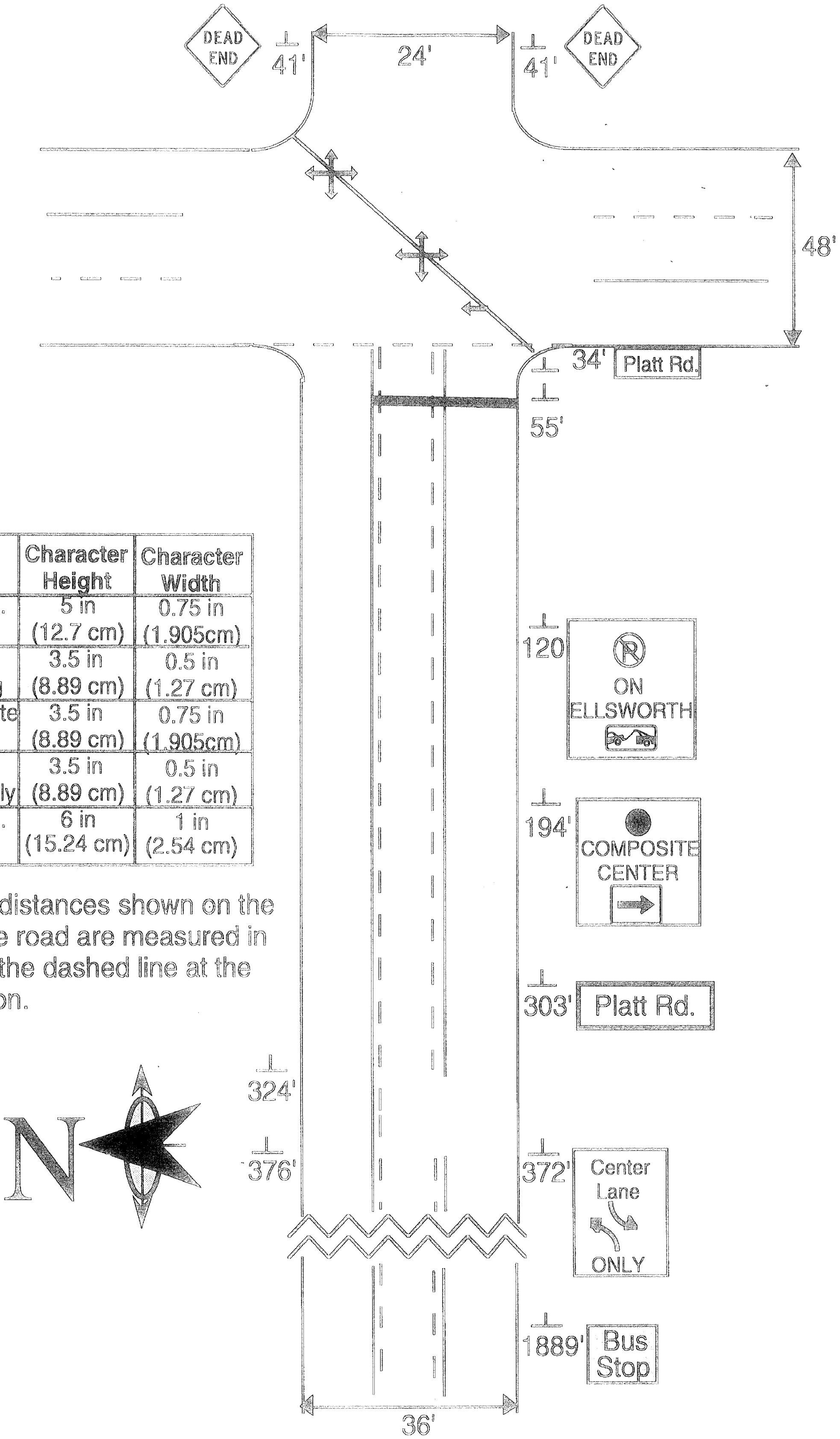
Figure 36. Packard and Platt intersection.




| Sign Name | Character Height | Character Width |
|---|---|---|
| No Turn On Red | 4 in (10.16 cm) | 0.75 in (1.905 cm) |
| Packard Rd. | 6 in (15.24 cm) | 1 in (2.54 cm) |
| Center Lane Only | 3 in (7.62 cm) | 0.75 in (1.905 cm) |

*All distances shown on the side of the road are measured in feet from the dashed line at the intersection.

