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Human Factors Research on Automobile Secondary Controls: A Literature Review

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16. Abstract

This report reviews every document appearing in the open literature (over 40) on human factors and the design of secondary controls (wiper, lights, etc.).

The report examines the following questions:

- What expectancies do drivers have for controls?
- What control designs do people prefer?
- What problems do drivers say they have with controls?
- What do the driver performance data show?
- How have human factors analyses been used to design controls?
- How should specific controls be designed?

While the literature yields considerable insight into how research should be conducted, a surprisingly small amount of what has been done is applicable to contemporary design problems. Most of the literature is over 10 years old, and because it addresses specific design questions for control designs that are no longer produced, it is of limited use. However, there is much to be gleaned from the general human factors literature.

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Overview

Project Significance

- will help Chrysler enhance usability of future secondary control designs (wiper, lights, etc.)
- improve human factors engineering/ergonomics image

Report Content

- reviews every nonproprietary report and paper on human factors and secondary controls (48 total) and design standards, grouped by issue (approximately 300 pages)

Issues Considered

- How should specific controls be designed?
- What do the current design standards require?
- What expectancies do drivers have for controls?
- What control designs do people prefer?
- What problems do drivers say they have with controls?
- What do the driver performance data show?
- How have human factors analyses been used to design controls and what procedures are available?
- What additional research is needed and how should it be conducted?

Highlights of Results

- Provides eleven general design rules and specific design recommendations on a control-by-control basis
- Condenses previous reports into an easy to read, results-oriented summary
- Provides an interpretive critique of the research methods and results so they can be applied to the design of new controls

Specific Findings

How Should Controls Be Designed?

The report includes a summary of design recommendations for 12 controls/control groups. Included are plots of expected locations, operation time data, error data, driver preferences, and human factors recommendations from every study in which a control of interest is mentioned. As an example, part of the section on the horn follows.

> Other studies present results consistent with Krumm (1974). For example, in other performance tests, activation times for the horn (on the steering wheel) were in the range of 1.2 s. (Malone et al.) to 1.4 s. (Faust-Adams and Nagel). Elsholz and Bortfeld (1978) found in their study that European drivers had difficulty with stalk-mounted horn controls, but not with "touch controls" mounted on the steering wheel...
>
> Previous design recommendations have all favored placing the horn control on the steering wheel. For example, ...
>
> Thus, there is considerable research support for locating the horn on the steering wheel hub or spokes, and not on a stalk... Definitive recommendations for size are given in Green, Ottens, Kerst, Adams, and Goldstein (1987)... Finally, some consideration should be given to coupling the horn (or more formally, the acoustic horn), with the headlight flashing function (optical horn) as was proposed in Green (1979)...

What Expectancies Do Drivers Have for Controls? (5 items)

There is no current data on where drivers expect to find controls. Studies on this were carried out in the 70's before stalk controls were common. They do, however, provide insight into how such studies should be conducted.

One the other hand, there is good data in the human factors literature on how drivers think automobile controls should operate. In brief, the direction-of-motion stereotypes are up, to the right, forward, or clockwise for "on" or "increase." A recent Ford study provides numeric data designers can use to select optimal control configurations.

What Control Designs Do People Prefer? (9 items)

The most current information on preferences is the Ford Best-In-Class study. The Automotive Industries article on it should be read by every automotive designer and engineer. Ford identified more than 400 concerns such as defroster switch operation and high-beam control accessibility. Juries identified which of many cars had the "best" design for each function. The success of the Taurus/Sable is a direct result of this program.

Hallen (1977) examined a related issue, reach preferences. Typically, drivers wanted controls to be 10-20 cm (4-8 inches) closer than their maximum reach. This data was collected when comfort/convenience was not important and has largely been ignored. It should not be.

What Problems Do Drivers Have Using Controls? (5 items)

Examinations of accident reports (from one study from the 70's with a small sample size) show that using controls can be distracting and lead to an accident. Most common are problems with the entertainment system, though problems have been reported with many other controls.

Supporting evidence comes from surveys of drivers. Malone et al. (1977) identified 100 instances where using a control "caused an accident," as well as 1500 instances of "close calls" in responses from 3500 drivers. Common problems included finding and operating the horn, defogger, and dimmer switches. It is not clear how applicable the data are to contemporary control designs. (For example, dimmer controls were floor-mounted then.)

What Do the Driver Performance Data Show? (18 items)

Studies of driver performance have examined time and errors using controls, and driver eye movements. Particularly noteworthy are the Anacapa Sciences 1974 and 1976 reports. Most performance studies concern whether stalk- or panel-mounted controls are better for driver safety and ease-of-use, a major issue in the '70s. Some key findings are:

1. The design of a control can have an enormous effect on driver performance. In one study when asked to honk a horn, it took drivers an about 1/2 second for spoke- and hub-mounted switches, but 29 seconds for rim-blow designs. Drivers also had major problems with stalk-mounted horn controls.

2. If a control is not within five inches of the surface on which it is expected to be located, performance will suffer.

3. Drivers may have major problems operating touch screens while driving. In one experiment, it took two to three times longer to use a touch screen than

dedicated controls, and the number of times drivers looked away from the road increased similarly.

What Human Factors Analysis Procedures Exist? (19 items)

Analysis procedures typically consider current convention, frequency-of-use, and criticality of the function being controlled in a nonquantitative manner. In part this is because reliable data on the frequency-of-use of controls do not exist. Human factors procedures (error analysis, human performance modelling, simulation) used by other industries have not been applied to automotive problems.

