UMTRI-84-39

SUBJECTIVE EVALUATION OF STEERING EFFORT LEVELS

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DECEMBER 1984

UMTRI The University of Michigan
Transportation Research Institute

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
UMTRI-84-39		

4. Title and Subtitle	5. Report Date
SUBJECTIVE EVALUATION OF STEERING EFFORT LEVELS	December 1984
	6. Performing Organization Code 388782
7. Author(s) P. Green, T. Gillespie, S. Reifeis, L. Wei-Hass, and D. Ottens	8. Performing Organization Report No. UMTRI-84-39
9. Performing Organization Name and Address The University of Michigan Transportation Research Institute Ann Arbor, Michigan 48109-2150 U.S.A.	10. Work Unit No. 11. Contract or Grant No. DRDA 85-919-P1
12. Sponsoring Agency Name and Address Ford Motor Company Manual Steering & Controls Department Powertrain and Chasis Product Engineering Dearborn, MI 48121	13. Type of Report and Period Covered Final - June-Dec. 1984 14. Sponsoring Agency Code

15. Supplementary Notes

Ford P.O. 47-X-462584

16. Abstract

Forty-five Ford Motor Company employees (43 men and 2 women), mostly managers, drove either a 1984 Ford Thunderbird Turbo-Coupe or a 1984 Ford LTD through 8 maneuvers. Maneuvers included: parallel parking, a low-speed slalom (7 mph), driving on a banked high-speed track (60 mph), driving in circles on a skid pad (25', 50', and 100' radii at 9, 14, and 20 mph, respectively), and two routes through residential neighborhoods in Dearborn, Michigan (at about 20 mph). During maneuvers the power steering assist level (and hence the steering effort required) was adjusted by an experimenter in the back seat to find the preferred level.

It was found that: (1) drivers wanted the assist level to decrease with speed, about 20 mph per setting; (2) desired assist levels for the Thunderbird (a sports car) were about one setting lower than those for the LTD (a family car); (3) typically two or more settings were called "OK," with those settings being centered around the preferred setting; and (4) preferences for assist were correlated (but not significally) with driver size (shoulder breadth), with bigger people wanting greater efforts.

17. Key Words	18. Distribution Statement
Steering efforts, power steering, human factors, human engineering, ergonomics, engineering psychology	

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	74	

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EXECUTIVE SUMMARY

TITLE:	Subjective Evaluation of Steering Effort Levels
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REPORT #:	UMTRI-84-39
DATE:	December 1984
SPONSOR:	Manual Controls and Steering Department Ford Motor Company

Purpose:

The purpose of this experiment was to establish driver preferences for power steering assist levels as a function of speed for two Ford cars.

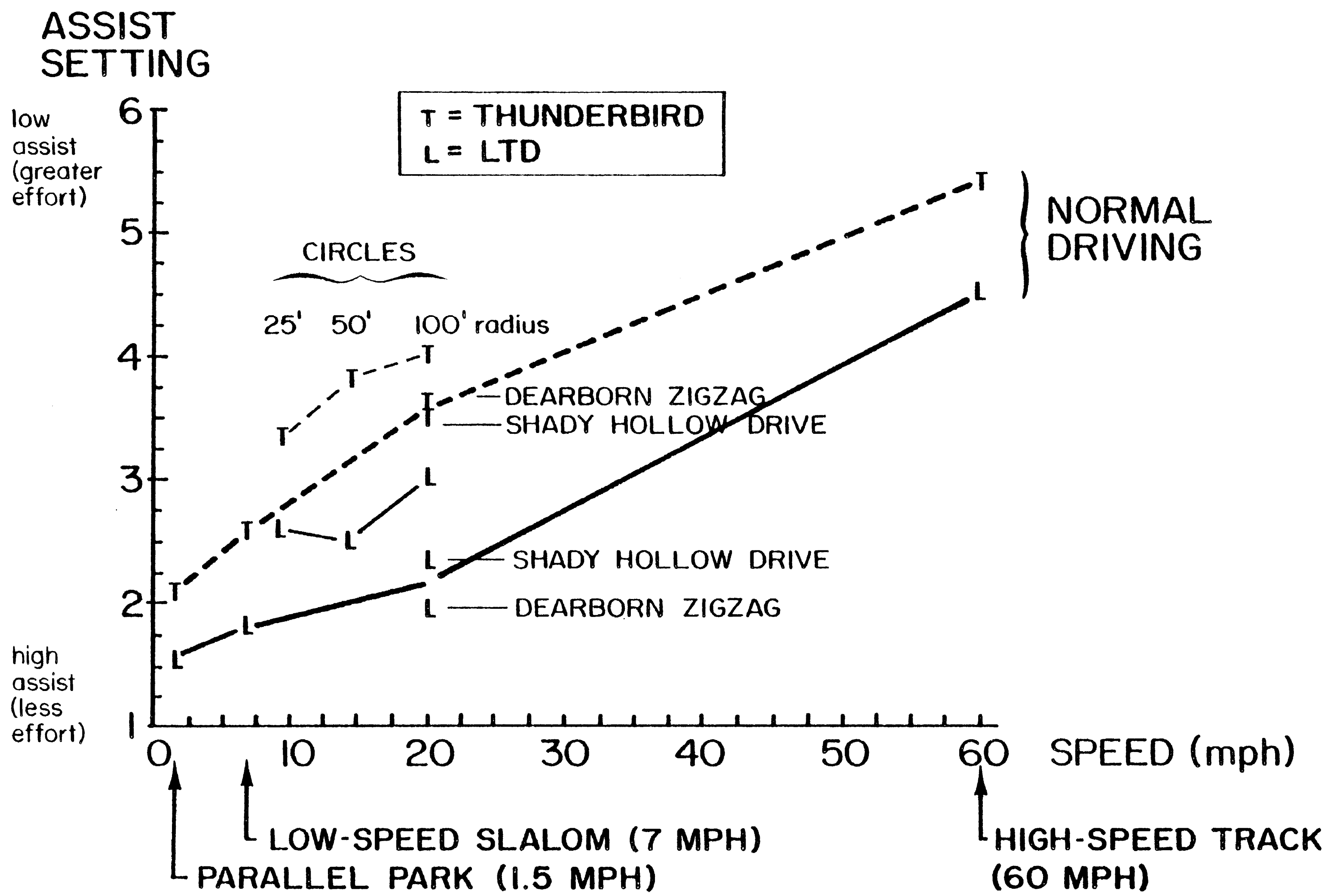
How the Research was Done:

Forty-five Ford employees (43 men and 2 women), mostly managers, drove either a 1984 Ford Thunderbird Turbo-Coupe or a 1984 Ford LTD through eight maneuvers: parallel parking, a low-speed slalom (7 mph), driving on a banked high-speed track (60 mph), driving in circles on a skid pad (25', 50', and 100' radii at 9, 14, and 20 mph respectively), and two routes through residential neighborhoods in Dearborn, Michigan (at about 20 mph). During maneuvers the power steering assist level was adjusted by an experimenter in the back seat to find the preferred level.

Findings

- Drivers clearly preferred steering assist to decrease as speed increased. (See the attached figure.)
- Drivers wanted greater steering efforts for the T-bird than the LTD. The experimental equipment did not allow the preferences to be evaluated directly in terms of steering torque values.
- Drivers wanted less assist when driving in constant-radius circles than highway driving at the same speed.
- Differences in preference between subjects were large enough to suggest that selection of an assist level for fixed assist systems, or assist ranges for variable-assist systems, should always be based on preferences from a jury of evaluators.
- The data suggest the following conclusions with regard to various features in a power steering system:

FIXED ASSIST − A power steering system providing only a fixed level of assist does not satisfy driver preferences at both low and high speeds.
VARIABLE-SPEED ASSIST − A power steering system that provides an assist level that varies linearly with speed can satisfy the average driver's preference for different assist levels at high and low speeds. However, an optimal choice of an overall assist level will fit the preferences of only about 25% of the drivers.
VARIABLE-SPEED ASSIST WITH MANUAL SETTING OF OVERALL LEVEL − To satisfy virtually all drivers, a power steering system must provide a manual setting for the overall level of assist, along with an automatic change in assist with speed.



Preferred assist setting by maneuver.
Note: The means used here differ slightly from those of Tables 4 and 5 because a different subset of drivers was used.

ACKNOWLEDGMENTS

Three individuals from the Ford Motor Company deserve mention: Glen Ulrich for his supportive role as project liaison, Walt Gordon for his technical assistance in assuring the proper operation of the experimental steering systems, and Mel Cant for his work in scheduling subjects. His knowledge of the Ford organization and diligence assured a steady supply of participants.

INTRODUCTION

Clearly, if a car is to be a commercial success, it must be safe and easy to drive. How well the steering system is designed is a major factor in determining a car's driveability.

In recent years there has been a resurgence of interest in steering systems. That has come about because of "downsizing" trends and increased use of front-wheel drive. With the shift from rear-wheel to front-wheel drive, a greater proportion of the vehicle's weight has been placed on the front wheels. This, along with a shift to wider tires, increases steering effort. In addition, competitive pressures have also led manufacturers to look for ways to improve their products, and improvements in steering are viewed as a prime candidate.

PREVIOUS RESEARCH

The design of steering systems has received considerable engineering attention since the earliest motor cars. Since World War II, feedback control and optimal control models of human tracking performance have been developed, primarily by those interested in predicting the handling qualities of aircraft and spacecraft (Poulton, 1974; Sheridan and Ferrell, 1974). Models have also been developed to predict the performance of drivers steering road vehicles (McRuer, Allen, Weir, and Klein, 1977; Gothelp, Milgram, and Blaauw, 1984). These models are concerned with minimizing steering error and for the most part ignore steering efforts and effort preferences, though there are some exceptions (Segel, 1964).

To reduce steering efforts, many cars are equipped with fixed-assist power steering systems. Unfortunately, those systems cannot fully satisfy all of the design requirements. If a car is to be easy to park, the assist levels must be able to counter high static steering torques. To provide good high-speed handling, assist levels should be low so as to provide feedback about the vehicle-road interaction and allow the driver to make small corrections in direction.

Several solutions to this dilemma have been proposed by foreign manufacturers. Nishikawa, Toshimitsu, and Aoki (1979) describe the operation of a variable-assistance power steering system introduced on the 1978 Honda Accord LX. Their design relies upon a speed sensor that controls a valve regulating the flow of hydraulic fluid to the steering gear spool valve. The system behaves as normal power steering at low speeds and gradually changes to a manual steering system as speeds increase. Nishikawa et al. provide detailed data for the LX on the relationships of steering wheel angle and torque as a function of speed. How driver preferences or performance were used to select them was omitted.

Adams (1983) provides a detailed description of how power steering systems work and how they can be designed to provide “road feel.” While some of his discussion is concerned with how it can be achieved by changes in valve design, the focus of his paper is on a system that uses a speed-proportional pump to regulate flow to the spool valve. He also alludes to a research vehicle developed by Cam Gears (a TRW English subsidiary) for determining the amount of “feel” drivers desire, but provides no details about it.

Jaksch (1983), in a comprehensive paper, provides a mathematical description of the various parameters that influence vehicle steering and handling and says how that information was used to design the Volvo 760 GLE. One of the relationships considered was steering wheel torque versus lateral acceleration for sinusoidal maneuvers.

Ito, Yoshida, Etoh, and Kozuka (1984) describe the design of an electronically controlled power steering system fitted on the 1984 Mitsubishi Sigma. Their system uses information on both vehicle speed and engine RPM to control system pressure rather than hydraulic fluid flow. They also provide data on effort versus speed, though with fewer details than Nishikawa, Toshimitsu, and Aoki (1978). In addition, they suggest that tests of effort were conducted, but provide no details.

Yamaguchi, Takahashi, Miyoshi, and Fukino (1984) describe Nissan's computer-controlled power steering system. It uses information on vehicle speed and steering wheel angular velocity as input to a flow bypass control valve. In addition, Nissan's design also has a switch, apparently to allow the driver to select one of three effort-speed functions for the 20–80 km range. Their paper contains numerous plots of lateral acceleration versus steering effort as a function of speed (for slalom maneuvers), steering wheel angular velocity versus steering effort as a function of speed, and data on several other system properties. No human performance data are provided.

In addition to increased interest in equipment design, there has been some renewed interest in identifying the various physical parameters that affect steering and handling. Norman (1984) describes the results of a test of domestic and foreign vehicles of various drive (front-versus rear-wheel) and steering system types. The purpose of the test was to evaluate handling for highway driving ("on-center handling"). One of the results emerging from the study was the development of a measure of steering effort: steering wheel torque at .1g lateral acceleration.

PURPOSE

The universe of driver-related factors that could influence handling and steering is quite large. The purpose of the work described in this report is to focus on the question of what power steering efforts drivers prefer. Engineering time spent on a thorough analysis of mechanical considerations is wasted if customer needs (system output) are unknown.

The experiment discussed here is a first attempt to determine the relationship between assist levels and speed. In particular, the following issues were examined:

1. How should the level of power steering assist vary with speed?
2. Do people want the same assist levels in sports and family cars?
3. How does the desired assist level vary with the size and strength of the driver?
4. What characteristics of a maneuver does a driver consider when determining preferred steering assist level?

TEST PLAN

Test Equipment and Materials

Two cars were supplied by Ford Motor Company for this experiment—a 1984 Ford Turbo Thunderbird two-door coupe and a 1984 Ford LTD four-door sedan. These two cars were selected by Ford because they represent distinct vehicle classes (sports and family cars, respectively) from which drivers were thought to expect very different handling characteristics.

The Thunderbird was equipped with a 2.3 liter four-cylinder turbocharged engine, a five-speed manual transmission, and P220/55R 390 Michelin tires. The vehicle was fitted with a variable-assist power steering gear, Ford number 7–026. The overall steering ratio was 15:1.

The LTD was fitted with a 3.8 liter six-cylinder engine, three-speed automatic transmission, and P185/75F14 Firestone tires. The vehicle was fitted with a variable-assist power steering gear, Ford number 6–129. The overall steering ratio was 20:1.

Standard Ford steering systems were used except for the power steering gear assemblies and controlling electronics. These modifications allowed the experimenter to vary the steering assist level while each car was moving in order to assess driver responses. The assemblies were modified by providing two control valves instead of one, and connecting to them a hydraulic flow divider and an electric stepper motor. By varying the relative pump flow to each gear control valve, the system boost could be varied. These design modifications were made by Kelsey-Hayes of Ann Arbor under contract to Ford Motor Company.

Several other minor modifications were made to the steering systems. For the LTD, the steering gear torsion bar diameter was .221 inches, the production size. For the Thunderbird, the steering gear torsion bar diameter was increased to .231 inches to provide more of a sports car feel (higher steering efforts) requested by car buffs. In addition, because of high friction within the flow divider/stepper motor module, the unit was converted to direct drive. Thus, the stepper motor acted directly on the valve spool rather than on an intermediate spring.

The steering assist level was controlled by an electronic unit built under contract for Ford by Engine and Controls Systems, Inc. of Livonia, Michigan. The controller was contained in a small aluminum box about the size of a large tool box. The box was connected to the vehicle via a heavy umbilical cable, linking the back of the box to a connector beneath the instrument panel on the passenger's side. The right front seat in both vehicles was removed to make room for the box and provide additional workspace for the experimenter sitting in the right rear seat.

The box had a thumbwheel that allowed the experimenter to manually select one of nine characteristic curves (increasing in effort from one to nine) that varied the assist level with speed. Shown in Figure 1 is the relationship between pump pressure and steering wheel torque at various settings. (Plots showing torque versus speed were not available when this report was written.) The system could also be programmed to switch automatically between levels at as many as three different speed choice points. That capability was used only in pilot tests.

The controller also had numeric displays for steering wheel torque (inch-pounds), vehicle speed (mph), steering wheel position (degrees), and power steering system pressure (psi). The displays showed instantaneous values, updating about once per second.

The information on vehicle speed was more reliable than the other vehicle performance data. The steering wheel position data were inconsistent, sometimes giving reasonable values and at other times showing large and unchanging negative numbers. The torque readings depended upon how warm the control box was, though temperature shifts were easily compensated for using a knob on the outside of the box to reset the zero torque valve. It is unknown how reliable the system pressure levels were. However, they were constantly changing, especially in the T-bird when the cycling of the cooling fan varied the load on the engine. Because of these variations, it was not possible to read the changing pressure display in a way that absolute values were meaningful.

To collect data on driver body size, a steel tape and a 210 cm caliper from a GPM anthropometric tool kit were used. Weights were measured using a Continental "Health-o-meter" model 230KG doctor's scale with a capacity of 140 kg.

People Tested

Forty-five Ford Motor Company employees, 43 men and 2 women from various Dearborn facilities, served as subjects. They were selected by Ford from a pool of volunteers not directly involved with steering system engineering. Subjects ranged in age from 28 to 62 with a mean of 45. About 40% were in the 35-45 decade. They reported they drove an average of 18,300 miles/year (range 10,000 − 30,000).

Except for one or two staff members, participants were Ford managers. Participants were generally trained in business administration, though there were quite a

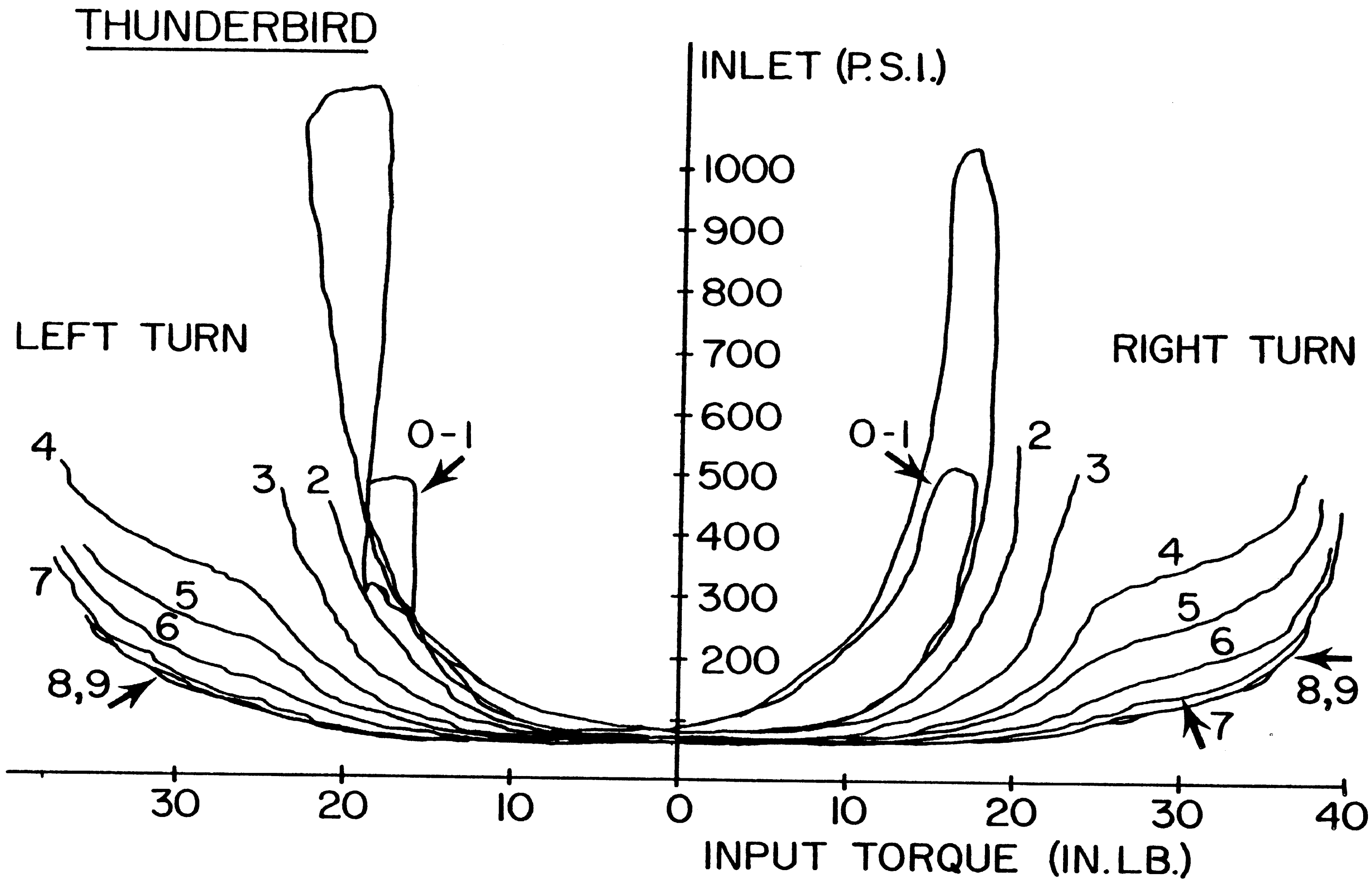


Figure 1a. Thunderbird torque-pump pressure curves.