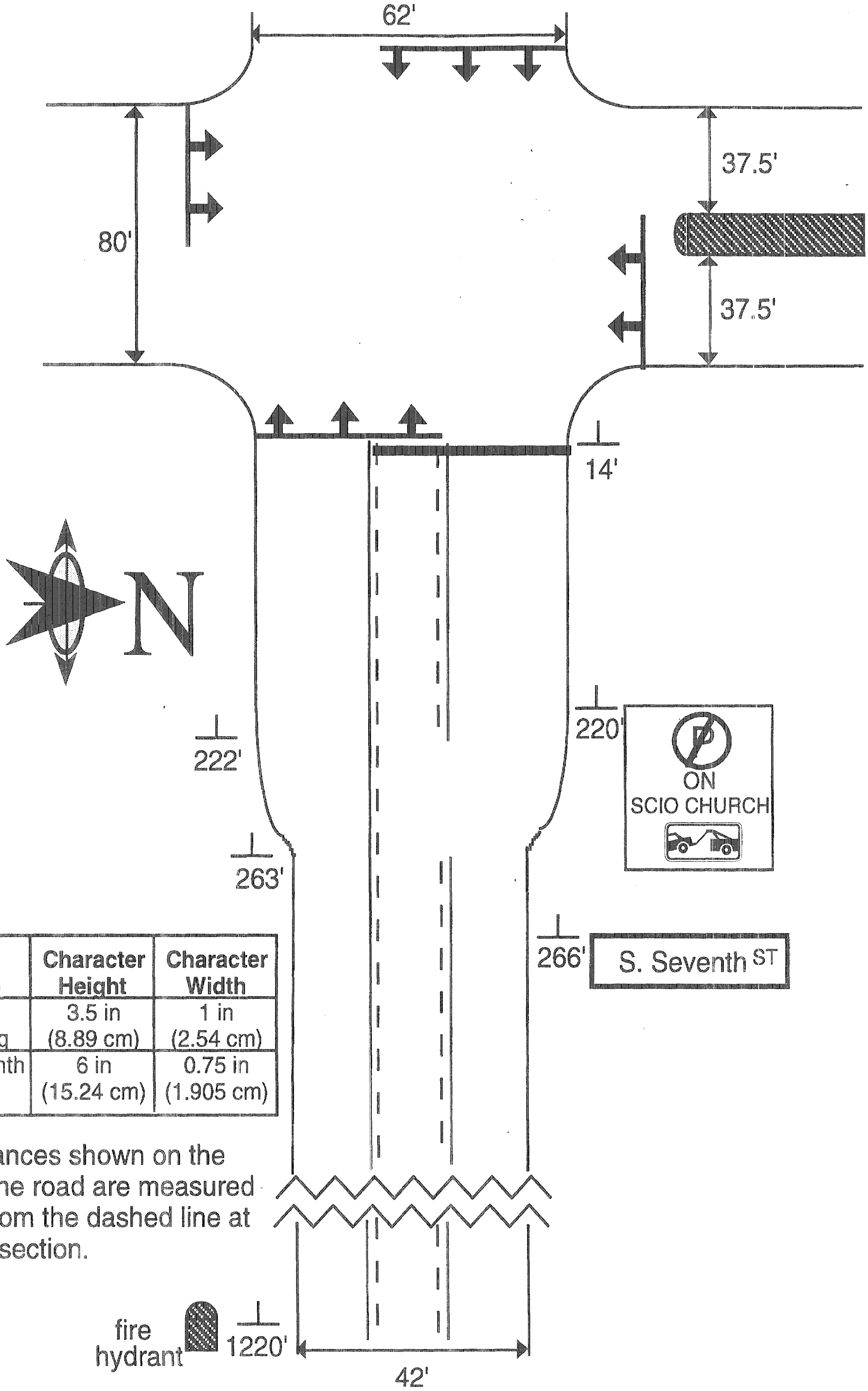
Figure 37. Stadium and Packard intersection.