Closing Remarks

Surprisingly little in the automotive literature is applicable to contemporary design problems. This is because the automotive human factors literature emphasizes safety and not ease-of-use, is dated (the data concern control designs no longer prevalent), and has too narrow a focus (emphasis on specific designs not a methodical analysis of alternatives or design principles). Further, the amount of research is surprisingly small (about 2 documents/year recently). (In contrast, there are at least 10-15 items per year on computer input devices, a level of output 5 times greater from an industry of comparable size.) Most of what continues to be useful are the methodological insights. The Challenge Fund Program is a noteworthy effort to overcome these difficulties.

On the other hand, the general human factors literature contains a wealth of information applicable to control design. Of particular value is the standard introductory textbook (Sanders and McCormick (1987), Human Factors in Engineering and Design (6th ed.), and the DOD design standard (U.S. Department of Defense, Military Standard 1472C, Human Engineering Design Criteria for Military Systems, Equipment, and Facilities). If human factors engineering is to do more than just "fight fires" in automotive contexts, then the research on automotive problems must be carried out in such a way that the research is not obsolete in a few years.

Other Reports in This Series

- Secondary Controls in Domestic 1986 Model Year Cars (Green, Ottens, and Adams) - describes the location, method of operation, types of switches used, etc., in secondary controls in 1986 cars.

- Driver Preferences for Secondary Controls (Green, Kerst, Ottens, Goldstein, and Adams) - describes an experiment in which 102 drivers identified which of 255 switch types they preferred for each of 24 secondary functions, where each switch should be located, and how those switches should operate.

PREFACE

This report describes the first phase of a three-phase effort to help Chrysler design future cars. It is intended to help make secondary controls such as the lights and wiper easy to use. This report describes and critiques the literature on human factors and automobile controls, and in addition, offers some design recommendations.

Two broad issues are considered in this review:

- What research methods have been utilized to study driver use of automobile instrument panel controls?

- What specific advice does the literature offer regarding the design of individual controls?

The second report in this series (Green, Ottens, and Adams, 1987), provides a statistical summary of the location, method of operation, and types of switches used for secondary controls in virtually all 1986 model-year cars sold in the U.S. A third report (Green, Ottens, Kerst, Adams, and Goldstein, 1987), describes driver preferences for switch types and locations for 31 secondary functions. Over 250 switch types have been examined.

All the research described above is supported by the Chrysler Challenge Fund. The Fund, established to create closer ties between the Chrysler Corporation and leading American universities, promotes direct access to the advanced technologies being developed in universities. It also aims to increase interaction between Chrysler engineering staff and university research personnel, as well as increase undergraduate and graduate student awareness of the engineering opportunities available at the Chrysler Corporation. So far, the three phases of this particular project have enabled seven undergraduate and two graduate students to obtain practical experience in automotive human factors research. Furthermore, an experiment related to this project is being developed for the human factors laboratory course which all University of Michigan's Industrial Engineering students are required to take.

Readers should approach this review by placing themselves in one of the following categories, depending upon their background and interest:

> Human Factors Researchers: Read the report from beginning to end, not skipping any of the sections.

<u>Designers</u>: Read the first three sections for an overview of the human factors field, then skip to sections entitled "What Do The Current Design Standards Require" and "How Should Specific Controls Be Designed" for a control-by-control summary of research results.

The authors would like to thank Tom Hamilton and Jim Pitt of the Chrysler Corporation for acting as project liaisons. Too often researchers are pressured to produce a report where speed, not thoroughness, is of the essence. The patience of these two gentlemen allowed us the time to do this work properly.

SCOPE OF THIS REPORT

As noted in the preface, this report concerns the first phase of a three-phase effort to make automobile controls such as the lights and wiper easy to use. This review discusses and critiques the human factors literature concerned with secondary controls found on automobile instrument panels. There is a similar, though vastly smaller body of literature on trucks and buses which is not considered here. The review mainly addresses studies specifically examining automotive controls, as opposed to general human factors research, and emphasizes data on U.S. drivers. No hardware reviews are considered in this report, as they are covered in the second report in this series (Green, Ottens, and Adams, 1987) to which they are directly tied. Also excluded are general information papers which provide neither research nor human factors methodologies (e.g. Nemeth, 1978.) Research examining design for the handicapped (e.g. Anger and Wayne, 1978) was also not reviewed, nor was any work on driver reach, with the exception of Hallen (1977), which is discussed in the section entitled "Where Do Drivers Expect To Find Controls." Work relating to anthropometry is being covered in another Challenge Fund project. (See Schneider, 1987.)

This report is written for engineers and industrial designers responsible for instrument panel design, as well as human factors specialists concerned with automotive applications. It is assumed readers have some prior knowledge of human factors engineering, the equivalent of one formal course in the subject.

This literature review is similar in many ways to Green (1979), since there has been little new work done on instrument panel human factors since then. However, while Green (1979) was concerned only with multifunction stalk controls, this review is broader and includes panel-mounted controls as well. This review examines every non-proprietary report and paper that has ever been written on human factors and automobile secondary controls (about 48 documents over 18 years.) It also examines related design standards.

This report considers nine specific questions:

1. **In general, what research has been done on secondary controls?**
2. **What do summaries of the human factors literature suggest?**
3. **Where do drivers expect to find secondary controls and how do they expect them to operate?**

4. Which control designs do people prefer?
5. With which controls do drivers have problems?
6. How long does it take to operate a control and how often are errors made for different designs?
7. How have human factors methods been used to analyze control designs and what procedures are available?
8. What do the design standards for controls require?
9. How should specific controls be designed?

INTRODUCTION TO RESEARCH ON SECONDARY CONTROLS

Over the last 18 years, about 48 nonproprietary reports and papers have been written on human factors and secondary controls. They can be grouped into eight categories that are parallel to the questions listed in the scope. These categories include:

1. Literature reviews-- collections of previous research evidence.

2. Control location expectancy surveys-- studies of where drivers expect to find various controls.

3. Preference surveys-- surveys concerning which control arrangements drivers prefer.

4. Problem surveys-- reports of difficulties drivers say they have in locating, reaching for, and activating controls.

5. Accident data analyses-- examinations of when and how often the use of controls is associated with accidents. That evidence comes from police data bases, as well as from surveys of near-accidents.