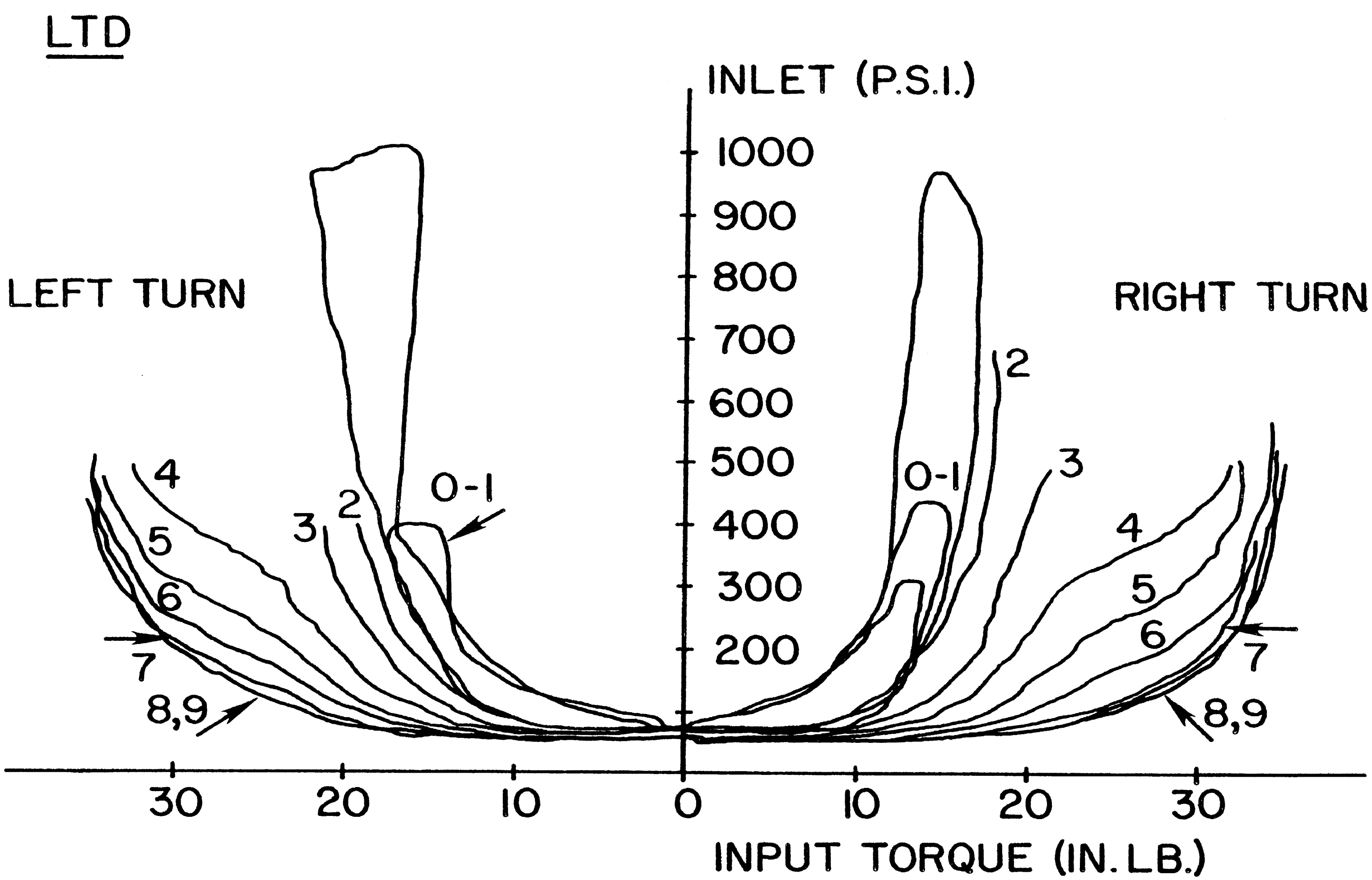


Figure 1b. LTD torque-pump pressure curves.

few engineers. Their work concerned mechanical engineering, materials engineering, product and business planning, and computer graphics.

For a number of analyses, the data of 15 subjects were discarded, leaving a core group of 30 subjects (29 men and 1 woman). Reasons for deleting data included improperly executed test procedures (experimenter errors) and equipment failures that led to erroneous or incomplete data sets.

The core subset had the same age mean, age range, and mean and range of annual mileage as the full sample. In addition, both groups had similar experience in driving a variety of vehicles (with different steering qualities; see Table 1), and similar first-hand knowledge of vehicles. (See Table 2.) Virtually all of the subjects had driven light trucks, and about half had driven other vehicles that have high steering effort levels. Less than half of the subjects were able to do many common repairs. This, and conversations with subjects, suggests they were not familiar with the technical details of steering system design, just as the public would not be.

TABLE 1

TYPES OF VEHICLES DRIVEN

	All Subjects (n=45)			Core Group (n=30)	
	Yes	No	Miss	Yes	No
Have You Ever Driven?	n(%)	n(%)	n	n(%)	n(%)
Light Truck	42(93)	3(7)	0	28(94)	2(6)
Heavy Truck	22(50)	22(50)	1	18(60)	12(40)
Snowmobile	19(43)	25(57)	1	12(40)	18(60)
Motorcycle	18(42)	26(58)	1	12(40)	18(60)
Farm Machinery	15(34)	29(66)	1	10(33)	20(67)
Construction Equipment	7(16)	37(84)	1	3(10)	27(90)
Military Vehicle (Tracked)	6(14)	38(86)	1	6(20)	24(80)

TABLE 2

REPAIRS SUBJECTS CAN DO

Repair	All Subjects		Core Group	
	Yes n(%)	No n(%)	Yes n(%)	No (n(%)
Tuneup	37(82)	8(18)	27(90)	3(10)
Oil Change	40(89)	5(11)	28(93)	2(7)
Brake Lining	28(62)	17(38)	20(67)	10(33)

Ford personnel (instead of the general public) were chosen as subjects because of their accessibility and because Ford believed they were driving the same model lease cars as those being tested. This did not always occur. (See Table 3.) In the interim between when subjects were recruited and when they were tested, many subjects had changed the vehicles they leased from Ford. In addition, many of the leased cars were actually being driven by the subjects' spouses, rather than the subjects.

Test Activities and Their Sequence

Eight different maneuvers were selected for testing: parallel parking, driving a low-speed slalom, driving around a high-speed track, driving in circles, and driving several routes on city streets. Maneuvers were selected so as to include as many different kinds of driving as could be found in the Dearborn, Michigan area. To avoid experimenter fatigue and subject boredom, the test sequence was designed to be completed within two hours.

Testing was done in October, November, and early December of 1984. Temperatures ranged from 30–60 degrees Fahrenheit. November and December were atypically warm and almost snow-free. Tests were conducted on sunny and overcast days, and during light rain showers. Tests were not conducted when it was snowing, during heavy rain storms, when there was ice or snow on the ground, or at any times when visibility or traction were noticeably impaired. All tests were done during the midmorning (9–11 AM) or midafternoon (1:30–3:30 PM) to avoid heavy and distracting traffic, and conflict with subjects' normally scheduled mealtimes.

TABLE 3

VEHICLES DRIVEN BY SUBJECTS

Group ->	All Subjects (n=44, 1 missing)		Core Group (n=30)	
Test Car ->	T-bird	LTD	T-bird	LTD
Their (regularly driven) vehicle				
Continental	8	5	6	3
T-bird/Cougar	4	1	2	0
LTD/Marquis	1	9	0	8
Escort/Lynx	1	1	1	1
Mustang/Capri	6	2	3	0
Ranger (pickup)	1	3	1	3
Tempo/Topaz	0	1	0	1
Other (74 Comet)	0	1	0	1
Total	21	23	13	17

Subjects reported to Ford Building 5 (Product Engineering) in Dearborn, Michigan. They were met by a Ford representative and an experimenter from the University of Michigan and then escorted to the visitor's parking lot. During that walk the purpose of the experiment was explained. (See Appendix A for the full instructions and Appendix B for the associated data sheets.) In addition, a synopsis of the maneuvers was provided. The subject completed several preliminary steps (signing a consent form, etc.), while the experimenter checked that the steering system of the test car (either an LTD or a T-bird) was operating properly. This entailed confirming that the displayed steering wheel angle was zero degrees when the steering wheel was pointed straight ahead, and adjusting the torque display to read zero inch-pounds torque when there was no torque on the steering wheel. In addition, proper operation of variable assist was also quickly checked. Following a Ford-developed procedure, the experimenter set the control thumbwheel to the lowest value (one) and observed the pump pressure. As the setting was slowly increased to nine (at a rate of about one setting per five seconds), the pump pressure should have decreased. In addition, Ford conducted a detailed calibration of both vehicles before this experiment, and a post-test calibration is scheduled. Pre-test data, summarized as plots of torque versus time for two maneuvers, are in Appendix C.

Subsequently, the subject drove out of the visitor's lot to the adjacent employee's lot. (See Figure 2.) To allow the subject to learn of the test car's capabilities, the steering effort was set at the two extremes (first one, then nine) and the subject was asked to weave slowly back and forth for a few hundred feet. If traffic or timing did not permit this to be done on the way out, the weaving was done in the corner of the lot.

To begin the parallel parking maneuver the subject pulled up next to a parked car so that the rear bumper of the test car was even with the front bumper of a car on the right. The subject was then shown an illustration of the parking maneuver. (See Appendix A.) The subject then backed the test vehicle in between the car and truck parked on the right, waited, and then pulled out. The test vehicle was considered parked when it was midway between the two stationary vehicles and within one foot of the curb. Subjects were told to park at a normal pace; the time to park was not recorded. While pulling in, the experimenter recorded the number of movements the vehicle made. (Backing up and then going forward would be two movements.)

When the subject had returned the test vehicle to the starting position, he or she was asked to rate the steering effort on a five-point scale. "Was that too easy, a bit too easy, ok, a bit too hard, or too hard?" The experimenter wrote down a code for the

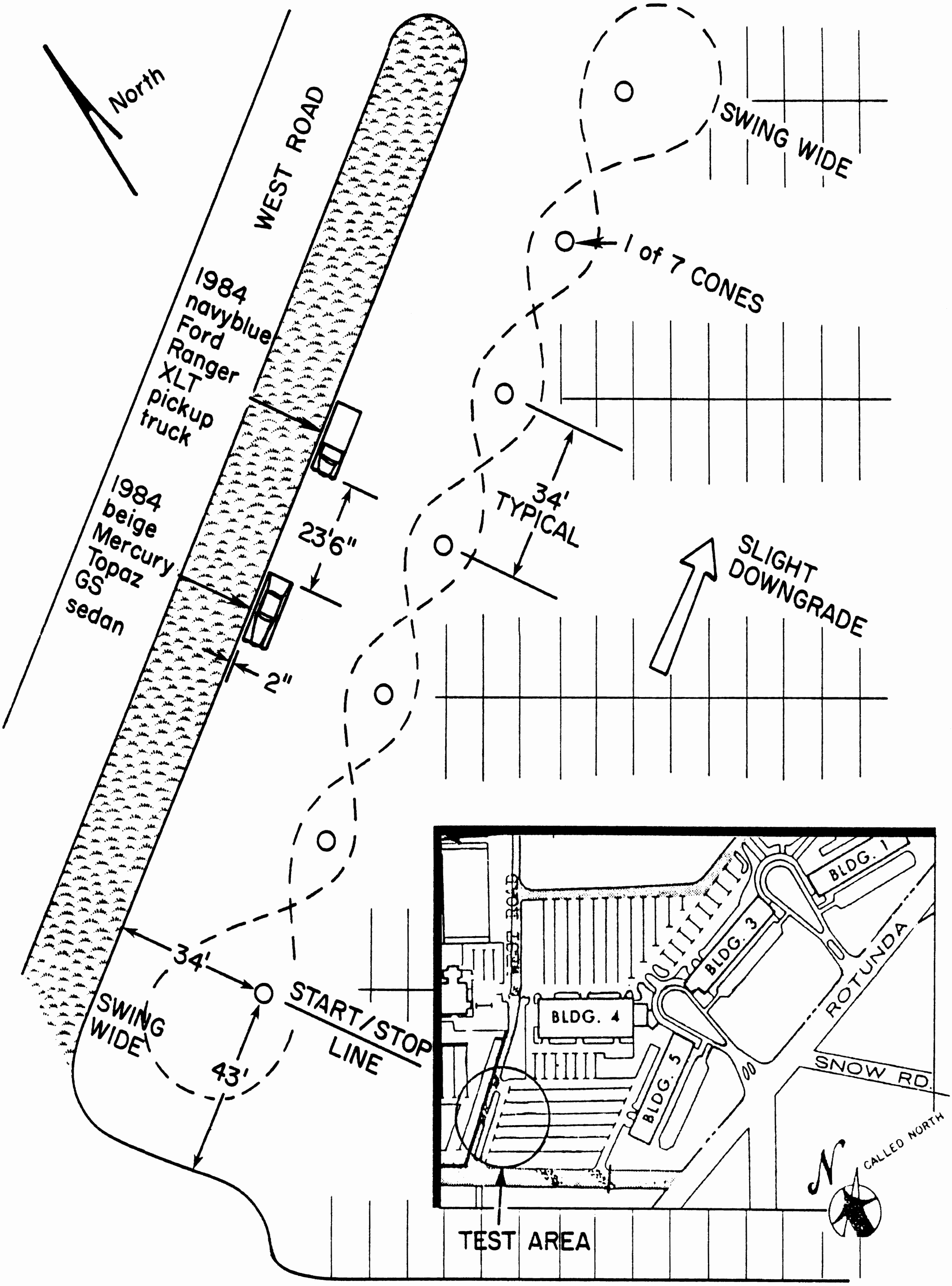


Figure 2. Parking lot - parking and slalom maneuvers.

subject's response (1=too easy, 5=too hard) on a data sheet. (See Appendix B.) Comments were also recorded.

For the first attempt at the parking maneuver the control box was set on one, the lightest steering effort. After each repetition of the parking maneuver, the steering assist setting was increased one step until the maximum (nine) was reached or until the subject said the effort was "a bit too hard" or "too hard." The experimenter then decreased the assist setting until the subject said it was "too easy" or "a bit too easy," or the lowest setting (one) was repeated. (Unfortunately, one experimenter misinterpreted the instructions, truncating the procedure when the subject first said it was "ok" rather than continuing on.) For every setting after the first, the subject was also asked, "In terms of the effort you prefer, was that worse than, the same as, or better than the previous setting?" To avoid excessive repetition of the instructions and minimize what subjects had to remember, key words describing the two judgments ("Was that too easy... Was that worse than...") appeared on a sheet taped above the glove compartment door.

This general procedure of collecting both ascending and descending thresholds, and preferences between successive settings, was followed for all maneuvers. Both directions were examined, because the value reported for a behavioral threshold depends upon whether one is going up or down the scale (Corso, 1967). Except for the high-speed track maneuvers (where it was known from pilot subjects that less assist was desired) and a few other instances where data indicated a particular subject preferred little assist, the search for the ascending threshold always began at setting one. For each new setting the subject was informed of the change, but was not told in which direction.

When the parking maneuver was completed, the subject was shown a sketch (contained in Appendix A) of the low-speed slalom course. (See also Figure 2.) Beginning at the start/stop line (painted on the parking lot), subjects were asked to weave between a straight line of seven cones, holding their speed to about seven miles per hour. Since the instrument panel speedometer did not provide an accurate indication of the vehicle's speed when moving that slowly, supplemental feedback was provided by the experimenter relying upon the speed shown by the control box. As before, effort ratings and preferences were collected.

After completing the slalom maneuver, the subject drove to the Ford Motor Company high-speed test track less than a mile away. (A sketch of the track, a 2.75 mile kidney-shaped loop with banked curves, is shown in Appendix A.) Subjects knew how to get there and most had driven on it before. Upon arriving at the track infield, the experimenter and the subject switched places. The experimenter made one loop of the track, explaining and demonstrating the maneuvers. Subjects were asked to set the cruise control at 60 mph, the posted speed, and drive on the inside lane. On the straight sections only, subjects were asked to gently weave back and forth within their own lane to get a feeling for the effort levels. They were told not to do so on curves. (When the weaving was not demonstrated, as was the case for some pilot subjects, drivers chose maneuvers that were far more severe than desired.)

Ratings of effort and relative preferences were obtained after the subject had driven the test car through at least one major curve and weaved down one straightaway. For the first setting usually an entire loop of the track was completed before judgments were elicited. This was to allow the subject to be acclimated to the track. It was emphasized to subjects that they should not offer a judgment until they were prepared to do so. In a few cases subjects asked for and were given an additional half loop of the track to experience a particular assist level. Because assist changes were sometimes sudden, they were made only at the beginning of straight sections.

After leaving the test track, subjects drove to the concrete pad in the infield. Painted on the pad were three concentric circles with radii of 25, 50, and 100 feet. Subjects were asked to begin by driving counterclockwise around the inner circle so that the left front tire was just outside it. On each trial the effort level was set and then the subject accelerated to 9 miles per hour, made 2 loops around the circle, and stopped. Judgments were then called for, the effort level was changed, and the subject began again. Because of the small turning circle and its repetition, it was possible to become dizzy or even car-sick during this maneuver. Subjects were forewarned of this possibility and told that they could stop at any time.

Subsequent to obtaining ascending and descending preferences for the inner circle, the same sequence of actions was completed for the middle, and then the outer circle. For the middle circle, subjects made only one loop per setting, driving at 14 mph before being asked for a judgment. For the outer circle, driven at 20 mph, a half loop per setting was sufficient to reach a decision.

When the circles were completed, the subject drove to Shady Hollow Drive, about three miles from the test track to the northwest. During the trip to Shady Hollow Drive, biographical information listed in Appendix A (age, job title, etc.) and data on familiarity with vehicles ("Have you ever driven a... Which of the following repairs can you do?) were collected.

Shady Hollow Drive, a two-block-long loop with a single entry/exit street, is adjacent to the Dearborn Country Club. It was chosen because the speeds driven (20 miles per hour actual, 25 mph posted) and turn radii are comparable to those of the circles, but on a real street.

Subjects were asked to drive the Shady Hollow loop counterclockwise. Subjects were exposed to each setting level for one straight section and two curves, and then they were asked about the effort as before. As with the high-speed track, settings were changed only on straight sections, and subjects were always forewarned. Further, subjects were always given additional driving time with a particular setting when they asked for it. To avoid being mistaken for drunk drivers, subjects were asked not to weave on this or any other public roads (as they did on the high-speed track).

In a few instances the drive enroute to the next maneuver was used to complete the biographical and familiarity data. Subjects often used this time to ask the experimenter questions about the experiment.

The final maneuver took place in a residential neighborhood in Dearborn directly south of the Ford Dearborn complex and about four miles from Shady Hollow Drive. (See Figure 3.) The posted speed limit was 25 mph, though most of the driving was done at speeds averaging 20 mph. The route was a series of alternating right and left turns at one-block intervals. Preferences were collected as before, with each subject being exposed to at least one turn and one straight section for each assist level.

When the maneuvers were completed, the subject returned to the starting point at Building 5. In Building 5, an enclosed office was used to collect five anthropometric measures that were potentially correlated with steering effort capabilities and, hence, assist preferences. All measurements were made using metric units. Anthropometric data were collected last, because most people are willing to provide personal information (such as weight) only after they have become thoroughly involved in an experiment.

Standing height (stature) was collected using a 210 cm caliper. Subjects were asked to remove their shoes and stand up straight against a partition with their heels together and hands at their side. Subjects looked straight ahead with their chins neither tucked nor raised.

With their shoes still off, subjects stood on the scale so their weight could be measured. Prior to getting on they were asked to take off their sport/suit jacket and remove any heavy objects from their pockets (wallets, change, keys, writing implements, calculators, etc.).

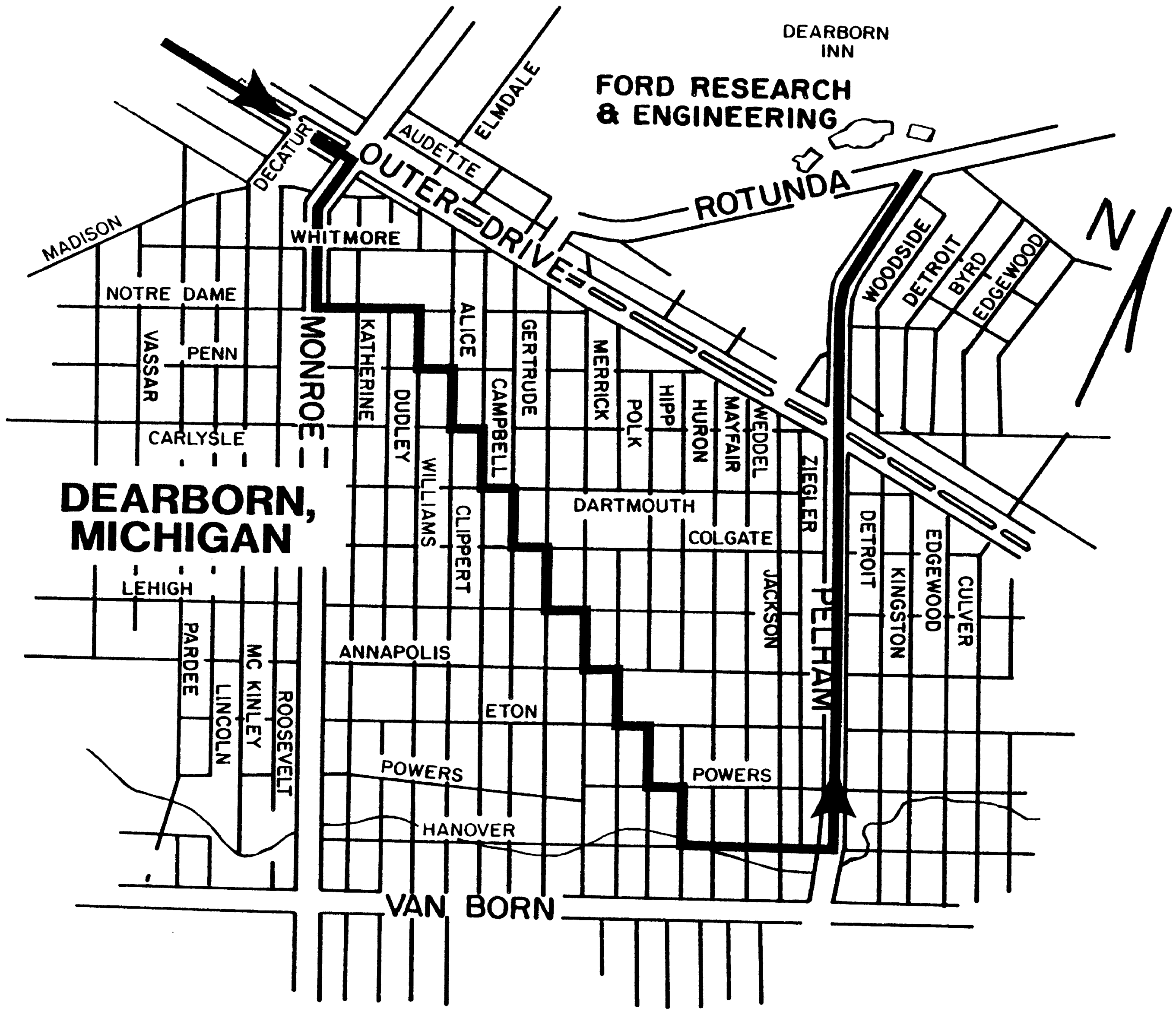


Figure 3. Dearborn zigzag route.