| Sign Name | Character Height | Character Width |
|---|---|---|
| Platt Rd. (20') | 5 in (12.7 cm) | 0.75 in (1.905cm) |
| No Parking | 3.5 in (8.89 cm) | 0.5 in (1.27 cm) |
| Composite Center | 3.5 in (8.89 cm) | 0.75 in (1.905cm) |
| Center Lane Only | 3.5 in (8.89 cm) | 0.5 in (1.27 cm) |
| Platt Rd. (303') | 6 in (15.24 cm) | 1 in (2.54 cm) |

Note: all distances shown on the side of the road are measured in feet from the dashed line at the intersection.

Figure 38. Ellsworth and Platt intersection.




| Sign Name | Character Height | Character Width |
|---|---|---|
| No Parking | 3.5 in (8.89 cm) | 1 in (2.54 cm) |
| S. Seventh St. | 6 in (15.24 cm) | 0.75 in (1.905 cm) |

*All distances shown on the side of the road are measured in feet from the dashed line at the intersection.

Figure 39. Scio Church and Seventh St. intersection.

## APPENDIX F - DISTANCES FROM STOPPING LINES TO INTERSECTION EDGES

### Part 1, Route-Following Condition

| Intersection | Distance (ft) |
|---|---|
| Washtenaw/Blockbuster Video | 64 |
| Washtenaw/Golfside (from East) | 40 |
| Packard/Hewitt | 25 |
| Packard/Mansfield | 16 |
| Washtenaw/Hewitt | 32 |
| Washtenaw/Builders Square | 64 |
| Washtenaw/Golfside (from West) | 30 |
| Packard/Dalton | 26 |
| Packard/Carpenter | 21 |
| Packard/Fernwood | 17 |
| Packard/Platt | 24 |
| Washtenaw/Huron Parkway | 28 |
| Washtenaw/Sheridan | 21 |
| Stadium/Washtenaw | unavailable |
| Stadium/St. Francis | 20 |
| Stadium/Brockman | 21 |
| Stadium/Packard | 42 |

### Part 2, Repeated-Approaches Condition

| Intersection | Distance (ft) |
|---|---|
| Ellsworth/Platt | 55 |
| Scio Church/Seventh St. | 14 |

## APPENDIX G - ADDITIONAL STATISTICS ON AGE AND SEX FOR ROUTE FOLLOWING

There has been some discussion as to how the appropriated distance for a message should be determined. Because there are huge differences in the desired distances, a message that is timely for one individual may be too soon or too late for another. Nonetheless, it has been suggested message timing should be based on the worst case, the older female group. The question then is, for that group, should the mean distance be used (in which case messages will occur too late for half of the sample) or some number of standard deviations from the mean (which might be far too soon for the younger males). To assist in considering those tradeoffs, additional summary statistics are given below for the Repeated Approach (part 1) task.

Distances (ft) at which the message was desired

| Age | Sex | Mean | Std. Dev. | Std. Error | # | Minimum | Maximum |
|---|---|---|---|---|---|---|---|
| young | female | 363 | 189 | 25 | 54 | 56 | 898 |
| young | male | 313 | 167 | 23 | 55 | 29 | 624 |
| middle | female | 491 | 220 | 29 | 58 | 34 | 1332 |
| middle | male | 330 | 134 | 20 | 47 | 57 | 628 |
| mature | female | 657 | 333 | 47 | 51 | 133 | 1813 |
| mature | male | 540 | 285 | 38 | 56 | 30 | 1433 |