6. Driver performance experiments-- investigations of response time, error rates, and other measures of how controls are used.

7. Human Factors (HF) analyses-- evaluations of particular designs with respect to human factors principles, standards, and current research.

8. Design stereotype reviews-- examination of current control designs in domestic and imported cars to determine what's common.

The mapping of the research publications in these categories is shown in Table 1, an expansion of a similar table in Green (1979). In this report, each of the above approaches (except for the material on design stereotypes) is discussed in detail in a separate section, with the individual documents shown in Table 1 discussed in chronological order. (The material on design stereotypes appears in Green, Ottens, and Adams, 1987.) Readers should note that the horizontal lines in Table 1 serve to group documents by year.

Table 1. Approaches Used in Studies of Secondary Controls

Document	Lit Review	Expect	Perform	Problems	Accidents	Analysis	Prefs	S-types
- Woodson, Conover, Miller and Selby, 1969 (also reported as Conover, Woodson, Selby, and Miller, 1969)	.	.	.	.	.	X	.	X
- Malone, Krumm, Shenk, and Kao, 1972 (also reported as Kao, Malone, and Krumm, 1972)	.	.	X	.	.	X	.	X
- Mortimer and Post, 1973	.	.	.	.	.	X	X	.
- Anacapa Sciences, 1974	.	X	X	X	.	.	.	X
- Krumm, 1974	.	.	X	X	.	.	.	X
- Kuechenmeister, 1974	.	.	X	.	.	.	X	.
- McGrath, 1974	.	X	.	.	.	.	.	X
- Middendorf, Dineen, and Hapsburg, 1974	.	.	X	.	.	.	.	.
- Perel, 1974	X	.	.	.	.	.	.	.
- Faust-Adams and Nagel, 1975	.	.	X	.	.	.	.	.
- Kuechenmeister, 1975	.	.	X	.	.	.	.	.
- Knaff, 1975	X	.	.	.	.	.	.	.
- Woodson and Selby, 1975	.	.	.	.	.	X	.	.
- Anacapa Sciences, 1976	.	X	X	X	.	.	.	X
- Simmonds, 1976a, b, c	.	.	.	.	.	X	.	.
- Perel, 1976	.	.	.	.	X	.	.	.
- Burger, Smith, Queen, and Slack, 1977	.	.	.	X	.	X	.	.
- Black, Woodson, and Selby, 1977	.	X	.	.	.	.	.	.
- Mourant, Moussa-Hamouda, and Howard, 1977 (also reported as Mourant, Herman, and Moussa-Hamouda, 1980)	.	.	X	X	.	.	X	.
- Hallen, 1977	.	.	.	.	.	.	X	.
- Elsholz and Bortfeld, 1978	.	.	X.	.	.	.	.	.
- Green, 1979	X	.	.	.	.	X	.	X
- Nicholson, 1979	X	.	.	.	.	.	.	.
- Treat et al., 1979	.	.	.	.	X	.	.	.
- Rockwell and Roach, 1980	.	.	.	.	.	X	.	.
- Friedman and Schmidtz, 1981	.	.	.	.	.	X	.	.
- Haller, Bouis, and Heintz, 1981 (also reported as Bouis, Haller, & Heintz, 1981; Heintz, Haller, & Bouis, 1982)	.	.	X	.	.	.	.	.
- McCallum, Dick, and Casey, 1982	.	.	X	.	.	X	X	.
-.Galer, Spicer, Geyer, & Holtum, 1983	.	.	X	.	.	.	.	.
- Khadilkar, 1983	.	.	X	.	.	X	.	.
- Green, 1984	.	.	.	.	.	X	.	.
- Heintz, Bouis, and Haller, 1985	.	.	X	.	.	X	.	.
- Jack, 1985	.	X	.	.	.	X	.	.
- Snyder and Monty, 1986	.	.	X	.	.	.	.	.
- Callahan, 1986a, b, c	.	.	.	.	.	.	X	.
- Saunby, Farber, and Jack, 1986	.	.	.	.	.	X	.	.
- Green, Ottens, and Adams, 1987	.	.	.	.	.	.	.	X
- Green, Kerst, Ottens, Goldstein, and Adams, 1987	.	.	.	.	.	.	X	.
- Turner and Green, 1987 (this report)	X	.	.	.	.	.	.	.
Totals (# documents using approach):	5	5	18	5	2	19	8	9

The two most common approaches used are human factors analyses (19 documents) and driver performance studies (18). There are also several studies of driver stereotypes (9) and preferences (8). On the other hand, accident data analyses (2) and problem surveys (5) are rare.

Also noteworthy is the general shift in focus from driver performance experiments in the 1960's and early 1970's to human factors analyses in the late '70s and 1980's. This is indicative of the trend towards more analytical work based on documented human factors principles, and less research to understand why differences occur. Furthermore, much of the work is methodologically constrained. Only 7 of the 48 documents discussed in this review use more than 2 of the approaches identified previously. This small number of documents published on secondary controls in the last two decades suggests a historic lack of interest in this topic by the automotive industry.

One can identify the major contributions not only by the number of approaches used, but also by the page count of each document. Shown in Figure 1 is a plot showing that information. In creating this figure, the number of pages in journal articles was multiplied by two so that the average word count per page would be equivalent to that of technical reports. Notice that the page lengths vary considerably reflecting a mix of short items (journal articles and SAE papers) and lengthy technical reports. In terms of length, Woodson, Conover, Miller, and Selby (1969), Malone, Krumm, Shenk, and Kao (1972), and Green (1979) stand out from among the rest.