To measure seated head height (the distance from the seat bottom to the top of a person's head), subjects were asked to sit on a desk with their feet dangling over the edge and their hands resting on their thighs. Their backs were unsupported. Data were collected using the 210 cm caliper.

Shoulder breadth was measured from the widest point of one shoulder muscle to the widest point of the other across the front. (It should be noted that one experimenter, after measuring the first subject correctly, measured the front to back distance (shoulder depth) for the remainder.) For subjects who were chubby, there was no clear widest point. For them, measurements were taken about 8 cm below the acromion, the bony prominence of the shoulder. The shoulder breadth measurement was also made using the 210 cm caliper.

Shoulder circumference was measured around the subject, using a steel tape measure. This measurement was taken at the same level as shoulder breadth. Care was taken to run the tape under the subject's tie and to put sufficient tension on the tape so that it fit snugly but did not compress the subject's skin.

RESULTS AND DISCUSSION

Pilot and Development Testing

Findings from pilot tests led to major changes in the research design. The first lesson was that the control system took months instead of days to become operational, far longer than anyone had predicted. This delay significantly affected the cost, duration, and staffing of the project.

A second lesson learned was that all of the maneuvers planned could not be completed in two hours. Additional maneuvers included in the original plans were stall parking (in the same area as the parallel parking) and driving down Telegraph Road (speed limit 45 mph). In addition to time constraints, the high traffic flow on Telegraph made weaving back and forth a dangerous maneuver. Also dropped was the idea of having each subject repeat all of the test maneuvers to obtain reliability data.

Pilot data also revealed problems with the steering control system (or at least early versions of it) in the automatic mode. In one pilot test, subjects were asked to weave through several cones and come to a smooth gradual stop, starting at about 30 mph. Subjects were asked to continue turning the wheel back and forth, even after they had stopped, until they could no longer feel an effort change. The control module was set to switch the effort from very hard (setting=9) to very easy (setting=1) at about 20 mph. Most subjects did not sense an effort change until several seconds after they stopped. Thus, the slow dynamics of the system made it inappropriate to use the automatic mode, because one would not know what assist level the system was operating at when a subject said the effort level was right, only what it was set for.

Also emerging from pilot tests was the conclusion that drivers were likely to rate more than one setting as "ok," but they did prefer some more than others. This led to adding the "better than" judgment to the procedure.

A great deal of time was spent in this preliminary phase assisting Ford in the development of a calibration procedure. Many of the early procedures proved to be unworkable, either because they were not humanly possible, took too long to complete, or required equipment that would not be regularly available. Consequently, the quick check method was developed and used as the primary calibration procedure.

Procedural Matters

The main experiment went smoothly. Many subjects commented positively about the maneuvers, procedures, and staff, suggesting a positive attitude toward the experiment. Most subjects had no problems with the instructions, though there were occasions where desired efforts and responsiveness became confused.

Virtually all subjects completed testing within two hours. Most took 1-1/2 to 2 hours to complete, with 1 hour and 45 minutes being the average. The duration of the individual maneuvers came within 1 or 2 minutes of the predicted times based on the pilot data. The duration for each subject depended upon his or her assist preferences. The greater the desired level, the more that had to be explored and the longer that subject took.

With regard to each specific maneuver, the design goals of the experiment were also met. From pilot data the spacing of the parked vehicles was set so the maneuver would be moderately difficult, and therefore the benefits of power steering would be readily apparent. That goal was achieved. The number of movements ranged from 2 to 8. Forty-five percent of the entries required 3 movements and 28 percent required 4. Subjects tended to park fairly carefully. Of the roughly 450 entries and exits, there were only 6 times where one of the parked vehicles was bumped.

It is worthwhile to point out that the difficulty of this maneuver was observed to be not only a function of the parked vehicle gap, but also of a potentially confounding factor, the drivers' field of view. For both cars it was difficult to see where the rear edge of the trunk was when looking out the back window, and where the front fenders were when looking ahead. The T-bird was the more difficult of the pair because of its rounded shape.

Many of the subjects had some difficulty in holding a constant speed in the low-speed slalom and slowest of the circle tests, especially in the T-bird, a manual transmission car. In fact, except for the parking maneuver and the high-speed track (where the speed was set by the cruise control), most subjects tended to drive too fast, both through the individual maneuvers and when traveling from one maneuver to another. This was particularly true for those driving the T-bird.

There were no problems with the residential driving. Subjects drove at the desired speeds and never got lost. In the zigzag route, there were only a few missed turns and subjects always got immediately back on course, a very favorable outcome considering the number of turns made across subjects. For both these routes, the desired assist level depended mainly upon the effort subjects felt while making turns. That is when subjects were most likely to volunteer comments about steering effort. Usually one turn was sufficient to make a judgment. Where more than one turn was required, it was because the control system had just been switched and not stabilized prior to the turn, or because of distractions from traffic. To avoid experimenter-related distractions, conversation with subjects was held to a minimum except when traveling between maneuvers. The need to control conversation was very apparent in pilot studies. At no time, however, was it controlled so that the atmosphere was unfriendly, stiff, or official.

What Did People Prefer?

The computation of preferences requires some explanation. For a typical maneuver a subject was asked if a maneuver was too easy, a bit too easy, ok, etc. In addition, subjects were asked if particular settings were "worse than, the same as, or better than" the previous setting. If a subject identified multiple ratings as "ok" but one was identified as "better than" the others, then that was the preferred rating. If only one rating was ok, then that obviously was the preferred rating. If several ratings were ok and rated as the same, then the preferred rating was the mean of the ratings. If no settings were called ok, then the preference was assumed to be where the shift from easy to hard occurred. For example, if a subject rated one setting too easy or a bit too easy (e.g., setting 2), and the next value a bit too hard or too hard (e.g., setting 3), then the preferred value was again the mean of the two settings (2.5). If the subject found the bottom of the scale (setting 1) a bit too hard or too hard, then the preference was arbitrarily called 1/2 setting below it (0.5). Likewise on the opposite end, if 9 was rated a bit too easy or too easy, then the preferred setting was called 9.5 .

Using this scheme the mean preferences for each of the eight maneuvers for the LTD and T-bird were computed for the core subset of subjects. Those data along with median and modal preferences are shown in Tables 4 and 5, respectively. Overall, however, the three measures correlate rather well, and subsequent analyses are based upon the means. Histograms of preferences for each vehicle-maneuver combination have been included in Appendix D.

While some might quibble with presenting means for what appear to be ordinally scaled data, the steering assist curves and other data suggest that the preferences are ratio scale data, especially in the middle of the range where many responses occurred. Furthermore, because of the small number of data points (13 T-bird, 17 LTD), the nonparametric measures of central tendency tend to hide subtle differences in the data. This is particularly true for the mode. In several cases there were three or more settings receiving the same number of "votes." (See Tables 4 and 5.)

Before discussing the maneuver-specific differences in detail, something needs to be said about which factors, in general, influenced the preferences. To examine them, Analysis of Variance (ANOVA) was used with Direction (up versus down) and Car (T-bird

TABLE 4

PREFERRED EFFORT SETTINGS FOR THE T-BIRD
(for 13 subjects)

Maneuver	Mean		Median		Mode	
	up	dn	up	dn	up	dn
1-Parallel park	2.1	2.0	2	2	2	2
2-Slalom	2.7	2.3	3	2	3	2
3-High-speed track	5.5	5.1	5	4.5	*	6
4–25' circle	3.2	3.1	3	3	3	2 or 3
5–50' circle	3.7	3.8	3.5	3.5	3 or 4	3
6–100' circle	4.1	3.8	4	4	**	4
7-Shady Hollow	3.4	3.3	3	3	3	3
8-Dearborn Zigzag	4.0	3.2	3	3	3	3

Notes:

* 3.5, 4, 5, 6 all with 2 votes
**1, 1.5, 2, 2.5, 3, 3.5, 4, 5, 5.5, 6.5, 7, 8 all with 1 vote

TABLE 5

PREFERRED EFFORT SETTINGS FOR THE LTD
(for 17 subjects)

Maneuver	Mean		Median		Mode	
	up	dn	up	dn	up	dn
1-Parallel park	2.0	2.1	1.5	2	1 or 1.5	1
2-Slalom	2.1	2.2	2.0	2	1 or 3	*
3-High-speed track	5.4	5.0	6	6	6	6 or 7
4–25' circle	2.8	2.8	3	2.5	4	2
5–50' circle	2.9	3.0	2.5	2	1	2
6–100' circle	3.3	3.2	3	3	1 or 3	3
7-Shady Hollow	2.5	2.4	2	2	1	2
8-Dearborn zigzag	2.4	2.3	2.5	2.5	1	1

Notes:

* 1, 1.5 or 3.5

versus LTD) treated as fixed effects, and Maneuver (8 levels) and Subject-nested-within-Car (12 levels) treated as random effects. (Only 12 subjects per vehicle were examined because the ANOVA software (BMDP8V-Dixon, Brown, Engelman, Frane, Hill, Jennrich and Toporek, 1981) requires a completely balanced design. The subjects discarded were those whose data was thought to be least reliable.) The summary of that analysis is shown in Table 6.

In most studies involving people, individual differences are a major contributing factor, often accounting for the largest percentage of the variances (Simon, 1976). In this ANOVA the differences between subjects were highly significant ($p < .001$). Preferred mean effort settings (averaged across maneuvers) ranged from 1.8 to 6.6 on the T-bird and from 1.0 to 4.9 on the LTD. A variance this large in preferences for power steering assist levels suggests that design decisions should be based on data from a jury of evaluators. The chances of one or two individuals being in the middle of the driver population range are small. Consequently, decisions based on one or two opinions may not reflect what typical drivers want.

TABLE 6

ANALYSIS OF VARIANCE OF PREFERENCES

Factor	df	dfe	F or F'	p
C – Car (T-bird vs LTD)	1	314.9	3.84	<.05
D – Direction (up vs dn)	1	169.0	5.93	<.05
M – Maneuver	7	154	21.38	<.001
S(C) – Subject–within–Car	22	154	12.90	<.001
CD	1	223.1	7.77	<.01
CM	7	154	.93	>.1
DM	7	154	.87	>.1
SD(C)	22	154	.99	>.1
SM(C)	154	–	–	–
CDM	7	154	.63	>.1
SDM(C)	154	–	–	–

One way to satisfy widely varying individual preferences is to allow for driver adjustments. For many years cars have had adjustable seats and steering wheels to accommodate individual differences. Likewise, a control could be provided for drivers to adjust the overall steering effort up or down. Since there were no interactions between subjects and other factors, such a simple adjustment could be effective. For the T-bird only 4 of the 12 subjects (33%) had their mean within +/– 1/2 step of the T-bird group mean, and 2 of the 12 LTD subjects were within +/–1/2 step of the LTD mean.

So far the preferences have been quantified in terms of the power-assist level which could be varied on the test vehicles. The assist level does not equate directly with the level of effort because of day-to-day variations in road-surface conditions, subjects, and test experiment behavior. Thus, these raw figures should be used with some caution.

For a small subset of the subjects, steering wheel torques were recorded during the circle maneuvers for which torque is fairly constant. Because of problems with reading the display and drifts with temperature, the torque data are not completely reliable. Nonetheless, they do provide some indication of the actual torque levels experienced and the associated preferences. Shown in Table 7 are the readings for five LTD subjects for three circle maneuvers. Preferences are indicated by the underlined number. For the inner circle, torques for setting 2 ranged from 10 to 22 inch-pounds and 11 to 23 inch-pounds for setting 3. (The mean setting preference for all 12 subjects was in between: 2.6). The range of the preferences for these five was from 15 to 21 inch-pounds. For the middle circle (again with a 12-subject mean of 2.6), the same trends appear (though for none of the settings were torque readings taken for all subjects. Finally, for the outer circle (preferred mean setting = 3.0 for all 12 subjects), the range for setting 4, an adjacent setting, was from 10 to 20 inch-pounds, while the actual preferences ranged from 12 to 17 inch-pounds. Thus, the range of torques observed at a particular setting was about double the range of torque preferences for these five subjects. While some of this variability is due to the way the maneuver was executed (driving faster or slower overall), variability in the equipment is also suspected.

Returning to the ANOVA, the direction in which one was going was also significant ($p<.01$), with the ratings while going up in the settings (mean=3.1) being slightly greater than the ones going down (mean=3.0). This effect is characteristic of human judgments and supports the need to collect preferences in both directions. It was also the basis for discarding data from subjects for whom a descending threshold was not obtained.

For some unknown reason, there was a significant interaction between the direction in which the ratings were collected (up versus down) and the test car. Mean preferences for the T-bird were 3.7 going up and 3.4 going down, while both were 2.5 for the LTD.

Of primary interest in this experiment were differences due to maneuvers (and speed) and between-car differences. The differences in preferences between maneuvers ($p<.001$) were highly significant. Prior to this experiment, it was thought that speed and preferred settings would be correlated. As shown in Figure 4, there is an approximate linear relationship between preferred setting and speed, equivalent to one setting for each 20-mile-per-hour increment in speed. Further, maneuvers requiring a steady steering torque (driving in circles) show preferences for distinctly higher settings than would be selected for normal driving at the same speed (where the duration of peak forces is brief). This is somewhat surprising, as one might expect effort decisions to be based on force

TABLE 7

TORQUES MEASURED IN CIRCLE MANEUVER
(Ascending only)

Circle	Subject Number	Setting 1	2	3	4	5	6	7	8	9
Inner	15	10	10	11	14	15	18	19		
Inner	17	13	15	16	18					
Inner	19	11	12	15	20					
Inner	23	m	22	23						
Inner	24	16	17	20	21	29	31			
Middle	15				14	16	18	20		
Middle	17			16	20	22	24			
Middle	19	15	17	20						
Middle	23	18	23	25						
Middle	24	18	22	24	26					
Outer	15				10	10	11	12	12	
Outer	17	10	11	14	16	17				
Outer	19	10	12	16	18					
Outer	23	15	16	17	20					
Outer	24	13	14	14	14	17	20			

Note:
m=mising data
The underscore indicates the preferred setting. Where it is midway between categories, so too is the preference.

integrated over time, in which case the data for continuous curves should be below those for highway driving. (Drivers would want more assist, not less.)

The differences in preferred assist settings for the two cars were very highly significant ($p<.001$). The mean for the T-bird (3.5) was a full setting above that of the LTD (2.5). Because the T-bird has a large torsion and for other reasons, it is believed that if a maneuver is performed the same way in both vehicles on the same setting, then the required T-bird efforts will be greater. This, combined with the absence of an interaction between maneuver (or speed) and test car, indicates that people want the T-bird efforts to be uniformly greater than those for the LTD at all speeds. There is, however, a suggestion in Figure 4 that the difference is reduced for parking maneuvers. That reduction is thought to be an artifact of this experiment. When the steering system

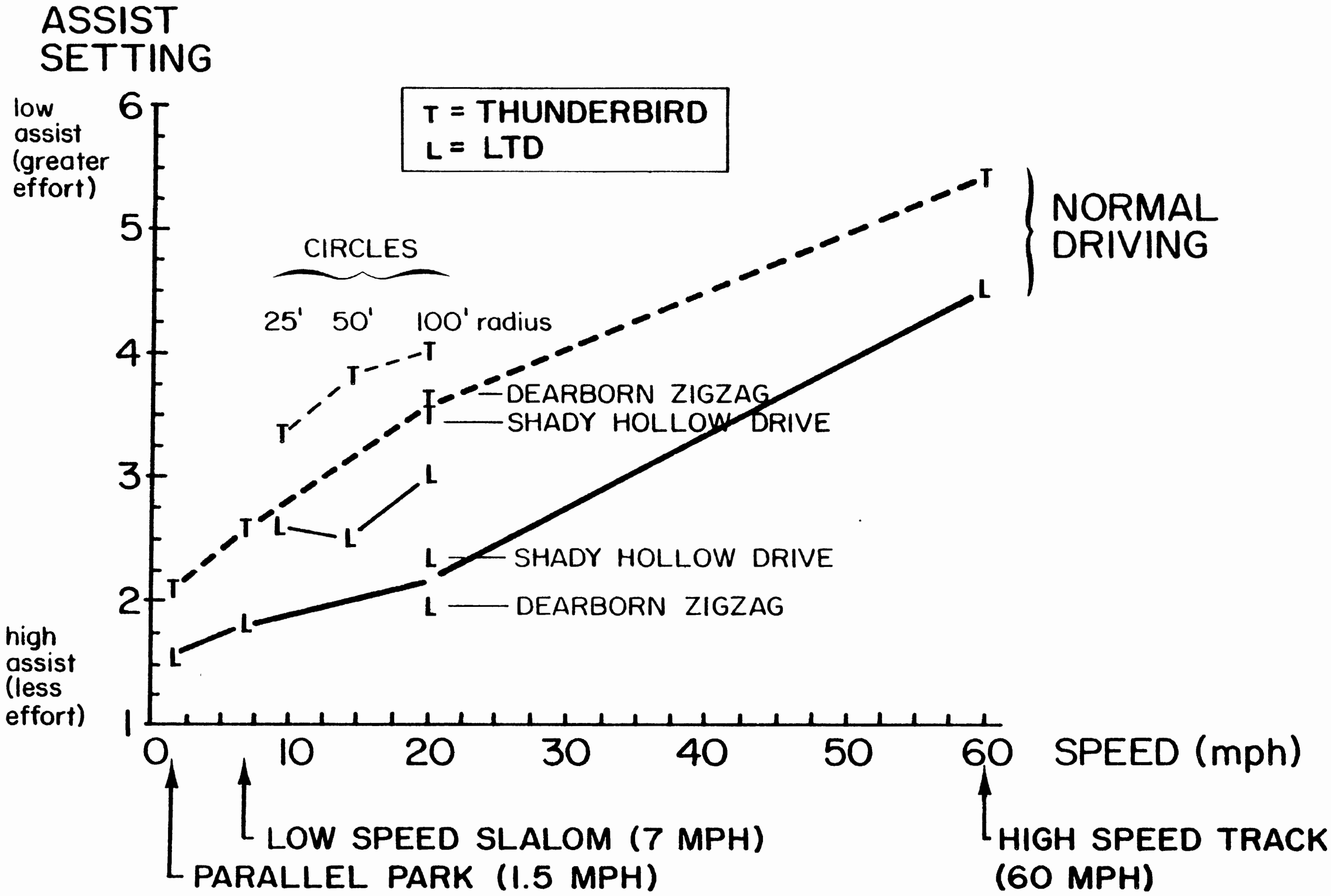


Figure 4. Preferred assist setting by maneuver.
Note: The means used here differ slightly from those of Tables 4 and 5 because a different subset of drivers was used.

was set to maximize assist (setting = 1) in the parking maneuver, some subjects driving the LTD said it was "a bit too hard." On the other hand, some subjects found the maximum effort setting of the T-bird to be "a bit too easy." Had the systems offered a wider range of settings, the preferred mean values at the speed extremes might have been different (lower for the LTD, higher for the T-bird)

What Do People Say Is OK?

In a typical maneuver, drivers usually identified more than one setting as "ok." Shown in Table 8 are the mean number of settings (not the mean setting) identified as "ok" by maneuver, vehicle, and direction in which the threshold was examined. Not shown are the standard deviations of the number of settings called "ok." Typically they were about 75% of the mean.

In general, fewer categories were identified as "ok" for low-speed maneuvers because of range limitations at the low end of the scale. (The effort could not be made easy enough for some.) For maneuvers at the other end of the scale (especially the high-speed track), the differences in effort between settings were small and therefore more categories were likely to be called "ok."

Also included in this report are histograms showing the percentage of the test subjects identifying each setting as "ok" by maneuver and test vehicle. Those histograms are in Appendix E. By and large they show that the preferred setting was near the middle of the range of those settings called "ok."

Can Preferences Be Predicted From Anthropometric Data?

Descriptive statistics for the five anthropometric measures collected for all subjects in this experiment (43 men, 2 women) are shown in Table 9. In Table 10 are the most current similar data for the male adult population (ages 18–74) from the 1974 National Health and Nutrition Examination Survey (referred to as HANES) as summarized in Abraham, Johnson, and Najjar (1979) and Johnson, Fulwood, Abraham, and Bryner (1981). The question is, "Were these Ford employees physically different from the U.S. adult population?" Subjects in this study stood about 3 centimeters (1.2 inches) taller than those in the 1974 survey and differed in sitting height by less than a centimeter. On the other hand, the subjects in this experiment were about 5.3 kilograms (about 11.6 pounds) heavier than those in the '74 survey. The other two measures examined in this study were not collected in '74.

TABLE 8

NUMBER OF SETTINGS CALLED "OK"

Vehicle ->	T-bird (n=13)		LTD (n=17)	
Direction ->	Going up	Going down	Going up	Going down
Maneuver				
Parallel park	1.0	1.4	2.1	1.4
Slalom	1.5	1.6	1.9	1.5
High-speed track	2.5	2.3	2.8	2.5
25' circle	1.5	1.1	2.1	1.3
50' circle	2.4	2.0	1.8	1.5
100' circle	2.3	2.1	2.1	1.7
Shady Hollow	2.0	2.1	1.8	2.1
Dearborn zigzag	2.0	1.8	2.1	1.5

Since 1974 the size of the adult male population has changed. Estimates are that the population is growing at a rate of about 1 cm per decade (Stoudt, 1978). In contrast, it is commonly reported that adult weights have not increased, at least in the last decade, because of increased interest in exercise and nutrition. Thus, it appears the differences between the sample and the male adult population as a whole are fairly small.

These anthropometric data were collected to see if they predicted desired steering efforts. The correlations of all measures with each other and with the mean preferred assist (averaged across maneuvers) for the subjects used in the ANOVA (minus 2 for whom shoulder breadth was not recorded) are shown in Table 11. (The mean and standard deviations of the body measures of this subgroup were almost identical to the entire sample and their preference means were much more reliable.) The correlations of the various body dimensions with each other came close to those reported in the literature. (For example, for Air Force flyers the correlation between height and weight is .52, and weight and shoulder circumference is .83 (National Aeronautics and Space Administration, 1978)).