A third perspective of these data is to aggregate the annual page counts as is done in Figure 2. Notice that the research in this area didn't begin until the late '60's, shortly after Nader's book, Unsafe At Any Speed (Nader, 1965) was published. Ignoring the last few years, there also seems to be a relationship between car production (in reality, sales) and research production (as measured by the three-year moving average of the number of pages written). When car production was low ('70-'71, '80-'82), there was virtually no research on controls, suggesting research support is highly discretionary. What makes the sales explanation hard to believe is that much of the work was supported by the federal government, and they don't sell cars. For example, from 1968 until 1977 15 of the 25 documents were directly supported by the federal government. (Two were supported indirectly.) It may be that when the industry was doing poorly, the government was less likely to fund research that might lead to new safety regulations (and purportedly increased costs). Whatever the reason, those searching for research literature in future years should examine places where industry-supported studies are likely to appear. Further, expectations of how much people will find should be based upon the health of the automotive industry at the time as well as trends given here on research production.

Studies of Automotive Controls
1969 - 1987

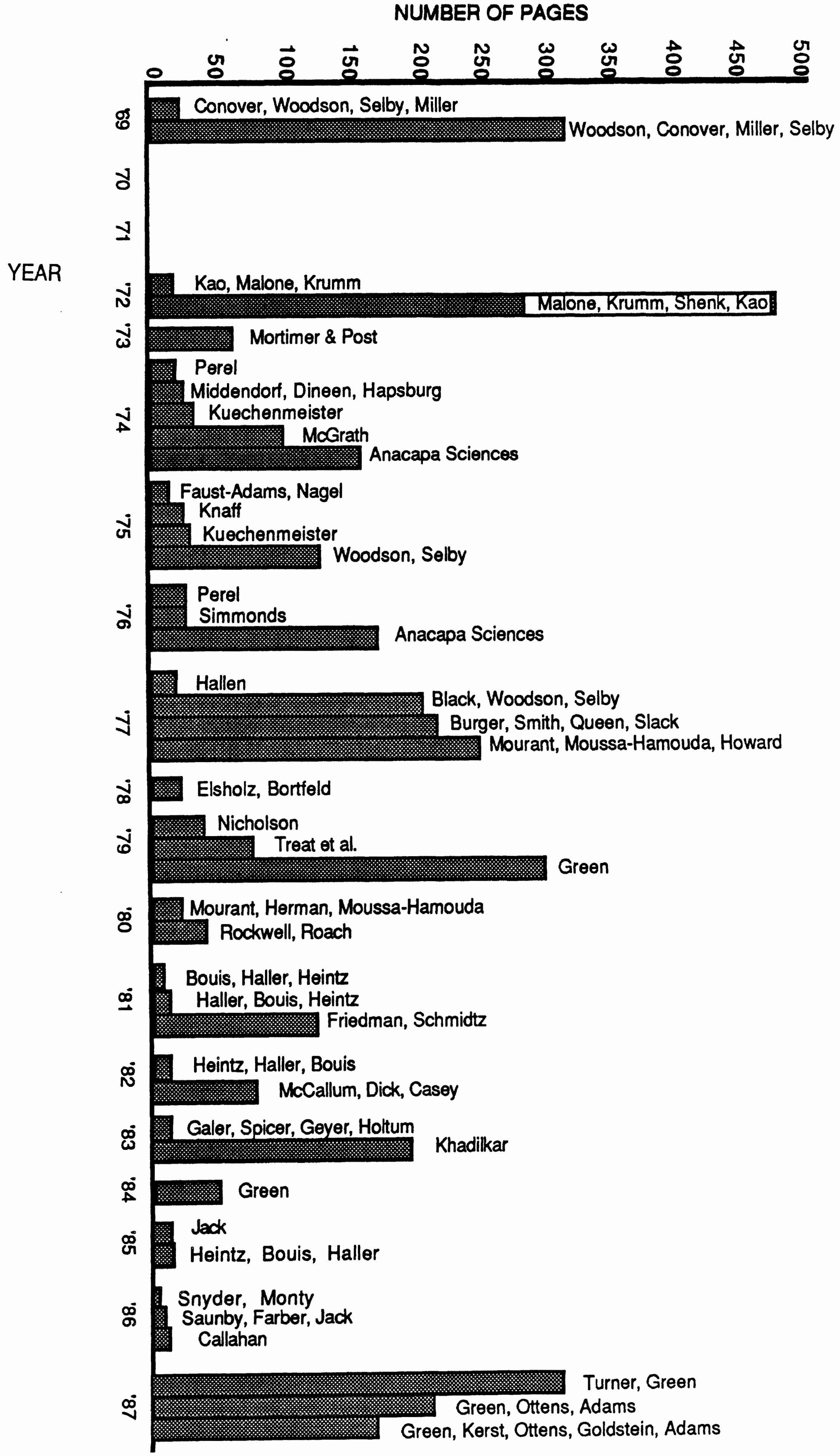


Figure 1, Studies of Automobile Controls

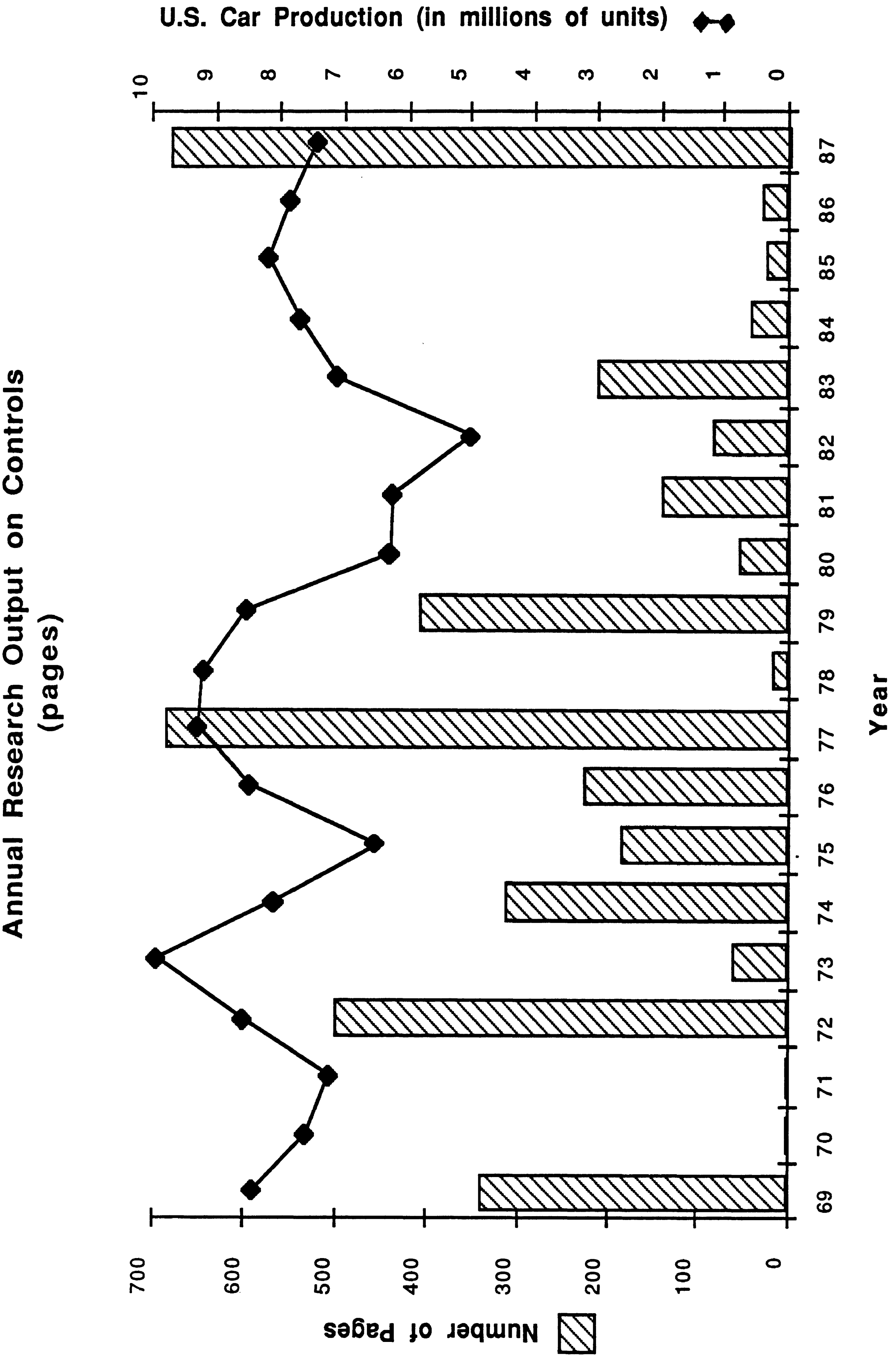


Figure 2, Annual Research Output on Controls

Much of the early research was conducted in the interest of building safer cars. In the late 1970's, the political climate changed and safety became a less important concern. As a consequence, government support stopped and very little new work was contracted out. In the 80's, output has been quite low, roughly two papers or reports every year, not much considering the importance of the problem.

These figures may be a bit misleading in that they do not reveal the renewed interest in controls that has occurred in the last year or two. Many car manufacturers have used the words "ergonomics," "human factors," and "human engineering" in their advertising, and as described later, have begun to pay greater attention to what customers want. One of these "wants" is a car that is easy to use. Cynics have remarked that cars are easy to use because, "everyone knows where the steering wheel, brake, and the gas pedal are, and how to use them." However, customer complaints about doors that are hard to open, seats that are uncomfortable, seat belts that are difficult to put on, controls that are hard to reach, displays that cannot be read by older drivers, and radios that are overwhelmingly complex, have led many to believe otherwise.

This change in attitude has several consequences. First, the shift from safety to ease-of-use has led to greater acceptance of human factors. Human factors work is viewed as leading to greater sales rather than as a cost. Second, the change in attitude has led to changes in the methods used (e.g. greater emphasis on preferences, less on performance), greater ties with marketing and less with accident investigation, and finally, a new emphasis on proprietary research.

WHAT DO THE HF LITERATURE SUMMARIES SUGGEST?

General Human Factors Literature

There are a number of textbooks devoted to the subject of human factors. All of the introductory texts contain at least one chapter on the subject of controls. For example, both of the first two textbooks on human factors, Applied Experimental Psychology (Chapanis, Garner, and Morgan, 1949) and Human Factors in Undersea Warfare (Craig and Ellison, 1949), dealt with that topic. In Chapanis et al. it was chapter 11, Controls for Human Use. In Craig and Ellison it was chapter 5, The Design of Controls. Later texts which saw widespread use also contain chapters on controls (Morgan, Cook, Chapanis, and Lund (1963) (chapter 6), McCormick (1970) (chapter 11), Woodson and Conover (1970) (chapter 2) and McCormick and Sanders (1982) (chapter 9)).

In the early 70's, the basic introductory texts were supplemented by the Human Engineering Guide to Equipment Design (Van Cott and Kinkade, 1972), often referred to as HEGED ("hedge-ed"). When the rate of growth of the profession increased in the 1980's, so too did the textbook market. McCormick's text (now jointly authored with Mark Sanders and in its sixth edition (Sanders and McCormick, 1987)) is still the most commonly used. A few have complained that Sanders and McCormick lacks problem sets (which most engineering texts contain) and is dated (primarily in its coverage of computer interfaces). This has motivated others to enter the textbook market. However, on the whole, Sanders and McCormick is a useful text for solving practical engineering problems and is a reference designers should have on hand. Two other well-known texts are Kantowitz and Sorkin (1983) and Bailey (1982). Kantowitz and Sorkin (1983) is written much like an introductory psychology text, with sidebars containing interesting stories and example applications. It does not contain as much hard technical data or any problems to solve, and its largest readership is in human factors courses offered in psychology departments. Bailey (1982), written while he was a member of the Bell Laboratories technical staff, emphasizes issues pertaining to human-computer interaction in fair detail. A new edition is being prepared.