TABLE 9

SUMMARY ANTHROPOMETRIC STATISTICS FOR ALL SUBJECTS

Measure	Sample Size	Minimum	Maximum	Mean	Standard Deviation
Standing height = stature	45	154.1 cm (60.7 in)	192.0 cm (75.6 in)	178.2 cm (70.2 in)	7.9 cm (3.1 in)
Mass/weight	45	57.0 kg (125.6 lb)	145.3 kg (320.2 lb)	83.3 kg (183.6 lb)	15.8 kg (34.8 lb)
Sitting height	45	79.3 cm (31.2 in)	98.4 cm (38.7 in)	90.8 cm (35.7 in)	3.8 cm (1.5 in)
Shoulder breadth	37	40.0 cm (15.7 in)	64.0 cm (25.1 in)	48.4 cm (19.1 in)	4.9 cm (1.9 in)
Shoulder circumference	45	108.0 cm (42.5 in)	154.0 cm (60.6 in)	120.3 cm (47.4 in)	8.6 cm (3.4 in)

TABLE 10

ANTHROPOMETRIC STATISTICS FOR ADULT MALES (as summarized in Abraham, Johnson, and Najja (1979) and Johnson, Fulwood, Abraham, and Bryner (1981))

Measure	Sample Size	Mean	Standard Deviation
Standing Height	5620	175.2 cm (69.0 in)	7.1 cm (2.8 in)
Mass/weight	5620	78.0 kg (172.0 lb)	13.8 kg (31.1 lb)
Sitting height	5261	91.7 cm (35.9 in)	3.9 cm (1.5 in)

Shoulder breadth shows the highest correlation with assist preferences, although the correlation was not quite statistically significant ($r(18) = .38$, $p = .1$). When these correlations were examined by vehicle, the correlation with preference was comparatively

TABLE 11

CORRELATIONS BETWEEN MEASURES

Measure					
Standing Height = Stature					
Weight	.40				
Sitting Height	.65	.24			
Shoulder Breadth	.29	.67	.07		
Shoulder Circumference	.27	.93	.07	.80	
Mean Assist Preference	.17	.17	.07	.36	.30
	Stature	Wt.	Sit. Ht.	Sh. Brdth.	Sh. Circ.

larger for the LTD (r=.58) and smaller for the T-bird (r=.22). Most likely these changes are just chance variation. Thus, though not statistically significant, the suggestion that bigger people prefer higher steering efforts cannot be dismissed. While this seems to be a minor point, many would claim that preferences are purely psychological phenomena and have nothing to do with body size (or strength).

The correlations between preferred assist settings and body size also are cause for some caution in associating the preferences reported here with those for all drivers. Just under one half of all drivers are female. Females average 13.7 centimeters (5.4 inches) shorter and 13.1 kilograms (29.0 pounds) less. Had more women been included in the sample (only one was included in the correlation computations), the correlations between preferences and body size would most likely have improved, because the range of body sizes would be increased.

More importantly, women tend to have considerably less upper body strength than men (about 40% less according to Laubach, 1976). Since it is primarily upper body muscles that are used in steering, the setting estimates generated based on this group of almost all male subjects will probably be too high for the general adult population, which is almost half female.

CONCLUSIONS

Basic Issues

At the outset of this experiment four key questions were identified as the focus of this experiment.

1) How should the level of power steering assist vary with speed?

According to these data, the power steering assist should increase about one setting for every 20 miles per hour, using the setting-torque combinations for the two cars as modified for this test. Typically, subjects in this experiment desired a setting of about 2 for parking maneuvers and 5 for driving at 60 mph.

Commentary:

Given the constraints of this experiment, preferences for assist were remarkably consistent. For example, for the two residential routes driven at 20 mph, the preferences were within a fraction of a setting of each other. This consistency is also reflected in the ANOVA of the preferences where the effect of maneuver (essentially speed) was highly significant ($p<.001$).

In examining these data the reader should bear in mind that these data are far from exhaustive. Particularly noteworthy is the gap between 20 and 60 mph, where no data were collected.

2) Do people want the same assist levels in sports and family cars?

No. The subjects wanted the assist for the sports car (the T-bird) to be about one setting greater than that for a family car (the LTD). In this experiment that difference was statistically significant ($p<.05$) and consistent at all speeds. (The interaction with maneuvers was not significant.)

Commentary:

Because of the way the control system was designed, the range of efforts it offered was sometimes less than what drivers wanted. For the LTD in parking maneuvers, some drivers thought the lowest level was "a bit too hard." Likewise for the T-bird, some drivers thought the highest setting (maximizing effort) was "a bit too easy." Had a greater range of efforts been provided, the differences between vehicles might not have been constant. Further, one must bear in mind that the T-bird was modified to offer greater average efforts than those found in production models.

Complicating the selection of desired effort levels are the large and highly statistically significant individual differences ($p<.001$). Fortunately, subject differences did not interact with any of the other factors in this experiment. Nonetheless, if the effort-speed combination was set at the mean levels for each car-speed combination tested, only about 25% of the subjects in this experiment would get the settings they preferred.

On the other hand, subjects typically identified about two settings as "ok." Using that criterion, a much larger percentage of the sample would be satisfied with the settings provided.

An alternative approach would be to provide the driver with a control to allow him or her to select the overall steering assist level. Since individual preferences did not interact with any of the other variables (especially the maneuver), this adjustment could be relatively straightforward. However, it is not clear how effective providing this capability would be. The ease of use of the control and driver motivation to make the adjustment are key factors, especially for cars driven regularly by more than one person. If the system is not well designed, drivers could be better off with a fixed setting than one that could be misadjusted by them.

3) How does the desired assist level vary with the size and strength of the driver?

The assist settings desired by drivers are possibly correlated with driver size or strength. Shoulder breadth (and to a lesser extent, shoulder circumference) were correlated with driver preferences for steering assist at a level close to that which would be statistically significant. Driver stature, weight, and sitting height were unrelated.

Commentary:

This sample of subjects contained only two women. Had more been included in this experiment, the correlations between body size and mean preferences would have increased. Restricting the range of a variable in a correlation always decreases the size and significance of its correlation with other variables.

Further, because women on the average have much less upper body strength than men (and presumably want to exert less torque), the preferred settings obtained in this experiment, which are biased towards men, are too high for the driving population as a whole, half of whom are women.

Also deflating the correlations, especially those involving shoulder breadth and circumference, was the use of multiple experimenters. Soft-tissue measures are particularly tricky to do, and slight variations in technique can lead to vastly different readings.

4) What characteristics of a maneuver does a driver consider when determining the preferred assist level?

In addition to the speed considerations previously mentioned, preferred assist judgments appear to be based upon a time-weighted average of the torques to be exerted. Drivers appear to focus their attention on the curves and swerves, since it is during those periods when they offer comments about steering effort. Surprisingly, drivers prefer less assist (greater efforts) for continuous curves at a given speed than ordinary highway driving.

Procedural Changes Suggested for Future Studies

The basic approach of this experiment proved to be a sound, workable, and cost-effective solution to the questions posed. The up/down method proved to be the appropriate procedure. As was expected, thresholds collected in each direction differed. The differences were small but nonetheless statistically significant ($p<.05$). Since representative data are desired, the same procedure should be used in future studies. In addition, categorical ratings of effort (too easy, ok, etc.) should also be collected, again using a five-point scale.

The two-hour time limit seemed to be a reasonable test duration. There was no evidence of subject boredom or fatigue. In future studies it might be desirable to test some subjects more than once to examine day-to-day variations (reliability) and more cleanly test between-vehicle differences. (In this experiment no subject drove both vehicles. It was not possible because of time constraints.)

For that matter, the variety of maneuvers also helped maintain subject interest. In subsequent studies, one of the residential driving maneuvers should be deleted. Two were included to provide an indication of the reliability of the procedure. Since the reliability is now known to be good, it is suggested that another maneuver be substituted to include the experience of highway driving at about 40 mph. This new maneuver would fill in a major gap in the effort-setting/speed function.

Also needed is a circle maneuver at about 40 mph. Because of time restrictions, it will be appropriate to substitute a 40 mph circle for the middle (50') circle maneuver. This maneuver would extend the generality of the finding that drivers prefer greater efforts for continuous circles than driving on city streets (with turns of the same radii) at the same speeds.

In addition to changing the maneuvers slightly, changes should also be made in the anthropometric measures taken. Biacromial breadth (a measure of shoulder breadth) should be added, along with measures of shoulder and arm muscle size. It is expected that these additional measures will take two minutes to collect. Anthropometric data are needed so the similarity of driver samples in various steering effort experiments can be compared.

It is important that future studies be conducted in such a way that the data are more generalizable. The data collected in this experiment are specific to the steering assist levels provided on the two vehicles tested. Changes in vehicle weight, torsion bar sizes, tire size or inflation pressure, or other common variations will alter the torques drivers experience in steering these cars. So, too, will the preferred steering assist settings change. This experiment would have had more general utility had it been possible to express subject preferences directly in terms of steering wheel torque.

To make future studies more generalizable, two things need to be done. First, a concerted attempt should be made to model the steering effort preferences as a function of the dynamics of the vehicle being driven, driver expectations about that class of vehicle, and the maneuver being performed. The goal should be to develop an adjunct to models of steering behavior similar to the feedback control and optimal control models used to examine handling qualities. This model would allow designers to match steering efforts to driver preferences on paper, rather than requiring tests using prototypes.

Second, the scope of future studies will have to be much larger than this one. Sophisticated equipment will be required to collect steering wheel angle and torque, vehicle speed, system setting, and other measures on a moment-by-moment basis. Unless that equipment is highly reliable, conducting such a study could be wasteful. There were occasions in this experiment when the system displayed steering wheel angles and other data that did not appear correct. Where torques were measured for the same maneuver performed by different subjects, the range of the torques offered by a setting was twice the range of driver preferences (for five subjects driving the LTD). A means to adjust for day-to-day variations in effort and automatically calibrate the system is most needed.

Also of value would be a digital speedometer, visible to the driver, specifically designed for accuracy at low speeds. Extending the range of the cruise control to operate at lower speeds or providing an adjustable speed governor would also prove to be useful.

Both devices would reduce the opportunities for error. If these devices cannot be provided, then the instructions for how fast to drive a manual transmission car should be given as a gear-RPM combination for slow speeds. ("Please hold the engine speed to 1900 RPM in first gear.")

Should all of this equipment be added, much more thought will have to be given to what data should be collected and when. Because one must sample several times per second to capture all driver responses, and maneuvers can last for several minutes and there are multiple maneuvers, it is quite possible to collect a megabyte or more of data per subject. Thus, the data acquisition system should be designed with a specific data reduction method in mind.

Along with these additional performance measures, new behavioral measures should also be recorded. The choice of hand motions (hand to hand, hand over hand, hand under hand, one finger, palming) while parking and steering through the low-speed slalom may influence driver effort preferences. At greater speeds the number of hands used and hand position on the wheel should be examined.

Probably the most significant change is who should be tested. In future studies the general public, and especially women, should be included in the sample. If steering settings are to be determined for the driving public, then people included in experiments should be representative of the customers.

Finally, some minor modifications are needed in the instructions to subjects. Occasionally a subject would confuse "effort" with "responsiveness" at the beginning of the first maneuver.

This experiment was a very positive first step in addressing questions of how variable-assist power steering systems should be designed so as to meet the broadest range of driver preferences. All of the questions posed at the beginning of the experiment were answered. Both subjects and experimenters enjoyed participating in it, with subjects frequently noting that they were glad their opinions and views as pseudo-customers were being solicited. They repeatedly emphasized the need for decisions to be based on scientific data, and not speculation or the personal experiences of only a few individuals.

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APPENDIX A

SUBJECTIVE EVALUATION OF STEERING EFFORT LEVELS
INSTRUCTIONS TO EXPERIMENTERS AND PARTICIPANTS

****

SUBJECTIVE EVALUATION OF STEERING EFFORT LEVELS
INSTRUCTIONS TO EXPERIMENTERS AND PARTICIPANTS

****

If needed, get fuel before the test begins. To get to the fuel station from the parking lot, take West Road and go towards Oakwood. Turn left at the street just before it. One block ahead on the right is the fuel station. Pull in and open the fuel filler door. The release button is in the armrest between the seats. The manual override is in the trunk. (The trunk can be opened using either the keys or the pushbutton in the glove compartment.) After filling up, mark down the mileage shown on the odometer, the department number (K8710), the fuel in gallons, and the vehicle number (T-bird=579T92, LTD=579T208, both noted on the keys and a windshield tag)) on the blue sheet under chassis engineering-test (T). Oil, washer, and other fluids can be obtained from the building nearest the pumps. Use the entrance closest to them.

Also before the test begins, set up the cones in the parking lot for the slalom. Further, be sure to calibrate the steering system three times/day (before the first subject, after the first subject, and after the second subject.) The calibration instructions are on a separate sheet.

Have the subject meet you on the third floor of Building 5.

ARE YOU___? HELLO, MY NAME IS _____ AND I AM THE EXPERIMENTER FOR THE STEERING EFFORT STUDY. (Don't say "test".) BEFORE WE GET GOING I WOULD LIKE TO NOTE THIS EXPERIMENT TAKES ABOUT 2 HOURS. IF YOU WOULD LIKE TO VISIT THE REST ROOM, NOW WOULD BE A GOOD TIME TO DO IT.

Walk to the car. While walking state the instructions. THE PURPOSE OF THIS EXPERIMENT IS TO EXAMINE THE HANDLING CHARACTERISTICS PEOPLE WOULD LIKE CARS TO HAVE. FORD HAS ASKED THE UNIVERSITY TO BEGIN LOOKING AT THAT QUESTION BY TESTING FORD PERSONNEL WITH LEASE CARS. YOU WILL BE ASKED TO DRIVE A MODIFIED T-BIRD TURBO COUPE OR A MODIFIED LTD, WHICHEVER YOU NORMALLY DRIVE, AROUND A PREVIOUSLY DETERMINED ROUTE. THE ROUTE INCLUDES PARKING MANEUVERS, LOOPS

AROUND THE DEARBORN TEST TRACK AT NORMAL SPEEDS, AND DRIVING ON THE STREETS OF DEARBORN. THIS TEST WILL TAKE ABOUT 2 HOURS TO COMPLETE.

THERE WILL BE NO SMOKING DURING THE TEST EXCEPT DURING BREAKS. IF YOU WISH TO SMOKE, WE ASK THAT IT TAKE PLACE OUTSIDE OF THE CAR.

YOU MAY WITHDRAW FROM THIS EXPERIMENT AT ANY TIME IF YOU WISH.

HERE IS THE CONSENT FORM THAT HAS IN WRITING WHAT I JUST SAID.

PLEASE SIGN IT SO WE CAN BEGIN.

Have the subject sign the form.

Both the experimenter and the subject should now get in the car. BEFORE WE GET STARTED, WHY DON'T YOU ADJUST THE SEAT AND MIRRORS SO THEY ARE WHERE YOU WANT THEM.

Open the grey box. Turn on the power (if you didn't before) and set the mode to manual. Make sure the switch by where the cable connects to the instrument panel is down.

PLEASE START THE CAR AND DRIVE OUT TO THE FAR EDGE OF THE LOT. I SHOULD NOTE THE PURPOSE OF THIS EXPERIMENT IS TO DETERMINE HOW THE STEERING SYSTEM SHOULD BE DESIGNED. THE FOCUS OF THIS EXPERIMENT IS ON HOW WELL THE SYSTEM HAS BEEN DESIGNED TO SUIT YOU AND NOT HOW WELL YOU DRIVE. THIS VEHICLE HAS BEEN DESIGNED SO THAT I CAN VARY THE STEERING EFFORT AND SENSITIVITY. IT CAN RANGE FROM THIS (set to 1) TO THIS (set to 9). (Have the subject waggle the steering wheel to get an indication of the assist levels.)

Set the steering system effort to 1 using the top thumbwheel in the grey box.

To get out of the visitor's lot, enter the "secret" number (4891, formerly 6810) on the number pad on the exit gate.

PLEASE PULL UP TO THE TAN TOPAZ AS IF YOU WERE GOING TO PARALLEL PARK BETWEEN THE TOPAZ AND THE PICKUP TRUCK, AND THEN STOP. (Show drawing of parallel parking test to the subject.) THIS PART OF THE EXPERIMENT IS CONCERNED WITH DETERMINING STEERING EFFORT LEVELS FOR PARALLEL PARKING. AS SHOWN ON THE DIAGRAM, YOU BEGIN WITH THE BACK OF YOUR CAR EVEN WITH THE FRONT OF THE TOPAZ. WHEN I SAY "GO" PLEASE BACK INTO THE SPOT AT A NORMAL, SAFE SPEED. THE CAR IS CONSIDERED "PARKED" WHEN IT IS CENTERED IN THE SPOT WITHIN 1 FOOT OF THE CURB AND THE WHEELS ARE STRAIGHT AHEAD. LET ME KNOW WHEN YOU ARE DONE.

GO – The subject parks the car.

OK, NOW I WANT YOU TO PULL OUT AND PUT THE CAR WHERE IT WAS BEFORE YOU BACKED IN. GO AHEAD. (In the comments column, record the number of times the subject changed direction. Record entering and leaving the spot separately.) OK, HOW WAS THAT, TOO EASY, A BIT TOO EASY, OK, A BIT TOO HARD, TOO HARD? (Record the response code (1-5) on the data sheet.)

OK, NOW WHY DON'T YOU TRY IT WITH THE STEERING SYSTEM ON THIS SETTING. GO. (Continue repeating until the subject says the steering is either a bit too stiff or too stiff, whichever comes first. For each step, record the number of direction changes and the response code. Then reverse the direction of the thumbwheel settings, make the vehicle easier to steer. Repeat until and including setting 1 or the subject says it is either a bit too easy or too easy, whichever comes first.

FINE. THE NEXT PART OF THE EXPERIMENT INVOLVES DRIVING THROUGH THE SLALOM. AS SHOWN ON THIS DIAGRAM, (show the diagram) YOU START AT THAT END (point to it) AND WHEN I SAY GO, DRIVE THROUGH THE SLALOM AT ABOUT 7 MILES PER HOUR. WHEN YOU GET BACK TO THE START/STOP LINE, STOP UNTIL I TELL YOU TO GO AGAIN. SINCE THE INSTRUMENT PANEL SPEEDOMETER DOES NOT DISPLAY SPEED ACCURATELY WHEN GOING THAT SLOWLY, I'LL TELL YOU IF YOU ARE GOING TOO FAST OR TOO SLOW. (THE TEST INSTRUMENTATION IN THIS BOX GIVES ME A MORE ACCURATE READING OF THE CAR'S SPEED.) IN CASE YOU ARE WORRIED, 7 MPH IS ACTUALLY QUITE SLOW FOR THIS SLALOM.

Reset the thumbwheel to 1 (easy).

OK, PLEASE DRIVE UP TO THE START LINE. GO.

As the subject drives through the slalom, watch the speed. If the subject goes 9 or 10 mph, be sure to tell him or her to slow down. With the LTD going downhill, one only needs to touch the accelerator to go fast enough. Also make sure the subject swings wide at the bottom.

When the subject gets back to the start/stop line ask the following. WAS THAT TOO EASY, A BIT TOO EASY, OK, A BIT TOO HARD, OR TOO HARD? Record the subject's response. Repeat the process with a higher setting of the steering system and continue repeating it until the subject says it is a bit too hard. Then, repeat the process in the opposite direction (making it easier) until the subject says it is a bit too easy or too easy.

FINE. THE NEXT PART OF THE EXPERIMENT TAKES PLACE AT THE TEST TRACK. DRIVE TO THE PARKING LOT EXIT AHEAD OF US AND MAKE A RIGHT TURN. (Subject drives out of lot.) GO STRAIGHT AHEAD AND CROSS OAKWOOD. (Wave to the guard in the guardhouse.) NOW MAKE A RIGHT TURN AND KEEP TO THE RIGHT TO GET TO THE TEST TRACK. SOME PEOPLE DON'T REALIZE THIS RAMP CARRIES TWO-WAY TRAFFIC. MAKE SURE YOU STAY TO THE RIGHT.

When you get to the center area say—PLEASE STOP HERE. LET'S SWITCH SO I CAN SHOW YOU WHAT I WOULD LIKE YOU TO DO NEXT. (Switch positions for the demo loop. Make sure you and the subject have fastened your seat belts and the headlights are on. (The track rules require that your lights be on during a test.) Also lock the doors.

I AM GOING TO DRIVE ONE LOOP AROUND THE TRACK TO SHOW YOU THE MANEUVERS I WOULD LIKE YOU TO PERFORM. (Enter the track and get up to speed (60 mph).) When you reach a straight section say—WHENEVER YOU ARE ON A STRAIGHT SECTION I WOULD LIKE YOU TO WEAVE BACK AND FORTH A BIT LIKE THIS. THE IDEA IS THAT THIS KIND OF MANEUVER WILL HELP YOU DECIDE HOW THE CAR IS HANDLING. WHILE I REALIZE THE CAR IS CAPABLE OF HANDLING FAR MORE SEVERE MANEUVERS, FOR REASONS OF SAFETY WE WOULD LIKE TO KEEP THE WEAVING FAIRLY MILD. BEFORE YOU PERFORM A WEAVING MANEUVER, ALWAYS CHECK IN YOUR MIRRORS TO MAKE SURE

THERE ARE NO OTHER VEHICLES NEARBY. (For that matter, the experimenter should also be on the lookout for other vehicles.)

DO ALL OF YOUR DRIVING ON THE INSIDE LANE WITH THE CRUISE CONTROL SET AT 60 MPH. DO YOU KNOW HOW? If the subject says no then say—FIRST YOU PUSH THIS TAB ON THE STEERING WHEEL SPOKE LABELED "ON." THAT TURNS THE SYSTEM ON. NEXT YOU ACCELERATE TO 60 MPH AND WHEN YOU ARE AT THAT SPEED YOU PRESS THE "SET" BUTTON. YOU CAN THEN TAKE YOUR FOOT OFF THE ACCELERATOR. TO SLOW DOWN EITHER HIT THE "OFF" BUTTON OR STEP ON THE BRAKE.

NOW IT IS YOUR TURN TO DRIVE. (Get off at the exit and switch positions.)

Set the thumbwheel to 3. Have the subject get on the test track and set the cruise control to 60 mph. After the subject has gone through 2 curves and weaved down a straight section ask – HOW DOES IT FEEL? IS IT TOO EASY, A BIT TOO EASY, OK, A BIT TOO HARD, OR TOO HARD. Record the subject's response on the data sheet. If the subject says it is "too easy" then skip to 5, otherwise keep increasing the effort using the thumbwheel, allowing the subject to go through two turns and one straight before asking the subject how the steering feels. Continue increasing until the subject says the steering is a "bit too hard" or after a 9 setting, whichever comes first. Then, decrease the thumbwheel value until the subject says the steering is a "bit too easy."

While driving make sure the headlights are on and you watch for other cars on the track.

When this task is done say—THIS PART OF THE EXPERIMENT IS DONE. PLEASE TAKE THE TRACK EXIT OVER THERE. When you reach the center area say – PLEASE DRIVE UP TO THE PARKED TRAILERS AND MAKE A LEFT TURN. When you get there say—IN THIS SECTION OF ROAD PLEASE KEEP TO THE RIGHT TO AVOID THE BUMPS.

When you get to the circle pad. PLEASE STOP FOR A MINUTE. Set the thumbwheel to 1. IN FRONT OF YOU ARE 3 CONCENTRIC CIRCLES PAINTED ON THE PAVEMENT. WE WILL START WITH THE INSIDE CIRCLE. PLEASE MAKE 2 CONTINUOUS LEFT LOOPS AROUND IT AND THEN STOP. DRIVE SO YOUR LEFT TIRE IS JUST OUTSIDE OF THE CIRCLE AND DO SO AT ABOUT 9 MPH. TRY AND

DRIVE AROUND THE CURVES SMOOTHLY WITHOUT WEAVING BACK AND FORTH. (Watch the speedo in the grey box as the subject drives.) OK, GO. As the subject makes the maneuver observe the torque display. When the subject stops, record a "typical" value for the 2 loops. WAS THAT TOO EASY, A BIT TOO EASY, OK, A BIT TOO HARD, OR TOO HARD? Record the subject's response. As before, keep increasing the thumbwheel until the subject says "bit too hard" or "too hard" and then decrease it until the subject says "too easy" or "a bit too easy" or he or she says 1 is ok.

Set the thumbwheel to 1. I WOULD LIKE TO REPEAT THE PROCESS WITH THE MIDDLE CIRCLE, ONLY THIS TIME STOP AFTER EVERY LOOP. THIS TIME PLEASE DRIVE AT ABOUT 14 MPH. Repeat the process of going past the threshold and then reversing direction and going past it again. After each loop, record the response code and a "typical" torque value.

Set the thumbwheel to 1. LAST I WOULD LIKE YOU TO DO THE OUTER CIRCLE. THIS TIME I WILL ASK YOU HOW IT FEELS EVERY HALF LOOP. YOU NEED NOT STOP. Repeat the threshold determination process, making sure you record the torque levels.

OK, STOP. Set the thumbwheel to 4. THE LAST PART OF THE DRIVING INVOLVES GOING THROUGH SEVERAL RESIDENTIAL SECTIONS OF DEARBORN AND DEARBORN HEIGHTS AS SHOWN ON THIS MAP. (Show the subject the map.) AS YOU CAN SEE YOU TAKE OAKWOOD NORTHWEST PAST MICHIGAN AVENUE. AT MICHIGAN AVE MAKE SURE YOU STAY IN THE CENTER LANE. OAKWOOD DEAD ENDS AT MORLEY. MAKE A RIGHT TURN THERE AND KEEP GOING UNTIL YOU GET TO BRADY. AT BRADY MAKE A LEFT. FOLLOW BRADY UNTIL YOU GET TO GOLF CIRCLE AND THEN MAKE A LEFT. WHEN YOU COME TO SHADY HOLLOW DRIVE MAKE A RIGHT TURN AND STOP. DON'T WORRY ABOUT REMEMBERING THESE DIRECTIONS. I'LL REMIND YOU WHEN TO TURN.

When you get to Shady Hollow Drive and have stopped, set the thumbwheel 1. THIS STREET FORMS A LOOP. JUST AS ON THE TEST TRACK AFTER 2 LOOPS AND A STRAIGHT SECTION, I'LL ASK YOU HOW THE STEERING FEELS, RECORD YOUR COMMENTS, AND THEN CHANGE THE EFFORT LEVEL. ANY QUESTIONS? OK, THEN BEGIN. MAKE A RIGHT TURN ON SHADY HOLLOW SO YOU DRIVE

AROUND THE LOOP COUNTERCLOCKWISE. ... IS IT TOO EASY, A BIT TOO EASY, OK, A BIT TOO HARD, OR TOO HARD? Repeat the process as before, collecting ascending and descending thresholds and recording the response codes.

WHY DON'T YOU STOP HERE SO I CAN SHOW YOU THE REST OF THE ROUTE. (Show the subject the map.) NEXT I WOULD LIKE YOU TO MAKE A RIGHT TURN FROM SHADY HOLLOW ON TO GOLF CREST AND FOLLOW IT UNTIL IT DEAD ENDS INTO CHERRY HILL. MAKE A RIGHT AT CHERRY HILL AND CONTINUE ON CHERRY HILL UNTIL YOU REACH OUTER DRIVE. YOU WANT TO EVENTUALLY GO SOUTH (LEFT) ON OUTER DRIVE. TO DO THAT MAKE A RIGHT TURN ONTO OUTER AND THEN GO ABOUT 100 FEET TO THE U-TURN CUT INTO THE CENTER ISLAND. TAKE OUTER DRIVE TO MONROE AND MAKE A RIGHT ONTO IT. TAKE MONROE TO NOTRE DAME WHERE YOU MAKE ANOTHER RIGHT. THEN GO DOWN THREE STREETS AND ZIGZAG THROUGH DEARBORN, ALTERNATING LEFT AND RIGHT TURNS AT EVERY CORNER. DURING THIS ZIGZAG SECTION, I WILL AGAIN REPEAT THE PROCEDURE OF ASKING YOU HOW THE STEERING SYSTEM FEELS. YOU NEED NOT WORRY ABOUT REMEMBERING WHEN TO TURN. I'LL TELL YOU WHEN. OK? THEN GO.

When you get to Williams, begin repeating the threshold procedure. Start at 1 and after every turn and a straight section, ask the subject how the steering feels. Continue increasing the thumbwheel until the subject says it is "a bit too hard" or "too hard" and then go in the opposite direction as before. If you have gone up and down but still have several turns left, cut the route off and head for Pelham.

THAT'S FINE. PLEASE DRIVE BACK TO BUILDING 5. GO LEFT ONTO PELHAM, CROSS ROTUNDA, AND TAKE THE SECOND RIGHT TO ENTER THE VISITOR'S PARKING LOT.

THERE IS ONE MORE THING YOU NEED TO DO. PLEASE FOLLOW ME UPSTAIRS FOR A MOMENT.

THE LAST THING WE ARE GOING TO DO TODAY IS TO TAKE SOME BODY SIZE MEASUREMENTS. THE THEORY IS THAT THE BIGGER SOMEONE IS, THE GREATER THE STEERING EFFORT THEY ARE WILLING TO EXERT.

While giving the instructions that follow, remove the anthropometric tools from the case and assemble the 210 cm caliper.

FIRST, I WOULD LIKE TO MEASURE HOW TALL YOU ARE. PLEASE TAKE OFF YOUR SHOES AND STAND UP STRAIGHT AGAINST THIS PARTITION. LOOK STRAIGHT AHEAD. Make sure the subject's chin is neither tucked nor pointed upward. Measure their height from the top of their head to the floor, being careful to compress their hair and assuring the caliper is vertical when the measurement is taken.

NEXT, I WOULD LIKE TO MEASURE YOUR WEIGHT. If the subject is wearing one say, PLEASE TAKE OFF YOUR JACKET. WOULD YOU EMPTY YOUR POCKETS OF ANYTHING THAT MIGHT AFFECT THAT MEASUREMENT (FOR EXAMPLE, KEYS, CHANGE, YOUR WALLET, PENS OR PENCILS, A CALCULATOR, AND SO FORTH). Make sure the subject does not put his or her shoes back on. Also check the scale is balanced. OK, NOW YOU CAN STEP UP ON THE SCALE. Weigh the subject.

NEXT, I WOULD LIKE TO MEASURE YOUR SEATED HEAD HEIGHT. Remove the two end sections from the 210 cm caliper. PLEASE SIT DOWN ON THIS DESK WITH YOU LEGS DANGLING OVER THE EDGE. SIT UP REASONABLY STRAIGHT WITH YOUR HANDS ON YOUR THIGHS. Pay attention to the subject's posture. The subject should be neither ramrod straight nor slouched over. Measure the distance from the top of the subject's head to the desktop. Be sure the caliper is vertical and the subject's hair is compressed when the measurement is taken.

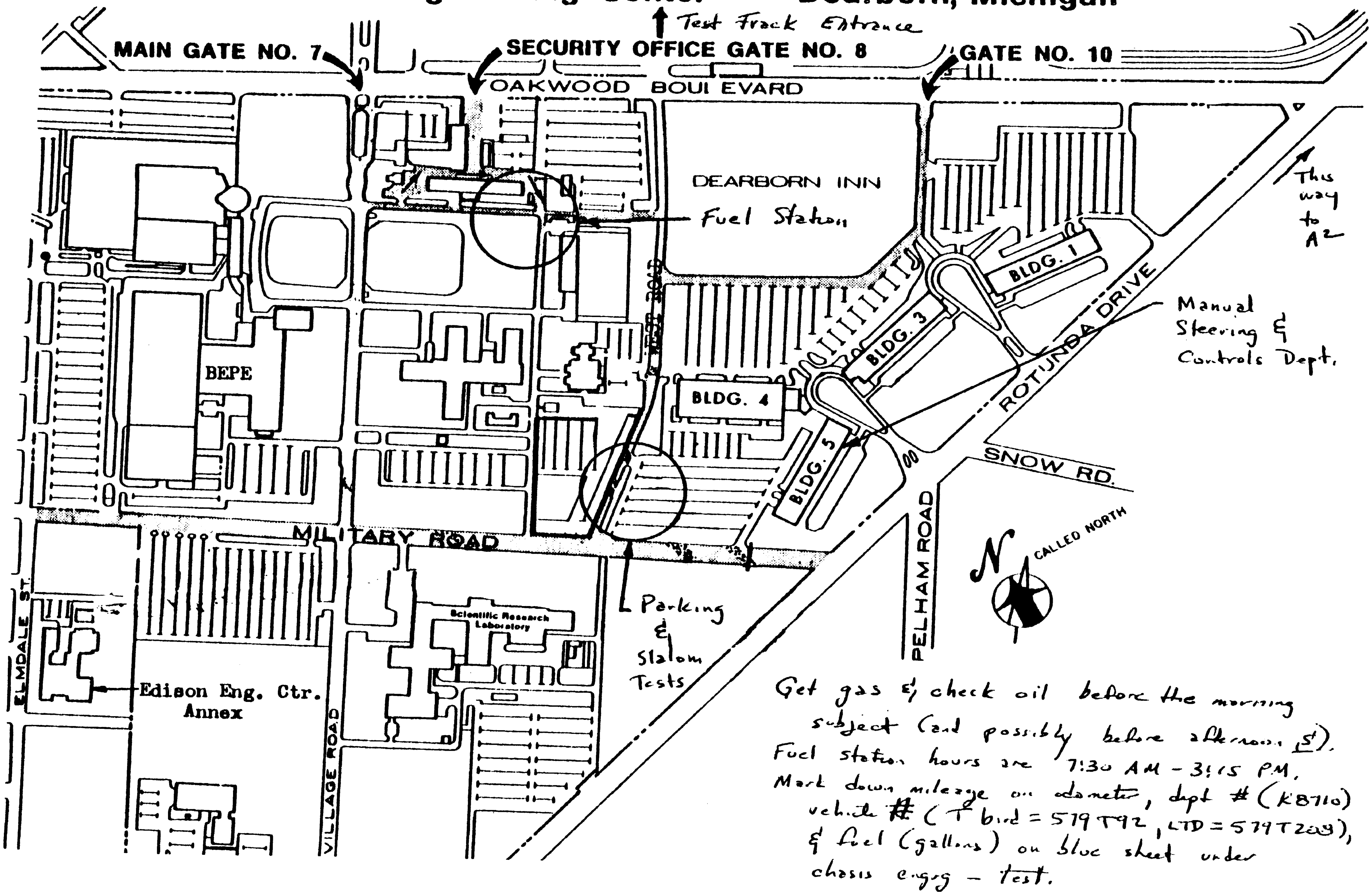
THE FOURTH MEASUREMENT TO BE TAKEN IS SHOULDER BREADTH. Put the slider back on the caliper. PLEASE STAND HERE AND FACE ME. SO THAT EVERYONE IS MEASURED IN THE SAME POSITION, WE ARE ASKING PEOPLE TO EXTEND THEIR ARMS OUTWARDS FROM THEIR SIDES LIKE THIS (so the arms and torso form a T) AND THEN TO LET THEM NATURALLY FALL TO THEIR SIDES. Measure the shoulder-to-shoulder distance across the front using the shoulder muscle and not the bone as the endpoints.

THE FINAL MEASUREMENT TO BE TAKEN IS SHOULDER CIRCUMFERENCE. AGAIN PLEASE EXTEND YOUR ARMS OUTWARD AND LET THEM FALL TO YOUR SIDES SO YOU WILL BE IN THE PROPER POSITION. Use the steel tape to take this measurement. Be sure the tape goes under the subject's tie (if one is worn), the skin is not compressed (but the tape is snug), and the places on the shoulders where the tape rests are the same as those for the shoulder breadth measurement.

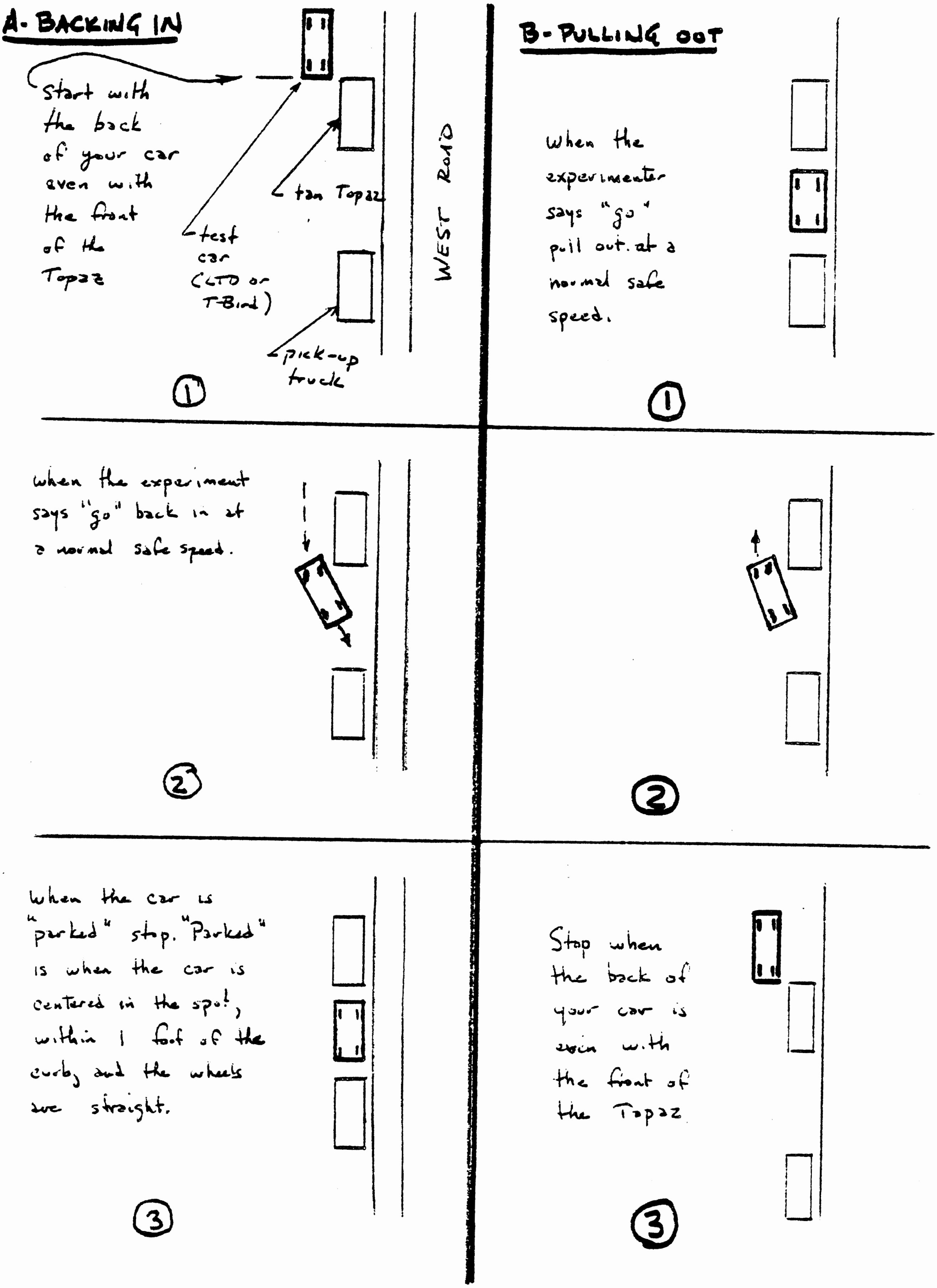
THANK YOU FOR YOUR COOPERATION. PLEASE DON'T FORGET YOUR ... (wallet, watch, etc.) DO YOU HAVE ANY QUESTIONS ABOUT THIS EXPERIMENT? (Answer them, of course.) ... OK, ONCE AGAIN THANK YOU FOR YOUR TIME.

Put the anthropometric tools back in the case.

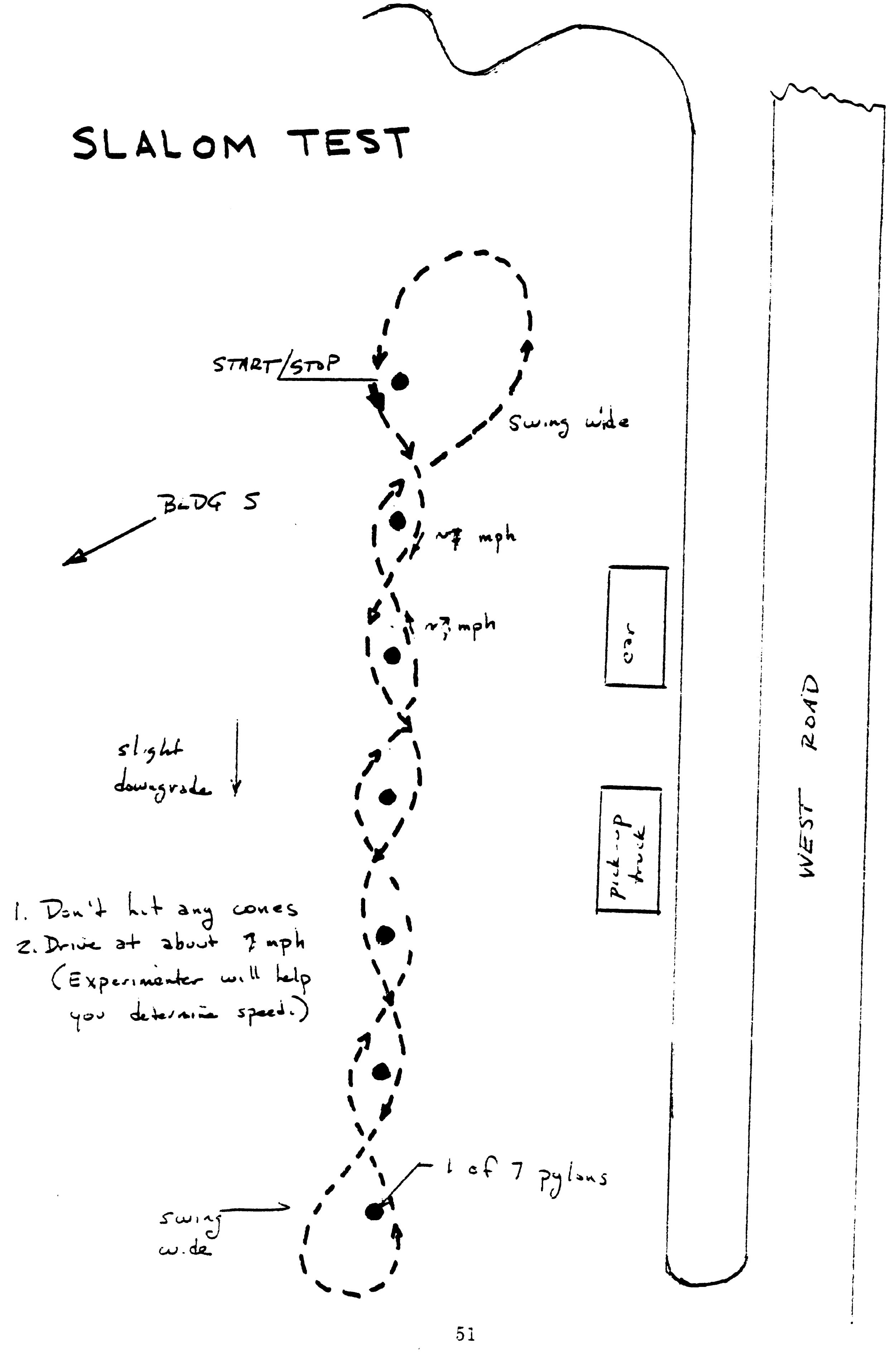
Research and Engineering Center Dearborn, Michigan