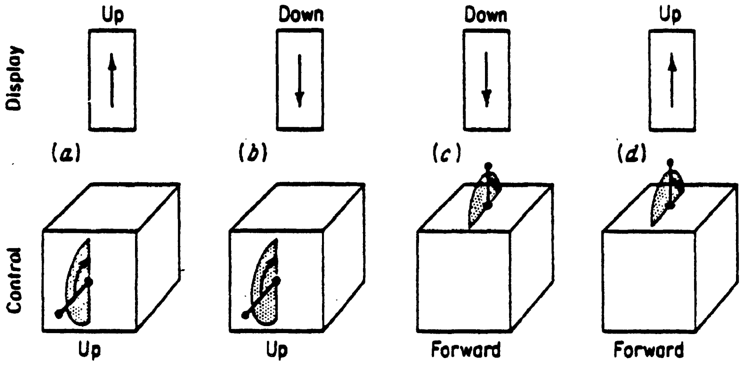
Unlike many areas of engineering and science, where there is a single or small number of commonly used handbooks (e.g., Mark's Standard Handbook for Mechanical Engineers (Baumeister, Avallone, and Baumeister, 1978), CRC Handbook of Chemistry and Physics (Weast, 1976), handbooks are not widely used in human factors engineering. The only well-known human factors handbook is Woodson (1981). Woodson is spotty in its coverage. Many areas are better covered in other works.

A more recent handbook is Salvendy (1987). A chapter is devoted to controls, but it is just one chapter out of about 70. Despite its length (1800+ pages), Salvendy tends to be a bit light on figures, tables, formulas, and other engineering data. Automotive designers will find Woodson (1981) more useful.

There are other textbooks dealing with specific areas of human factors, including Wickens (1984) on human performance theory, and the two-volume Eastman Kodak Company (1983; 1986) set dealing with applications of human factors to workplace design. Finally, there is a two-volume set of notes and readings used in a short course on human factors engineering taught each summer at the University of Michigan (Pew and Green, 1986). The notes are in an outline format and are most useful to those attending the course. However, since they are revised annually, they are usually more current, especially the references, than textbooks.

The content of the chapter or chapters on controls in most human factors textbooks is fairly consistent. Typically they cover the basic schemes for coding controls (labeling, shape, texture, size, location, color, etc.) and factors pertaining to the movement of controls (control/display ratio, resistance, deadspace, hysteresis, etc.). They also discuss the design of common controls such as keyboards, knobs, pushbuttons, levers, cranks, handwheels, and foot pedals. For these controls specific design recommendations for control size, spacing, and operating forces are given. Most texts also cover cursor control devices (mice, light pens, touch pads, etc.) and mention exotic control devices (e.g., eye fixation slaved controls) as well. Shown in Figures 3 and 4 are two typical pages from McCormick and Sanders (1987) for those readers unfamiliar with human factors texts.

Other sources of design guidance are military standards. At one time, HEL-STD-6-66 was commonly used by the military (but not by private industry) as a procurement requirement. Many years ago, this document was superceded by a generic human factors standard, Mil Standard 1472 (MIL-STD-1472C, Human Engineering Design Criteria for Military Systems, Equipment and Facilities). This several-hundred page military standard is very comprehensive. While obviously intended for military applications, it is the only broad-base human factors standard in existence and is therefore used in civilian contexts as well. Every practicing human factors engineer should have a copy, since it is viewed as the defacto human factors standard. It is well known that 1472 is a minimal standard, and is so viewed in product liability cases. The 1472 document contains a lengthy and exacting description of standards for control arrangements, coding, dimensions, actuation forces, etc. (See Figure 5 for sample text). In using 1472, one should realize that the anthropometric data is based on a sample of the military population, which is somewhat less variable that a similar civilian sample.



Average Tracking Score	239	149	221	227

FIGURE 9-5
Tracking performance with horizontally mounted and vertically mounted stick controls and varying control-display relationships. *(Source: Adapted from Spragg, Finck, & Smith, 1959, data based on trials 9 to 16.)*

mounted stick, on the horizontal lateral-cutting plane, there was less difference between the *forward-up* and *forward-down* relationships.

Based on these studies and others, Grandjean (1981) recommended the movement compatibility relationships shown in Figure 9–6 for rotary and stick-type controls and linear displays located in various planes.

Movement Relationships of Rotary Vehicular Controls In the operation of most vehicles there is no "display" to reflect the "output" of the system; rather, there is a "response" of the vehicle. In such instances, if the wheel control is in a horizontal plane, an operator tends to assume an orientation toward the forward point

FIGURE 9-6
Recommended movement relationships for rotary and stick-type controls and linear displays located in various planes. *(Source: Grandjean, 1981; fig. 113.)*