PARALLEL PARKING TEST

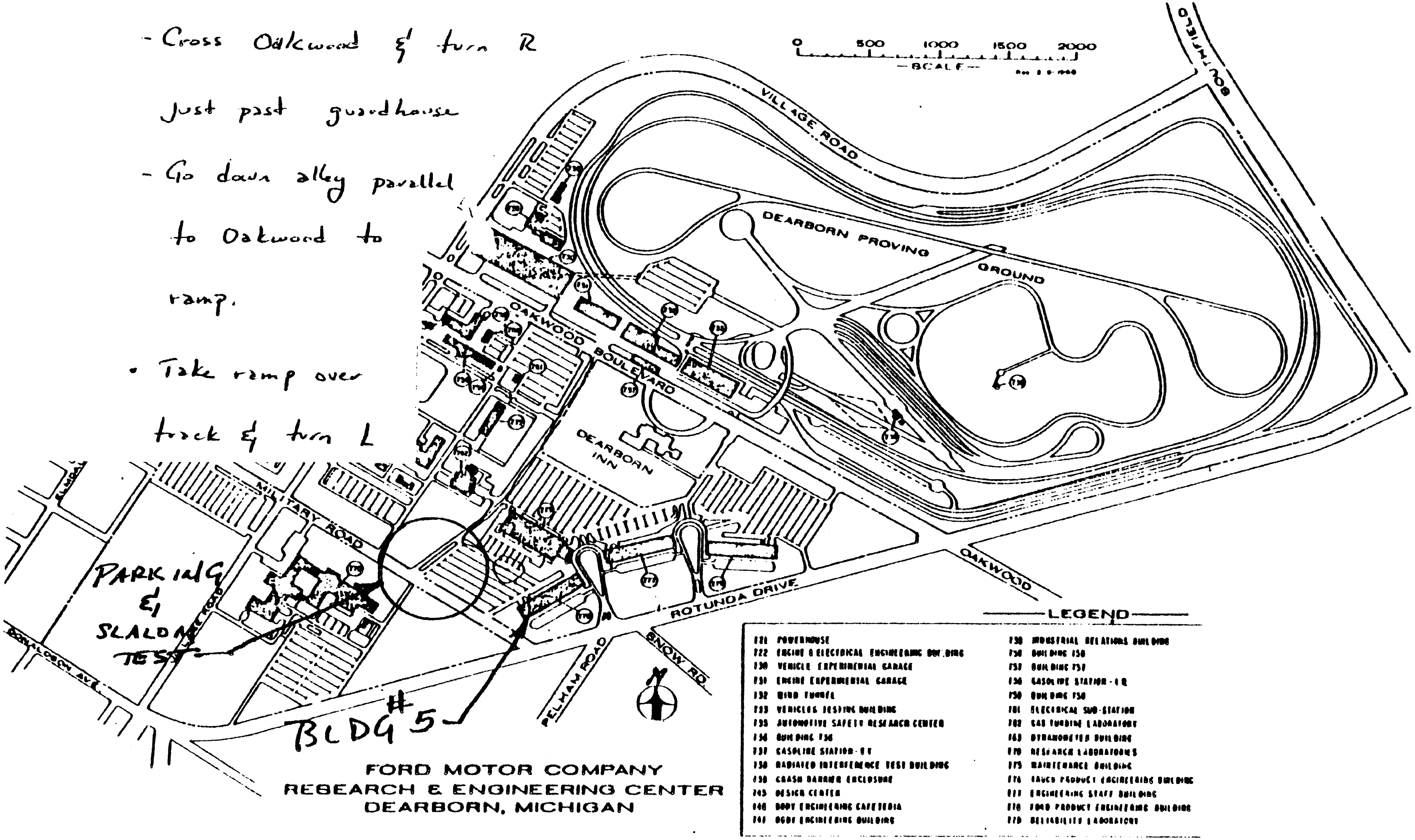


SLALOM TEST


START/STOP
Swing wide
BLDG 5
~7 mph
~7 mph
car
slight downgrade
pick-up truck
WEST ROAD
1. Don't hit any cones
2. Drive at about 7 mph
(Experimenter will help you determine speed.)
1 of 7 pylons
swing wide

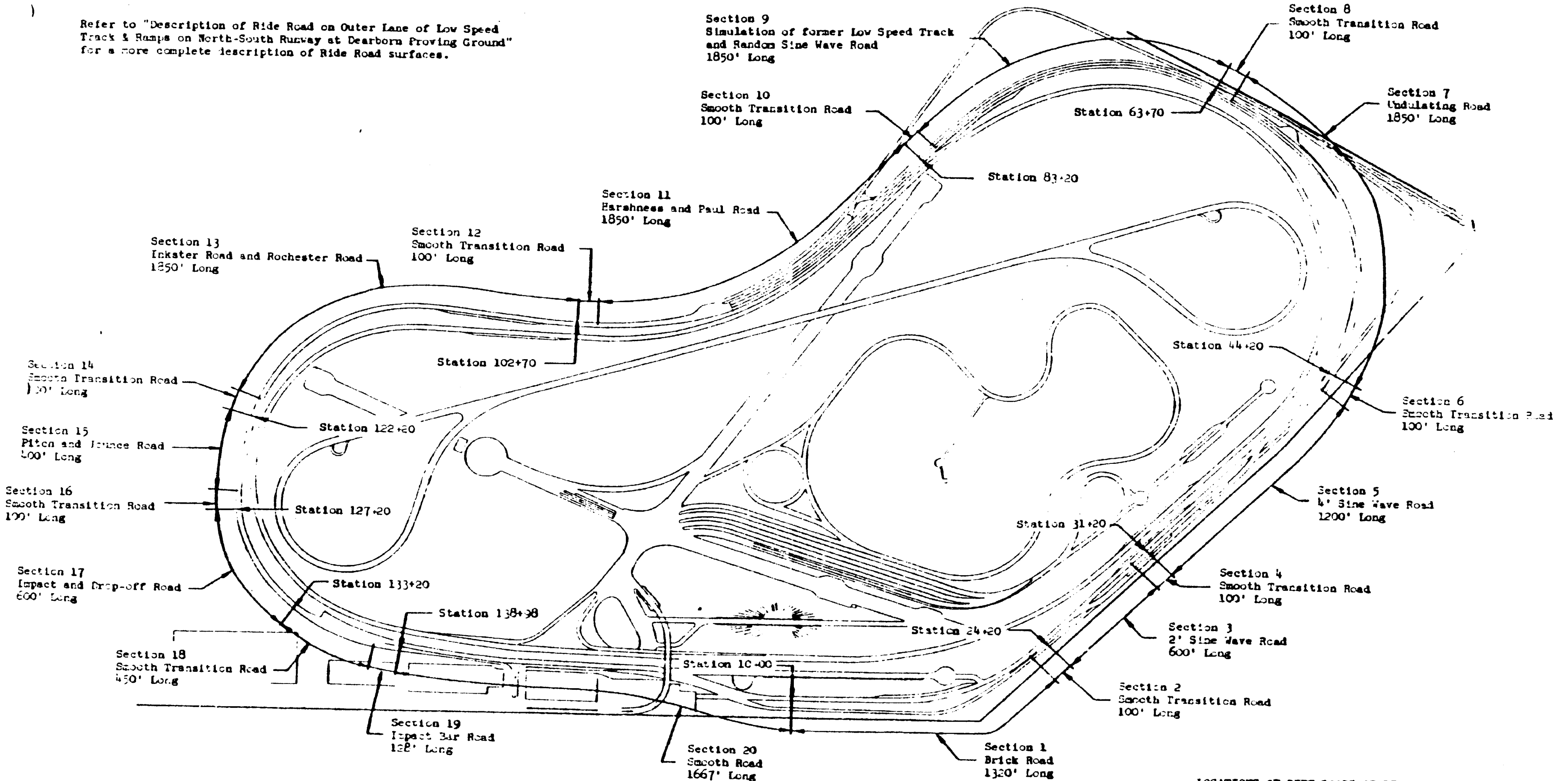
ROUTE FROM THE PARKING LOT TO THE TEST TRACK

- Take West Road to Oakwood
- Cross Oakwood & turn R just past guardhouse
- Go down alley parallel to Oakwood to ramp.
- Take ramp over track & turn L



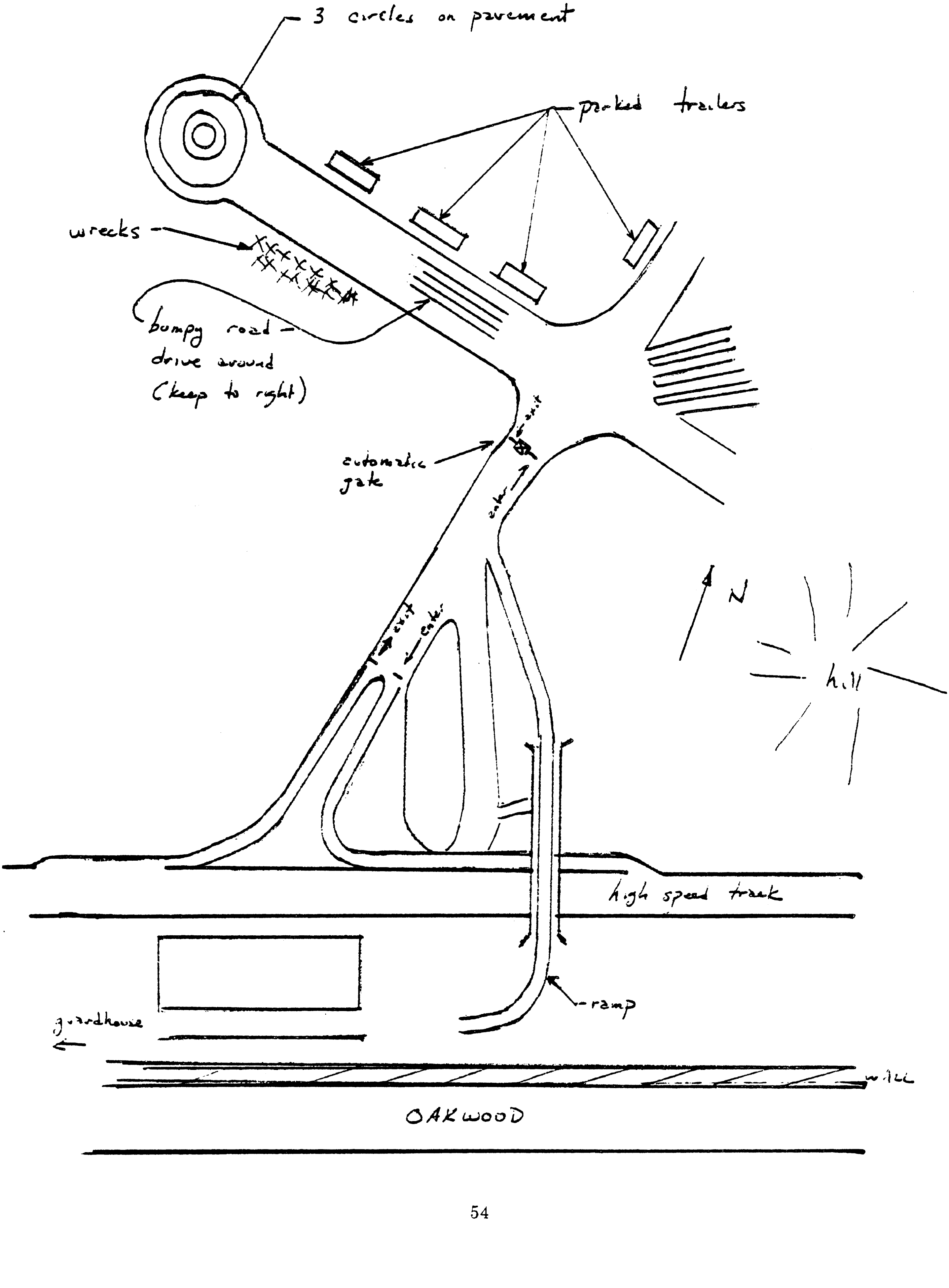
TEST TRACK

Refer to "Description of Ride Road on Outer Lane of Low Speed Track & Ramps on North-South Runway at Dearborn Proving Ground" for a more complete description of Ride Road surfaces.



LOCATIONS OF RIDE ROADS AT DEARBORN PROVING GROUND

TEST TRACK DETAIL



U of M test

Oct 15 - Nov 30, 1984

1984 T-bird Turbo Coupe - red
(MI # 14M562)

1984 LTD - bronze
(MI #15M125)

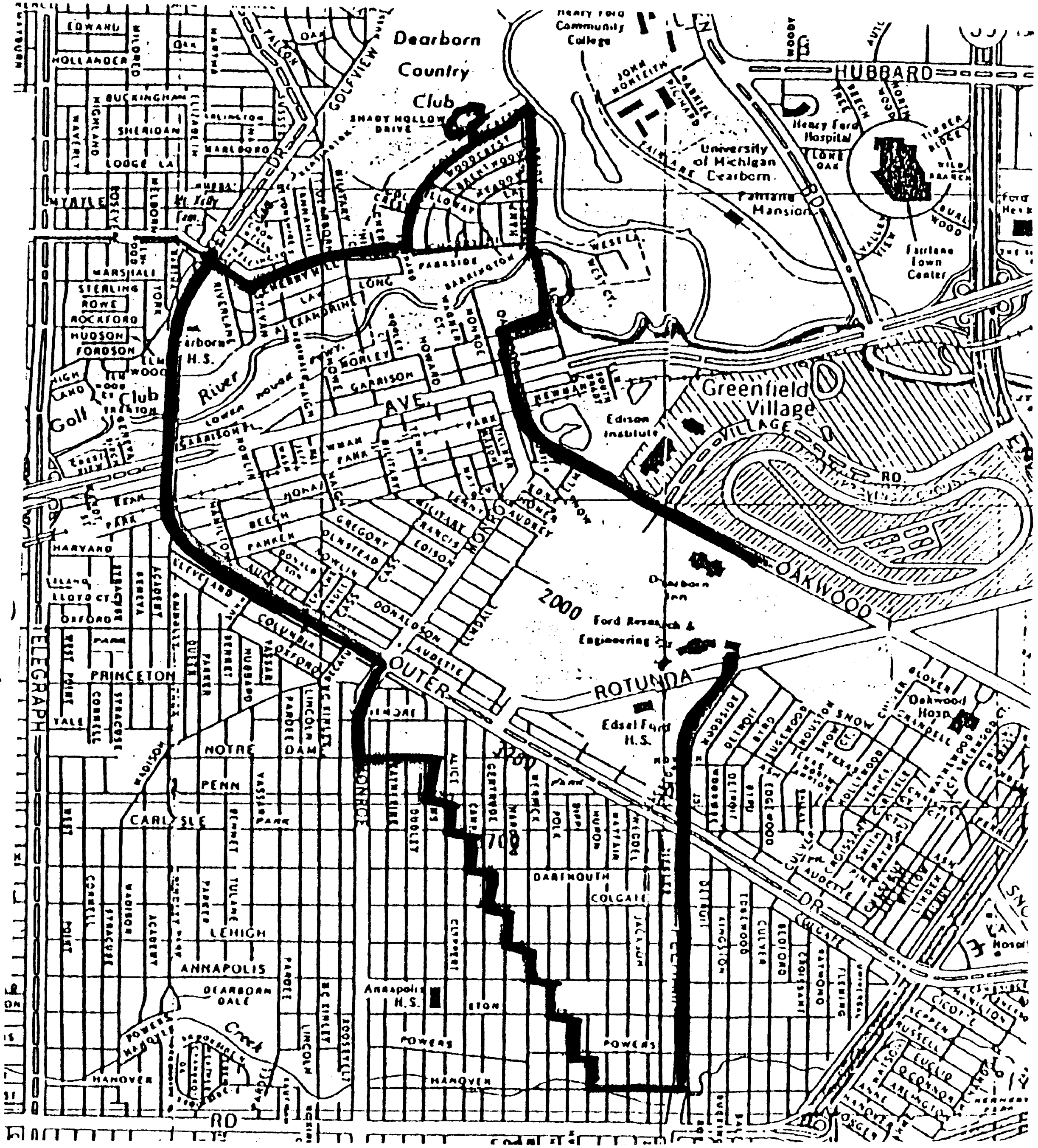
driven by Ford employees

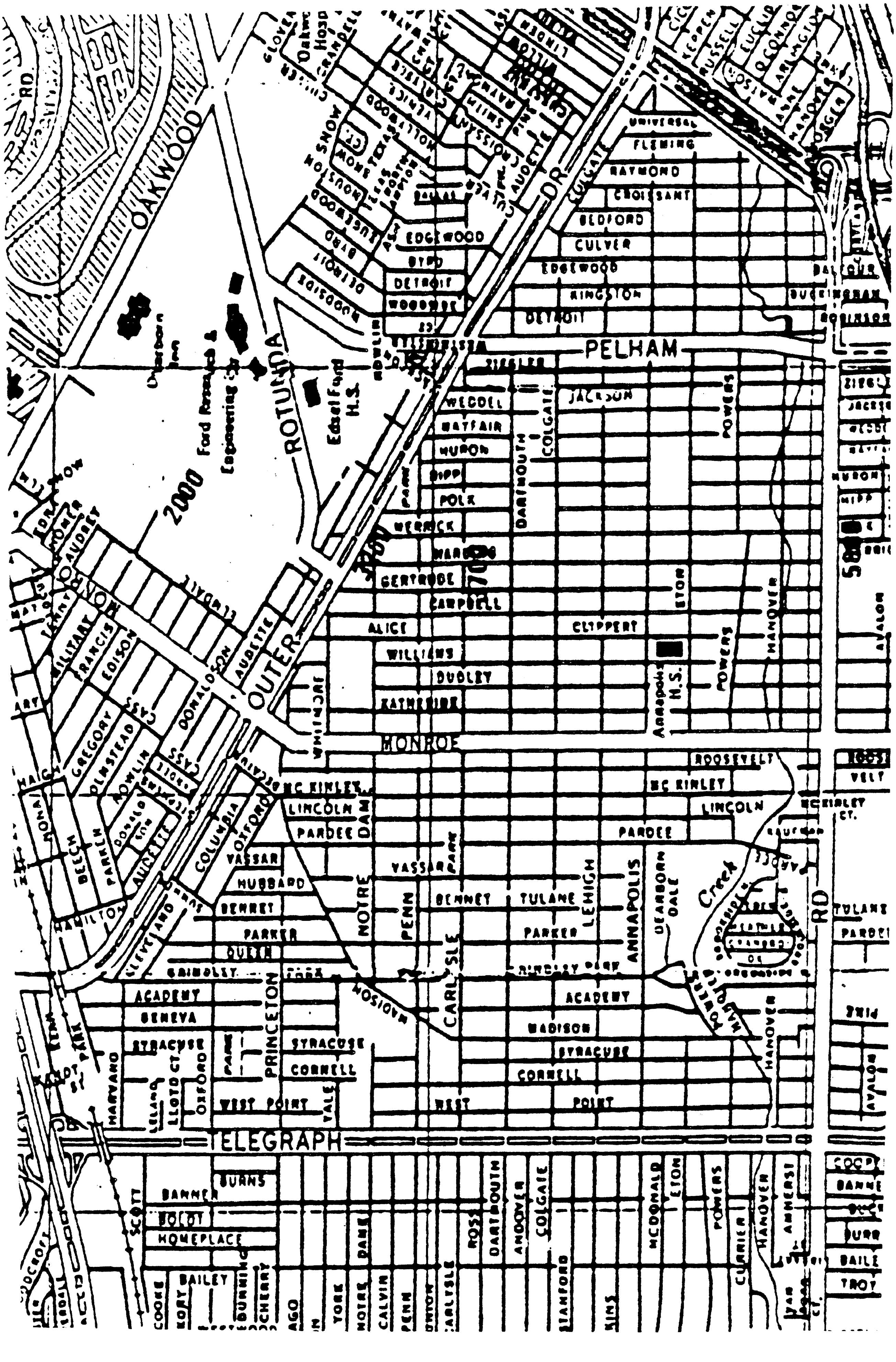
U of M scientists

Paul Green (manager -764 4158)
Stacy Ricfeis
Lisa Weis-Haas
MJ Price
Don others

Ford Liason

Glenn Ulrich 322 7018




OAKWOOD
RD.
ROTUNDA
Edsel Ford H.S.
2000
OUTER
DR.
PELHAM
MONROE
TELEGRAPH
EDGEWOOD
DETROIT
FLEMING
RAYMOND
CROISSANT
BEDFORD
CULVER
KINGSTON
ZIEGLER
JACKSON
WEDDELL
HURON
POLK
GERTRUDE
CAMPBELL
ALICE
WILLIAMS
DUDLEY
CLIPPERT
DARTMOUTH
COLGATE
POWERS
ETON
HANOVER
Annapolis H.S.
AVALON
ROOSEVELT
MC KINLEY
LINCOLN
PARDEE
VASSAR
HUBBARD
BENNET
TULANE
PARKER
NOTRE DAME
PENN
CARLYSLE
LEHIGH
ANNAPOLIS
Creek
ACADEMY
GENEVA
SYRACUSE
CORNELL
WEST POINT
MADISON
PRINCETON
OXFORD
YALE
HARVARD
CASS
GREGORY
OLMSTEAD
FRANCIS
EDISON
MILITARY
BEECH
PARKER
COLUMBIA
CLEVELAND
HAMILTON
AUDETTE
SCOTT
BANNER
HOMEPLACE
BURNS
BAILEY
YORK
CALVIN
ROSS
ANDOVER
STANFORD
MCDONALD
CURRIER
AMHERST
TROY

APPENDIX B

DATA SHEETS

HUMAN FACTORS DIVISION

Paul Green, Principal Investigator (U of M)
Dan Ahrns, Project Manager (Ford)

Participant Consent Form

The purpose of this experiment is to examine the handling characteristics people would like cars to have. Ford has asked the University to begin looking at that question by testing Ford personnel with lease cars. You will be asked to drive a modified T-bird turbo coupe or a modified LTD, whichever you normally drive, around a previously determined route. The route includes parking maneuvers, loops around the Dearborn test track at normal speeds, and driving on the streets of Dearborn. This test will take about 2 hours to complete.

There will be no smoking during the test except during breaks. If you wish to smoke, we ask that it take place outside of the car.

You may withdraw from this test at any time if you wish.

I have read this consent form and understand it.

Date	Please print name
Witness (experimenter)	Signature

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*************************************************************
* UNIVERSITY OF MICHIGAN TRANSPORTATION RESEARCH INSTITUTE *
*                   HUMAN FACTORS DIVISION                  *
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Subjective Evaluation of Steering Effort
Biographical and Anthropometric Data Sheet

Please complete the following information:

NAME ____________________________________ WORK PHONE ______________

DEPARTMENT ___________________________ JOB TITLE ___________________

AGE _______ SEX (circle one) M F

VEHICLE YOU DRIVE NOW (circle one)

CONTINENTAL MARK TBIRD/COUGAR MARQUIS/LTD ESCORT/LYNX CAPRI/MUSTANG

TYPE OF STEERING (circle one) MANUAL POWER

MILES DRIVE/YEAR __________________

PREVIOUS VEHICLE (year, make, model) ______________________________

EXPERIENCE WITH OTHER VEHICLES - HAVE YOU EVER DRIVEN... (circle y or n)

LIGHT TRUCK	YES	NO
HEAVY TRUCK	YES	NO
SNOWMOBILE	YES	NO
MOTORCYCLE	YES	NO
FARM MACHINERY	YES	NO
CONSTRUCTION EQUIPMENT	YES	NO
MILITARY VEHICLE (TANK)	YES	NO

CAR REPAIRS YOU CAN DO

TUNEUP	YES	NO
OIL CHANGE	YES	NO
BRAKE LINING REPLACEMENT	YES	NO

****
This section is to be completed by the experimenter

STANDING HEIGHT ___________ WEIGHT ___________ SEATED HEIGHT ____________

SHOULDER BREADTH _________________ SHOULDER CIRCUMFERENCE _______________

****

* UNIVERSITY OF MICHIGAN TRANSPORTATION RESEARCH INSTITUTE *

* HUMAN FACTORS DIVISION *

****

Subjective Evaluation of Steering Effort-Raw Data Sheet

SUBJECT NAME & # ---------- ------------------------

EXPERIMENTER ------------------------------------

DATE & TIME --------------- ------------------

CAR (circle one) TBIRD LTD

WEATHER (circle one) CLEAR OVERCAST FOGGY RAINING SNOWING

TEMPERATURE (circle one) 20's 30's 40's 50's 60's 70's

MANEUVER & SPEED (circle one)

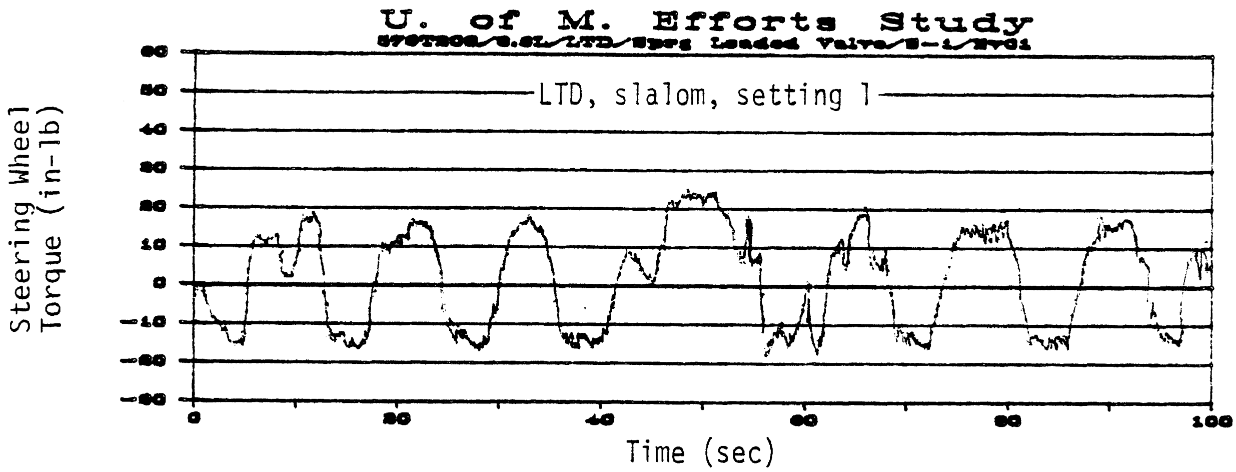
PARALLEL PARK SLALOM (6-7) HIGH SPEED TRACK (60)

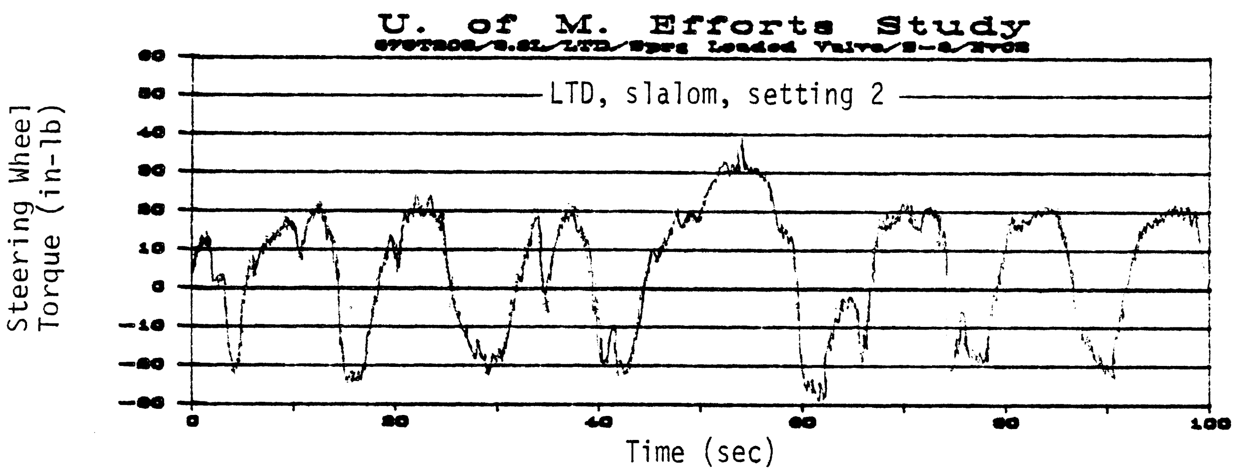
CIRCLES (9/14/20) SHADY HOLLOW (20) DEARBORN ZIG-ZAG (20+)

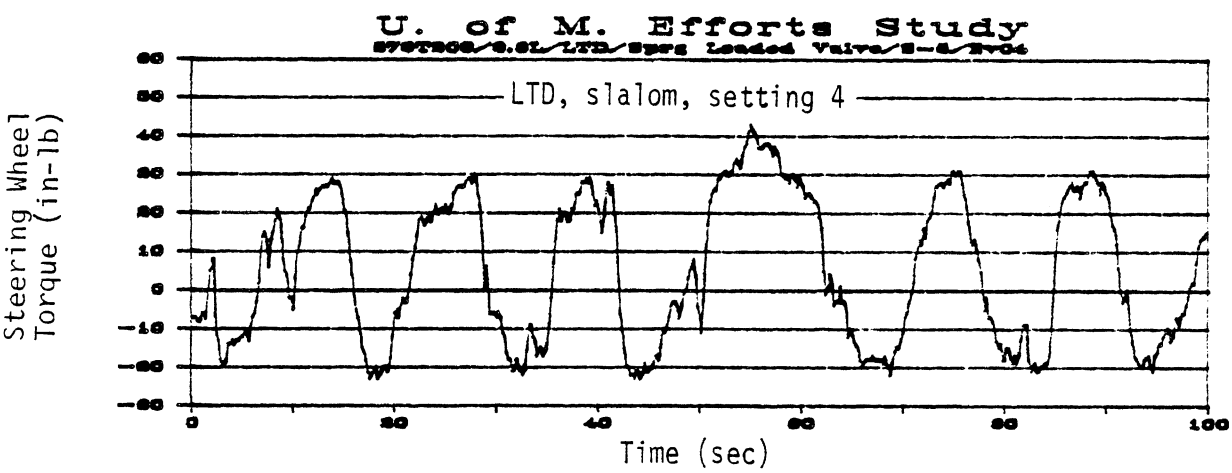
```
*****************************************************************************
Response Codes:      |  -=missing              Relative to what
                     |  1=too easy             you prefer-------
            .--------|  2=bit too easy
            |        |  3=ok              |    -=worse than before
            |        |  4=bit too hard  .--|   0=same as before
            |        |  5=too hard      |  |   +=better than before
            |           .---------------'
            V           V
BOOST   |     RESPONSE      |COMMENT (# direction changes for park, B=bump
SETTING |#1 (1-5)|#2(-,0,+)|    torque setting for circles)
-----------------------------------------------< start most tests at 1 --
easy 1  |        |          |
     2  |        |          |
     3  |        |          |
 - - - - - - - - - - - - - - - - - - - - - - -< start high speed at 3
     4  |        |          |
     5  |        |          |
     6  |        |          |
 - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
     7  |        |          |
     8  |        |          |
hard 9  |        |          |
 - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
     8  |        |          |
     7  |        |          |
     6  |        |          |
 - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
     5  |        |          |
     4  |        |          |
     3  |        |          |
 - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
     2  |        |          |
easy 1  |        |          |
```

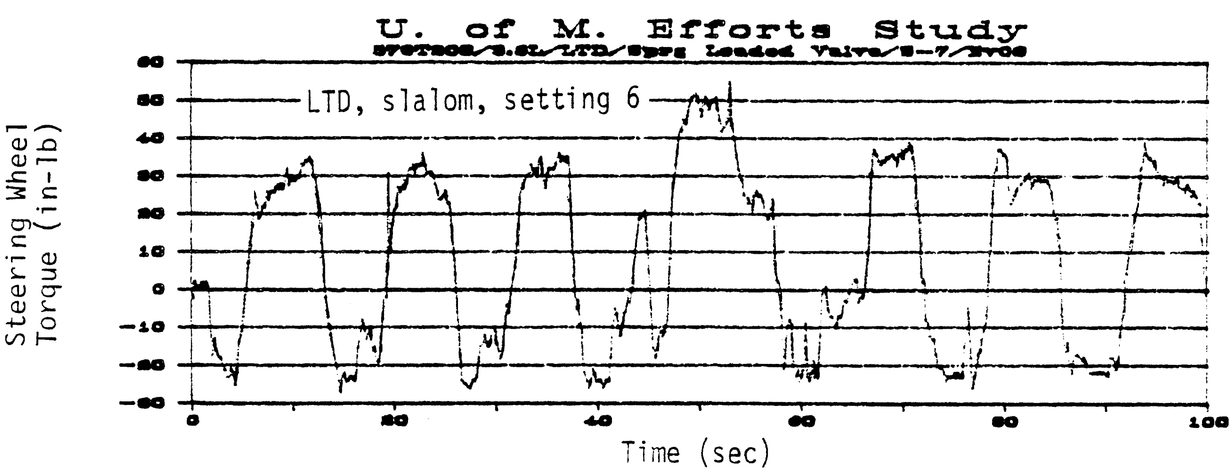
APPENDIX C

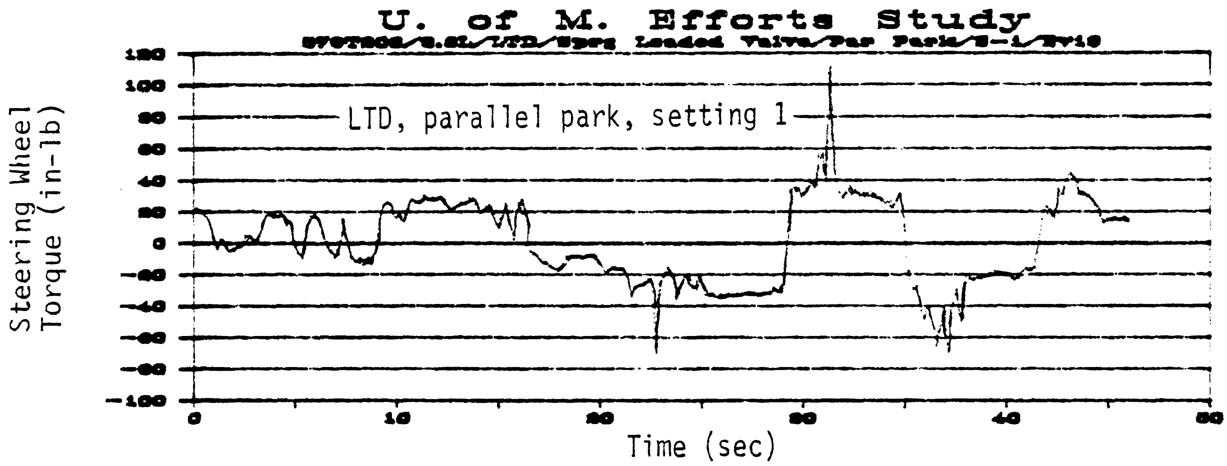
PRE-TEST TORQUE DATA FOR TWO MANEUVERS

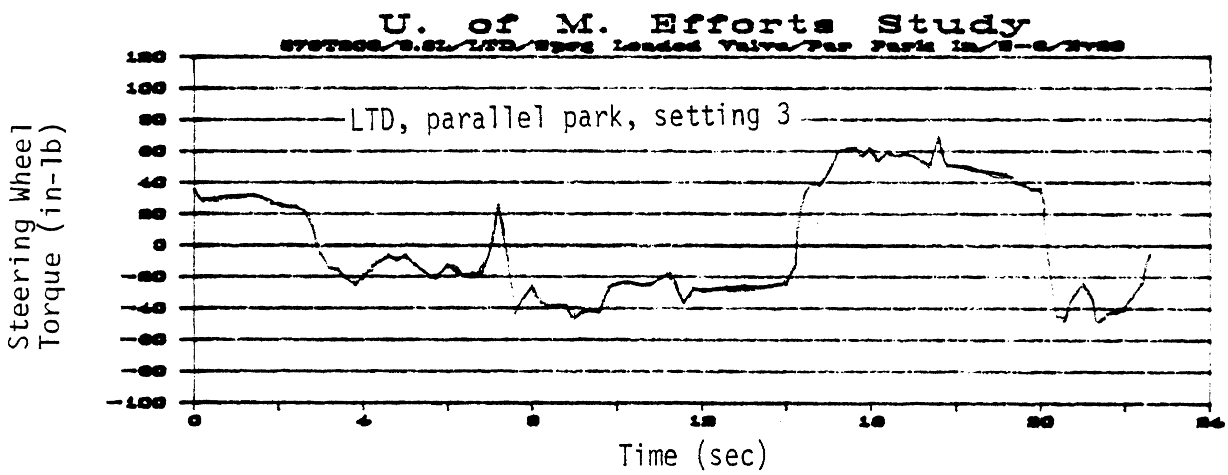

U. of M. Efforts Study
LTD, slalom, setting 1
Steering Wheel Torque (in-lb)
Time (sec)

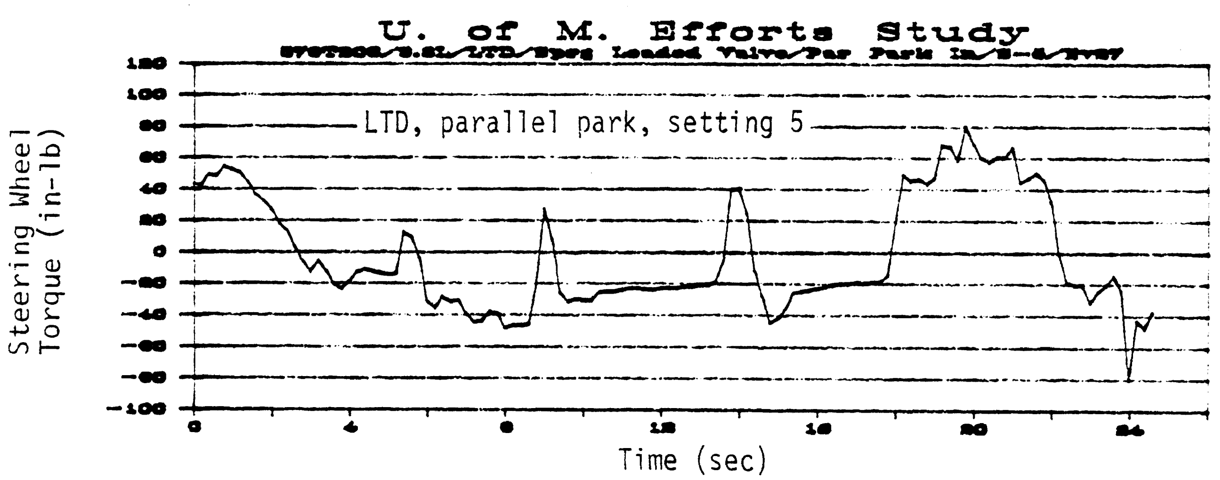

U. of M. Efforts Study
LTD, slalom, setting 2
Steering Wheel Torque (in-lb)
Time (sec)

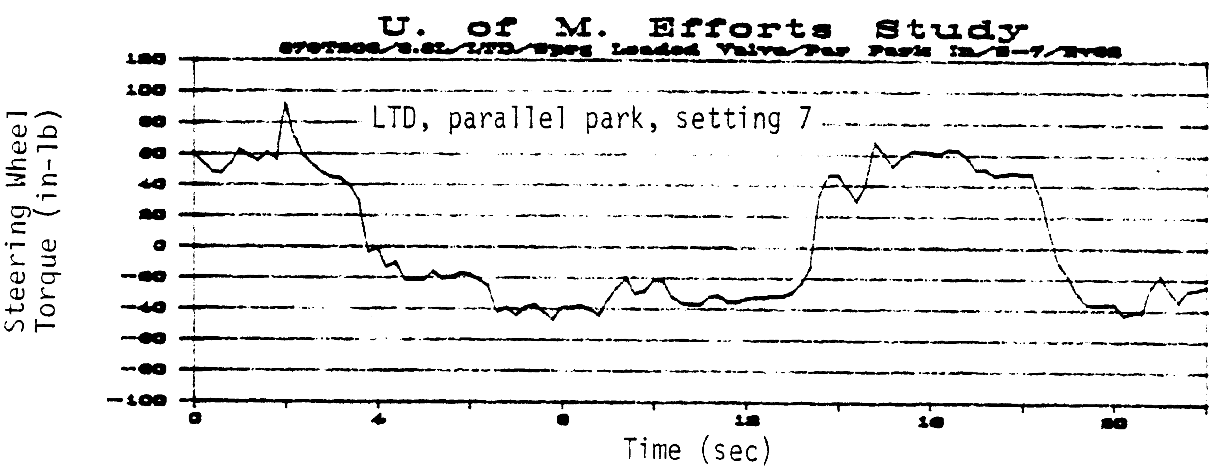

U. of M. Efforts Study
LTD, slalom, setting 4
Steering Wheel Torque (in-lb)
Time (sec)


U. of M. Efforts Study
LTD, slalom, setting 6
Steering Wheel Torque (in-lb)
Time (sec)


U. of M. Efforts Study
Steering Wheel Torque (in-lb)
LTD, parallel park, setting 1
120
100
80
60
40
20
0
-20
-40
-60
-80
-100
0
10
20
30
40
50
Time (sec)


U. of M. Efforts Study
Steering Wheel Torque (in-lb)
LTD, parallel park, setting 3
120
100
80
60
40
20
0
-20
-40
-60
-80
-100
0
4
8
12
16
20
24
Time (sec)


U. of M. Efforts Study
Steering Wheel Torque (in-lb)
LTD, parallel park, setting 5
120
100
80
60
40
20
0
-20
-40
-60
-80
-100
0
4
8
12
16
20
24
Time (sec)


U. of M. Efforts Study
Steering Wheel Torque (in-lb)
LTD, parallel park, setting 7
120
100
80
60
40
20
0
-20
-40
-60
-80
-100
0
4
8
12
16
20
Time (sec)

APPENDIX D

PREFERENCE HISTOGRAMS BY CAR AND MANEUVERS

T-bird - parallel parking going up

MIDPOINT	COUNT (EACH X= 1)
1.0000	3 +XXX
1.5000	0 +
2.0000	5 +XXXXX
2.5000	2 +XX
3.0000	2 +XX
3.5000	1 +X
TOTAL	13

T-bird - slalom going up

MIDPOINT	COUNT (EACH X= 1)
1.0000	2 +XX
1.5000	1 +X
2.0000	2 +XX
2.5000	1 +X
3.0000	4 +XXXX
3.5000	1 +X
4.0000	0 +
4.5000	1 +X
5.0000	0 +
5.5000	1 +X
TOTAL	13

T-bird - high-speed track going up

MIDPOINT	COUNT (EACH X= 1)
3.5000	2 +XX
4.0000	2 +XX
4.5000	1 +X
5.0000	2 +XX
5.5000	1 +X
6.0000	2 +XX
6.5000	0 +
7.0000	1 +X
7.5000	0 +
8.0000	1 +X
8.5000	0 +
9.0000	1 +X
TOTAL	13

T-bird - parallel parking going down

MIDPOINT	COUNT (EACH X= 1)
1.0000	2 +XX
1.5000	1 +X
2.0000	6 +XXXXXX
2.5000	4 +XXXX
TOTAL	13

T-bird slalom going down

MIDPOINT	COUNT (EACH X= 1)
1.0000	2 +XX
1.5000	2 +XX
2.0000	5 +XXXXX
2.5000	0 +
3.0000	1 +X
3.5000	0 +
4.0000	3 +XXX
TOTAL	13

T-bird - high-speed track going down

MIDPOINT	COUNT (EACH X= 1)
2.0000	1 +X
2.5000	1 +X
3.0000	1 +X
3.5000	0 +
4.0000	2 +XX
4.5000	2 +XX
5.0000	0 +
5.5000	0 +
6.0000	3 +XXX
6.5000	0 +
7.0000	1 +X
7.5000	0 +
8.0000	1 +X
8.5000	1 +X
TOTAL	13

T-bird - 25' circle going up

MIDPOINT	COUNT	(EACH X= 1)
1.0000	1	+X
1.5000	0	+
2.0000	3	+XXX
2.5000	0	+
3.0000	5	+XXXXX
3.5000	1	+X
4.0000	0	+
4.5000	0	+
5.0000	2	+XX
5.5000	0	+
6.0000	1	+X
TOTAL	13	

T-bird - 25' circle going down

MIDPOINT	COUNT	(EACH X= 1)
1.0000	1	+X
1.5000	0	+
2.0000	3	+XXX
2.5000	1	+X
3.0000	3	+XXX
3.5000	2	+XX
4.0000	1	+X
4.5000	0	+
5.0000	1	+X
5.5000	0	+
6.0000	1	+X
TOTAL	13	