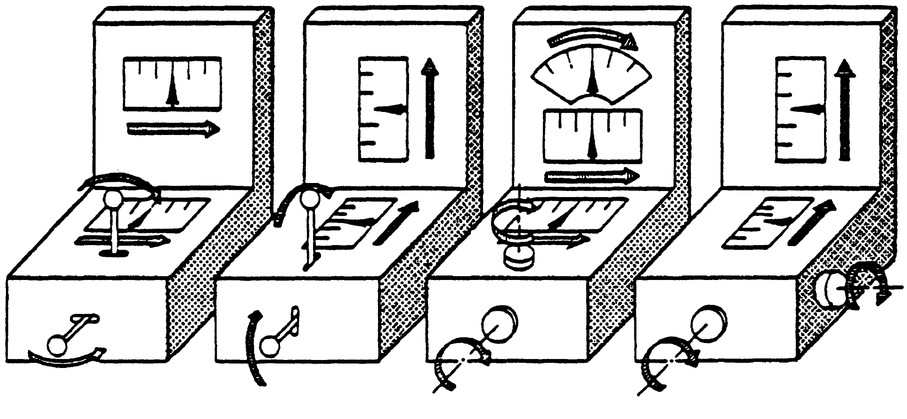


Figure 3, Page 241 from Sanders and McCormick, 1987

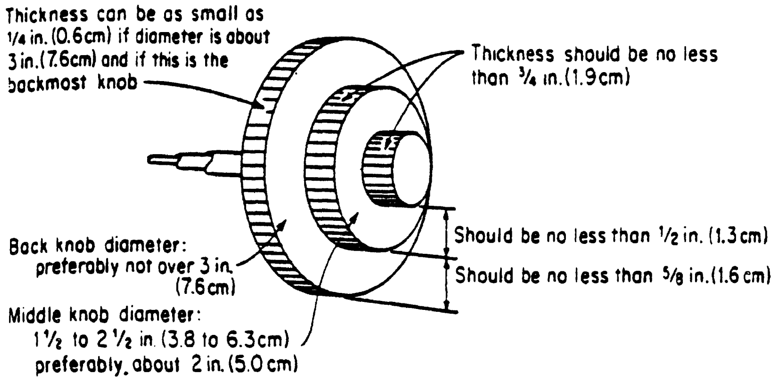


FIGURE 10-13
Dimensions of concentrically mounted knobs that are desirable in order to allow human beings to differentiate knobs by touch. *(Source: Adapted from Bradley, 1969.)*

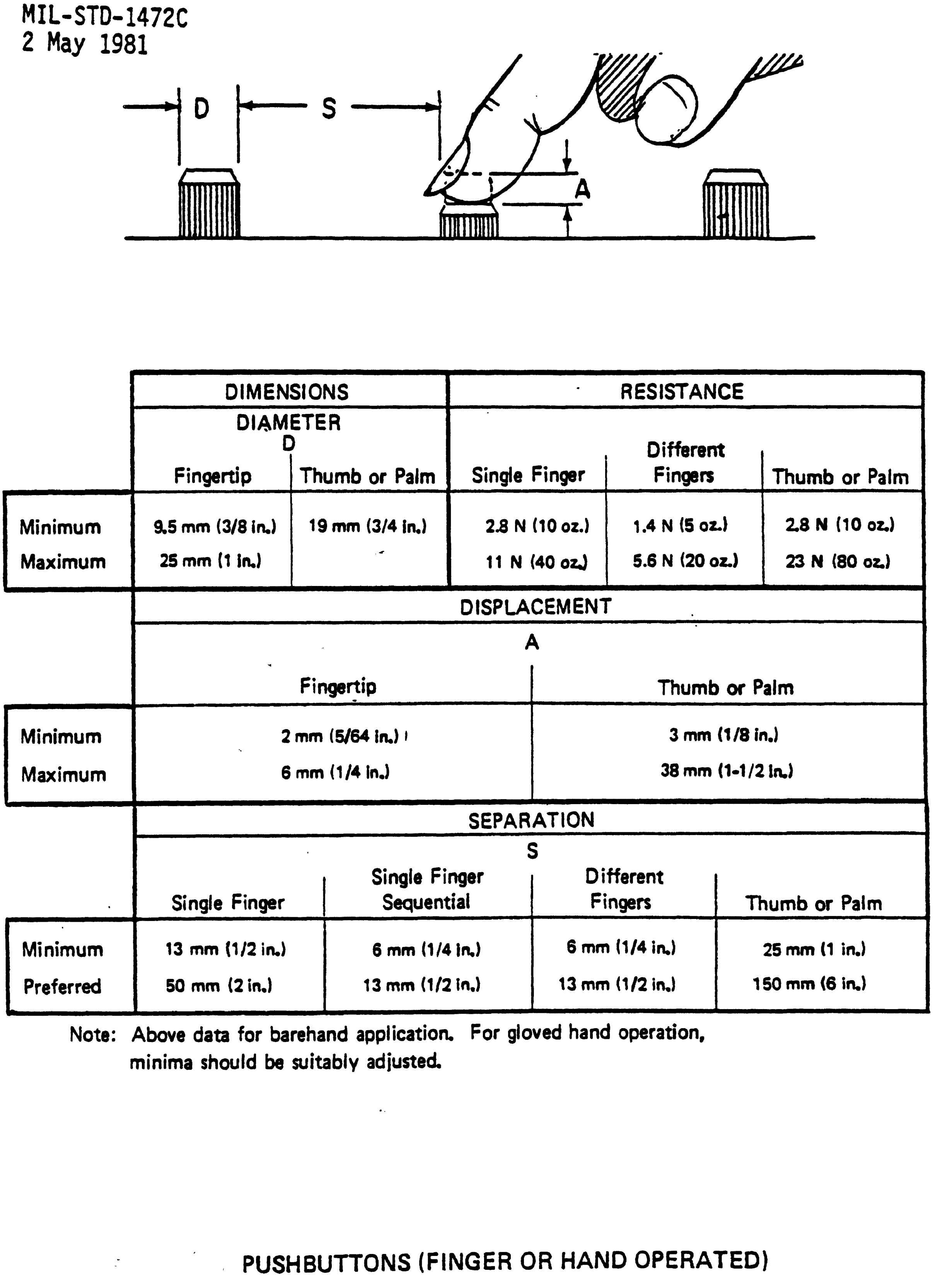
this, Bradley (1969) used various combinations of such knobs and various performance criteria (errors, reach time, and turning time). He found that the dimensions shown in Figure 10–13 were optimum.