T-bird - 50' circle going up

MIDPOINT	COUNT	(EACH X= 1)
1.0000	2	+XX
1.5000	0	+
2.0000	1	+X
2.5000	0	+
3.0000	3	+XXX
3.5000	1	+X
4.0000	3	+XXX
4.5000	1	+X
5.0000	0	+
5.5000	0	+
6.0000	0	+
6.5000	1	+X
7.0000	0	+
7.5000	0	+
8.0000	1	+X
TOTAL	13	

T-bird - 50' circle going down

MIDPOINT	COUNT	(EACH X= 1)
2.0000	2	+XX
2.5000	1	+X
3.0000	3	+XXX
3.5000	1	+X
4.0000	1	+X
4.5000	2	+XX
5.0000	0	+
5.5000	1	+X
6.0000	0	+
6.5000	0	+
7.0000	0	+
7.5000	0	+
8.0000	1	+X
MISSING	1	
TOTAL	13	

T-bird - 100' circle going up

MIDPOINT	COUNT	(EACH X= 1)
1.0000	1	+X
1.5000	1	+X
2.0000	1	+X
2.5000	1	+X
3.0000	1	+X
3.5000	1	+X
4.0000	1	+X
4.5000	0	+
5.0000	1	+X
5.5000	1	+X
6.0000	0	+
6.5000	1	+X
7.0000	1	+X
7.5000	0	+
8.0000	1	+X
MISSING	1	
TOTAL	13	

T-bird - 100' circle Going down

MIDPOINT	COUNT	(EACH X= 1)
1.5000	2	+XX
2.0000	1	+X
2.5000	0	+
3.0000	1	+X
3.5000	1	+X
4.0000	4	+XXXX
4.5000	0	+
5.0000	1	+X
5.5000	1	+X
6.0000	0	+
6.5000	0	+
7.0000	0	+
7.5000	0	+
8.0000	1	+X
MISSING	1	
TOTAL	13	

T-bird - Shady Hollow
going up

MIDPOINT	COUNT (EACH X= 1)
1.0000	1 +X
1.5000	1 +X
2.0000	1 +X
2.5000	0 +
3.0000	6 +XXXXXX
3.5000	1 +X
4.0000	0 +
4.5000	2 +XX
5.0000	0 +
5.5000	0 +
6.0000	0 +
6.5000	0 +
7.0000	0 +
7.5000	0 +
8.0000	0 +
8.5000	0 +
9.0000	1 +X
TOTAL	13

T-bird - Shady Hollow
going down

MIDPOINT	COUNT (EACH X= 1)
1.0000	1 +X
1.5000	0 +
2.0000	2 +XX
2.5000	1 +X
3.0000	5 +XXXXX
3.5000	0 +
4.0000	3 +XXX
4.5000	0 +
5.0000	0 +
5.5000	0 +
6.0000	0 +
6.5000	0 +
7.0000	0 +
7.5000	0 +
8.0000	0 +
8.5000	1 +X
TOTAL	13

T-bird - Dearborn zigzag
going up

MIDPOINT	COUNT (EACH X= 1)
2.0000	1 +X
2.5000	0 +
3.0000	8 +XXXXXXXX
3.5000	1 +X
4.0000	0 +
4.5000	1 +X
5.0000	0 +
5.5000	0 +
6.0000	0 +
6.5000	0 +
7.0000	0 +
7.5000	0 +
8.0000	0 +
8.5000	1 +X
9.0000	1 +X
TOTAL	13

T-bird - Dearborn zigzag
going down

MIDPOINT	COUNT (EACH X= 1)
1.0000	1 +X
1.5000	0 +
2.0000	2 +XX
2.5000	1 +X
3.0000	6 +XXXXXX
3.5000	1 +X
4.0000	1 +X
4.5000	0 +
5.0000	0 +
5.5000	0 +
6.0000	0 +
6.5000	0 +
7.0000	0 +
7.5000	0 +
8.0000	0 +
8.5000	1 +X
TOTAL	13

LTD - parallel parking
going up

MIDPOINT	COUNT (EACH X= 1)
1.0000	5 +XXXXX
1.5000	5 +XXXXX
2.0000	3 +XXX
2.5000	0 +
3.0000	3 +XXX
3.5000	0 +
4.0000	0 +
4.5000	0 +
5.0000	0 +
5.5000	0 +
6.0000	0 +
6.5000	0 +
7.0000	1 +X
TOTAL	17

LTD - parallel parking
going down

MIDPOINT	COUNT (EACH X= 1)
1.0000	5 +XXXXX
1.5000	3 +XXX
2.0000	3 +XXX
2.5000	3 +XXX
3.0000	1 +X
3.5000	0 +
4.0000	0 +
4.5000	0 +
5.0000	0 +
5.5000	0 +
6.0000	0 +
6.5000	0 +
7.0000	1 +X
MISSING	1
TOTAL	17

LTD - slalom going up

MIDPOINT	COUNT (EACH X= 1)
.50000	2 +XX
1.0000	4 +XXXX
1.5000	2 +XX
2.0000	2 +XX
2.5000	1 +X
3.0000	4 +XXXX
3.5000	1 +X
4.0000	0 +
4.5000	0 +
5.0000	1 +X
TOTAL	17

LTD - slalom going down

MIDPOINT	COUNT (EACH X= 1)
.50000	2 +XX
1.0000	3 +XXX
1.5000	3 +XXX
2.0000	2 +XX
2.5000	2 +XX
3.0000	1 +X
3.5000	3 +XXX
4.0000	0 +
4.5000	0 +
5.0000	0 +
5.5000	0 +
6.0000	1 +X
TOTAL	17

LTD - high-speed track going up

MIDPOINT	COUNT (EACH X= 1)
1.5000	1 +X
2.0000	1 +X
2.5000	0 +
3.0000	2 +XX
3.5000	1 +X
4.0000	1 +X
4.5000	0 +
5.0000	2 +XX
5.5000	0 +
6.0000	4 +XXXX
6.5000	0 +
7.0000	2 +XX
7.5000	0 +
8.0000	1 +X
8.5000	0 +
9.0000	2 +XX
TOTAL	17

LTD - high-speed track going down

MIDPOINT	COUNT (EACH X= 1)
1.5000	1 +X
2.0000	1 +X
2.5000	2 +XX
3.0000	2 +XX
3.5000	0 +
4.0000	0 +
4.5000	1 +X
5.0000	1 +X
5.5000	0 +
6.0000	3 +XXX
6.5000	2 +XX
7.0000	3 +XXX
7.5000	0 +
8.0000	0 +
8.5000	0 +
9.0000	1 +X
TOTAL	17

LTD - 25' circle going up

MIDPOINT	COUNT (EACH X= 1)
.50000	1 +X
1.0000	2 +XX
1.5000	2 +XX
2.0000	2 +XX
2.5000	1 +X
3.0000	3 +XXX
3.5000	0 +
4.0000	4 +XXXX
4.5000	0 +
5.0000	1 +X
5.5000	0 +
6.0000	1 +X
TOTAL	17

LTD - 25' circle going down

MIDPOINT	COUNT (EACH X= 1)
.50000	1 +X
1.0000	1 +X
1.5000	0 +
2.0000	5 +XXXXX
2.5000	2 +XX
3.0000	1 +X
3.5000	1 +X
4.0000	3 +XXX
4.5000	0 +
5.0000	2 +XX
MISSING	1
TOTAL	17

LTD - 50' circle
going up

MIDPOINT	COUNT (EACH X= 1)
.50000	1 +X
1.0000	4 +XXXX
1.5000	1 +X
2.0000	2 +XX
2.5000	1 +X
3.0000	2 +XX
3.5000	1 +X
4.0000	2 +XX
4.5000	0 +
5.0000	0 +
5.5000	1 +X
6.0000	1 +X
6.5000	0 +
7.0000	1 +X
TOTAL	17

LTD - 50' circle
going down

MIDPOINT	COUNT (EACH X= 1)
.50000	1 +X
1.0000	2 +XX
1.5000	1 +X
2.0000	5 +XXXXX
2.5000	1 +X
3.0000	1 +X
3.5000	0 +
4.0000	1 +X
4.5000	1 +X
5.0000	1 +X
5.5000	1 +X
6.0000	2 +XX
TOTAL	17

LTD - 100' circle
going up

MIDPOINT	COUNT (EACH X= 1)
.50000	1 +X
1.0000	3 +XXX
1.5000	0 +
2.0000	1 +X
2.5000	1 +X
3.0000	3 +XXX
3.5000	2 +XX
4.0000	1 +X
4.5000	1 +X
5.0000	0 +
5.5000	0 +
6.0000	0 +
6.5000	1 +X
7.0000	2 +XX
MISSING	1
TOTAL	17

LTD - 100' circle
going up

MIDPOINT	COUNT (EACH X= 1)
.50000	1 +X
1.0000	3 +XXX
1.5000	0 +
2.0000	2 +XX
2.5000	0 +
3.0000	4 +XXXX
3.5000	0 +
4.0000	2 +XX
4.5000	1 +X
5.0000	0 +
5.5000	1 +X
6.0000	0 +
6.5000	1 +X
7.0000	0 +
7.5000	1 +X
MISSING	1
TOTAL	17

LTD - Shady Hollow
going up

MIDPOINT	COUNT (EACH X= 1)
.50000	1 +X
1.0000	5 +XXXXX
1.5000	0 +
2.0000	3 +XXX
2.5000	1 +X
3.0000	2 +XX
3.5000	0 +
4.0000	1 +X
4.5000	0 +
5.0000	1 +X
5.5000	1 +X
6.0000	1 +X
MISSING	1
TOTAL	17

LTD - Shady Hollow
going down

MIDPOINT	COUNT (EACH X= 1)
1.0000	3 +XXX
1.5000	3 +XXX
2.0000	4 +XXXX
2.5000	2 +XX
3.0000	1 +X
3.5000	1 +X
4.0000	1 +X
4.5000	1 +X
5.0000	1 +X
TOTAL	17

LTD - Dearborn zigzag
going up

MIDPOINT	COUNT (EACH X= 1)
1.0000	6 +XXXXXX
1.5000	2 +XX
2.0000	0 +
2.5000	2 +XX
3.0000	3 +XXX
3.5000	1 +X
4.0000	1 +X
4.5000	0 +
5.0000	1 +X
5.5000	0 +
6.0000	1 +X
TOTAL	17

LTD - Dearborn zigzag
going down

MIDPOINT	COUNT (EACH X= 1)
.50000	1 +X
1.0000	5 +XXXXX
1.5000	1 +X
2.0000	1 +X
2.5000	1 +X
3.0000	4 +XXXX
3.5000	0 +
4.0000	2 +XX
4.5000	0 +
5.0000	1 +X
MISSING	1
TOTAL	17

APPENDIX E

HISTOGRAMS OF SETTINGS CALLED "OK" BY CAR AND MANEUVER

Note: Each "x" represents one person saying a setting was "ok" for a particular maneuver. The midpoint column indicates the setting where 1-9 correspond to settings 1-9 going up and 10-17 represent 8-1 going down. The data shown are for 12 LTD drivers and 12 T-bird drivers. Since each person would identify any number of levels as ok (0 or several), the number of x's is often not an even multiple of 12.

T-bird - parallel parking

MIDPOINT	HIST%	COUNT (EACH X= 1)
1.0000	10.7	3 +XXX
2.0000	17.9	5 +XXXXX
3.0000	10.7	3 +XXX
4.0000	3.6	1 +X
5.0000	0.	0 +
6.0000	0.	0 +
7.0000	0.	0 +
8.0000	0.	0 +
9.0000	0.	0 +
10.000	0.	0 +
11.000	0.	0 +
12.000	0.	0 +
13.000	0.	0 +
14.000	0.	0 +
15.000	7.1	2 +XX
16.000	28.6	8 +XXXXXXXX
17.000	21.4	6 +XXXXXX

T-bird - slalom

MIDPOINT	HIST%	(EACH X= 1)
1.0000	10.5	4 +XXXX
2.0000	5.3	2 +XX
3.0000	15.8	6 +XXXXXX
4.0000	10.5	4 +XXXX
5.0000	5.3	2 +XX
6.0000	2.6	1 +X
7.0000	0.	0 +
8.0000	0.	0 +
9.0000	0.	0 +
10.000	0.	0 +
11.000	0.	0 +
12.000	2.6	1 +X
13.000	2.6	1 +X
14.000	7.9	3 +XXX
15.000	10.5	4 +XXXX
16.000	15.8	6 +XXXXXX
17.000	10.5	4 +XXXX

T-bird - high-speed track

MIDPOINT	HIST%	(EACH X= 1)
1.0000	1.6	1 +X
2.0000	1.6	1 +X
3.0000	7.8	5 +XXXXX
4.0000	12.5	8 +XXXXXXXX
5.0000	10.9	7 +XXXXXXX
6.0000	7.8	5 +XXXXX
7.0000	6.3	4 +XXXX
8.0000	6.3	4 +XXXX
9.0000	3.1	2 +XX
10.000	3.1	2 +XX
11.000	6.3	4 +XXXX
12.000	7.8	5 +XXXXX
13.000	4.7	3 +XXX
14.000	6.3	4 +XXXX
15.000	6.3	4 +XXXX
16.000	4.7	3 +XXX
17.000	3.1	2 +XX

T-bird - 25' circle

MIDPOINT	HIST%	(EACH X= 1)
1.0000	3.1	1 +X
2.0000	6.3	2 +XX
3.0000	25.0	8 +XXXXXXXX
4.0000	12.5	4 +XXXX
5.0000	9.4	3 +XXX
6.0000	3.1	1 +X
7.0000	0.	0 +
8.0000	0.	0 +
9.0000	0.	0 +
10.000	0.	0 +
11.000	0.	0 +
12.000	3.1	1 +X
13.000	3.1	1 +X
14.000	9.4	3 +XXX
15.000	12.5	4 +XXXX
16.000	6.3	2 +XX
17.000	6.3	2 +XX

T-bird - 50' circle

MIDPOINT	HIST%	(EACH X= 1)
1.0000	3.7	2 +XX
2.0000	7.4	4 +XXXX
3.0000	9.3	5 +XXXXX
4.0000	9.3	5 +XXXXX
5.0000	5.6	3 +XXX
6.0000	5.6	3 +XXX
7.0000	5.6	3 +XXX
8.0000	5.6	3 +XXX
9.0000	3.7	2 +XX
10.000	3.7	2 +XX
11.000	3.7	2 +XX
12.000	5.6	3 +XXX
13.000	3.7	2 +XX
14.000	7.4	4 +XXXX
15.000	11.1	6 +XXXXXX
16.000	5.6	3 +XXX
17.000	3.7	2 +XX

T-bird - 100' circle

MIDPOINT	HIST%	(EACH X= 1)
1.0000	1.9	1 +X
2.0000	5.6	3 +XXX
3.0000	11.1	6 +XXXXXX
4.0000	9.3	5 +XXXXX
5.0000	7.4	4 +XXXX
6.0000	5.6	3 +XXX
7.0000	5.6	3 +XXX
8.0000	3.7	2 +XX
9.0000	3.7	2 +XX
10.000	3.7	2 +XX
11.000	3.7	2 +XX
12.000	3.7	2 +XX
13.000	5.6	3 +XXX
14.000	9.3	5 +XXXXX
15.000	5.6	3 +XXX
16.000	7.4	4 +XXXX
17.000	7.4	4 +XXXX

T-bird - Shady Hollow

MIDPOINT	HIST%	(EACH X= 1)
1.0000	6.4	3 +XXX
2.0000	2.1	1 +X
3.0000	17.0	8 +XXXXXXXX
4.0000	8.5	4 +XXXX
5.0000	4.3	2 +XX
6.0000	2.1	1 +X
7.0000	2.1	1 +X
8.0000	2.1	1 +X
9.0000	4.3	2 +XX
10.000	4.3	2 +XX
11.000	4.3	2 +XX
12.000	2.1	1 +X
13.000	2.1	1 +X
14.000	8.5	4 +XXXX
15.000	19.1	9 +XXXXXXXXX
16.000	8.5	4 +XXXX

T-bird - Dearborn zigzag

MIDPOINT	HIST%	(EACH X= 1)
1.0000	6.7	3 +XXX
2.0000	8.9	4 +XXXX
3.0000	15.6	7 +XXXXXXX
4.0000	6.7	3 +XXX
5.0000	4.4	2 +XX
6.0000	2.2	1 +X
7.0000	2.2	1 +X
8.0000	4.4	2 +XX
9.0000	4.4	2 +XX
10.000	4.4	2 +XX
11.000	2.2	1 +X
12.000	2.2	1 +X
13.000	2.2	1 +X
14.000	2.2	1 +X
15.000	15.6	7 +XXXXXXX
16.000	11.1	5 +XXXXX
17.000	4.4	2 +XX

LTD - Parallel parking

MIDPOINT	HIST%	(EACH X= 1)
1.0000	28.9	11 +XXXXXXXXXXX
2.0000	23.7	9 +XXXXXXXXX
3.0000	5.3	2 +XX
4.0000	0.	0 +
5.0000	0.	0 +
6.0000	0.	0 +
7.0000	0.	0 +
8.0000	0.	0 +
9.0000	0.	0 +
10.000	0.	0 +
11.000	0.	0 +
12.000	0.	0 +
13.000	0.	0 +
14.000	0.	0 +
15.000	2.6	1 +X
16.000	18.4	7 +XXXXXXX
17.000	21.1	8 +XXXXXXXX

LTD - slalom

MIDPOINT	HIST%	(EACH X= 1)
1.0000	25.0	8 +XXXXXXXX
2.0000	21.9	7 +XXXXXXX
3.0000	12.5	4 +XXXX
4.0000	0.	0 +
5.0000	0.	0 +
6.0000	0.	0 +
7.0000	0.	0 +
8.0000	0.	0 +
9.0000	0.	0 +
10.000	0.	0 +
11.000	0.	0 +
12.000	0.	0 +
13.000	0.	0 +
14.000	0.	0 +
15.000	6.3	2 +XX
16.000	18.8	6 +XXXXXX
17.000	15.6	5 +XXXXX

LTD - High-speed track

MIDPOINT	HIST%	(EACH X= 1)
1.0000	2.0	1 +X
2.0000	5.9	3 +XXX
3.0000	15.7	8 +XXXXXXXX
4.0000	9.8	5 +XXXXX
5.0000	3.9	2 +XX
6.0000	9.8	5 +XXXXX
7.0000	2.0	1 +X
8.0000	2.0	1 +X
9.0000	0.	0 +
10.000	0.	0 +
11.000	5.9	3 +XXX
12.000	5.9	3 +XXX
13.000	5.9	3 +XXX
14.000	3.9	2 +XX
15.000	11.8	6 +XXXXXX
16.000	9.8	5 +XXXXX
17.000	5.9	3 +XXX

LTD - 25' circle

MIDPOINT	HIST%	(EACH X= 1)
1.0000	15.8	6 +XXXXXX
2.0000	13.2	5 +XXXXX
3.0000	13.2	5 +XXXXX
4.0000	5.3	2 +XX
5.0000	2.6	1 +X
6.0000	5.3	2 +XX
7.0000	0.	0 +
8.0000	0.	0 +
9.0000	0.	0 +
10.000	0.	0 +
11.000	0.	0 +
12.000	0.	0 +
13.000	5.3	2 +XX
14.000	5.3	2 +XX
15.000	7.9	3 +XXX
16.000	13.2	5 +XXXXX
17.000	13.2	5 +XXXXX

LTD - 50' circle

MIDPOINT	HIST%	(EACH X= 1)
1.0000	12.5	4 +XXXX
2.0000	12.5	4 +XXXX
3.0000	9.4	3 +XXX
4.0000	9.4	3 +XXX
5.0000	3.1	1 +X
6.0000	3.1	1 +X
7.0000	0.	0 +
8.0000	0.	0 +
9.0000	0.	0 +
10.000	0.	0 +
11.000	0.	0 +
12.000	3.1	1 +X
13.000	6.3	2 +XX
14.000	6.3	2 +XX
15.000	9.4	3 +XXX
16.000	15.6	5 +XXXXX
17.000	9.4	3 +XXX

LTD - 100' circle

MIDPOINT	HIST%	(EACH X= 1)
1.0000	9.3	4 +XXXX
2.0000	11.6	5 +XXXXX
3.0000	11.6	5 +XXXXX
4.0000	4.7	2 +XX
5.0000	2.3	1 +X
6.0000	2.3	1 +X
7.0000	4.7	2 +XX
8.0000	4.7	2 +XX
9.0000	2.3	1 +X
10.000	4.7	2 +XX
11.000	4.7	2 +XX
12.000	2.3	1 +X
13.000	4.7	2 +XX
14.000	4.7	2 +XX
15.000	9.3	4 +XXXX
16.000	9.3	4 +XXXX
17.000	7.0	3 +XXX

LTD - Shady Hollow

MIDPOINT	HIST%	(EACH X= 1)
1.0000	9.1	4 +XXXX
2.0000	13.6	6 +XXXXXX
3.0000	9.1	4 +XXXX
4.0000	6.8	3 +XXX
5.0000	4.5	2 +XX
6.0000	2.3	1 +X
7.0000	0.	0 +
8.0000	0.	0 +
9.0000	0.	0 +
10.000	0.	0 +
11.000	0.	0 +
12.000	2.3	1 +X
13.000	4.5	2 +XX
14.000	6.8	3 +XXX
15.000	11.4	5 +XXXXX
16.000	15.9	7 +XXXXXXX
17.000	13.6	6 +XXXXXX

LTD - Dearborn zigzag

MIDPOINT	HIST%	(EACH X= 1)
1.0000	22.2	8 +XXXXXXXX
2.0000	13.9	5 +XXXXX
3.0000	13.9	5 +XXXXX
4.0000	0.	0 +
5.0000	0.	0 +
6.0000	0.	0 +
7.0000	0.	0 +
8.0000	0.	0 +
9.0000	0.	0 +
10.000	0.	0 +
11.000	0.	0 +
12.000	0.	0 +
13.000	0.	0 +
14.000	2.8	1 +X
15.000	11.1	4 +XXXX
16.000	16.7	6 +XXXXXX
17.000	19.4	7 +XXXXXXX