Knobs for Producing Torque

Often, control knobs are used to apply fairly high levels of torque to equipment, for example, in turning on or off a water faucet, tightening a clamp mechanism, or turning a door knob. Kohl (1983) measured the maximum isometric force that females could exert on smooth aluminum knobs of various shapes and sizes [diameters of 2.5 to 5.5 in (6.4 to 14.0 cm)]. Subjects performed the task under two conditions: with greased hands and with hands covered with a nonslip compound. Figure 10–14 presents results after performance is averaged across the various knob sizes. It is no surprise that greasy hands reduced the amount of force (torque) that could be applied to the knobs. There was little effect of knob shape when the nonslip compound was used; however, with greased hands, torque *decreased* as the number of sides on the knob increased. As might be expected, the larger the knob diameter, the more torque that could be developed, but this effect diminished as the number of sides on the knob increased. Kohl cautioned that the triangular knob caused discomfort and therefore recommended the square shape.

Brullinger and Muntzinger (1984) performed a similar experiment, varying the shape of knobs having a diameter of 80 mm (3.15 in). The subjects in this experiment were males, and they performed the task with clean knobs and with knobs soiled with dirt and oil. Figure 10–15 shows the knob shapes used and the average maximum torque produced with each. Larger differences in torque production were found between shapes in this study than in Kohl's study. The control producing the highest average torque (i.e., control 1, a rectangular bar) was not recommended because of the discomfort caused by the edges digging into the palm of the hand. Control 4, in soiled conditions, and control 5, in clean conditions, were recommended.

Figure 4, Page 277 from Sanders and McCormick, 1987



MIL-STD-1472C
2 May 1981

	DIMENSIONS		RESISTANCE		
	DIAMETER D				
	Fingertip	Thumb or Palm	Single Finger	Different Fingers	Thumb or Palm
Minimum	9.5 mm (3/8 in.)	19 mm (3/4 in.)	2.8 N (10 oz.)	1.4 N (5 oz.)	2.8 N (10 oz.)
Maximum	25 mm (1 in.)		11 N (40 oz.)	5.6 N (20 oz.)	23 N (80 oz.)

	DISPLACEMENT A	
	Fingertip	Thumb or Palm
Minimum	2 mm (5/64 in.)	3 mm (1/8 in.)
Maximum	6 mm (1/4 in.)	38 mm (1-1/2 in.)

	SEPARATION S			
	Single Finger	Single Finger Sequential	Different Fingers	Thumb or Palm
Minimum	13 mm (1/2 in.)	6 mm (1/4 in.)	6 mm (1/4 in.)	25 mm (1 in.)
Preferred	50 mm (2 in.)	13 mm (1/2 in.)	13 mm (1/2 in.)	150 mm (6 in.)

Note: Above data for barehand application. For gloved hand operation, minima should be suitably adjusted.

PUSHBUTTONS (FINGER OR HAND OPERATED)

Figure 5. Sample Page from Mil Standard 1472C

What then, should automotive designers read? Sanders and McCormick (1987) is the most comprehensive textbook available, and if designers are regularly dealing with human factors problems, they should have a personal copy of it. Designers should also have a copy of MIL-STD-1472C, and abide by it when developing vehicles. Finally, completion of a human factors course (such as the University of Michigan Short Course) can also be helpful in providing the most up-to-date information in this field.

Previous Literature Reviews Concerning Secondary Controls

Supplementing and enhancing the information contained in textbooks are the literature reviews published in various automotive and human factors journals which specifically address human factors and automobile controls. In Perel (1974), there is a review of the five National Highway Traffic Safety Administration (NHTSA) studies concerning controls and displays for which Perel was contract monitor. They include Woodson, Conover, Miller, and Selby (1969), and Krumm (1974), as well as a study concerning driver eye position and driver needs, and one concerning driver brake force capabilities. Details of each of the first three studies are given later in this report, and therefore will not be described here. NHTSA was sponsoring all these projects with an eye toward providing a data base for the development of Federal Motor Vehicle Safety Standards (FMVSS) in the area of controls and displays (FMVSS No. 101). Perel concluded that there was a need for further research in the area of driver/vehicle mismatches as well as for standardization of control locations between manufacturers. Perel (1974) is useful as an overview of the five projects, but is less meaningful now as a description of current research than it was in 1974.

Knaff (1975) expanded the focus of driver control studies, reviewing literature concerned with human brake pedal force, seatbelt usage, and control design. Only two of the reports he reviewed concern the design of secondary controls. Thus, Knaff (1975) offers little additional information pertaining to research on automobile control design.

Nicholson (1979) also summarizes NHTSA reports covering a wide variety of subjects, some of which are related to controls design. (Other issues discussed include restraint systems, driver visibility, ride quality, accident data systems, etc.) Six references in the Nicholson paper deal specifically with controls, and the paper describes key points in these works. It is only a brief report, but it is an interesting overview and a useful introduction for those who know little about the field of automotive human factors.

Green (1979) reviews an extensive collection of literature, as well as vehicle hardware, concerning multifunction stalk controls. However, that report also briefly discusses panel-mounted controls as well, a necessary part of any study of vehicle controls. This report is several hundred pages long and contains much more in-depth information than the reviews described earlier. The section headings used in that report are similar to those used here, and many of the reports reviewed in it are also reviewed here, though more broadly because this report concerns all controls, not just stalk controls. Due to these similarities, a detailed re-iteration of that literature review will not be given here.

Green (1979) also describes an extensive vehicle survey carried out on the location and method of operation of all multifunction stalk configurations found in 1977-1979 model year domestic and foreign automobiles. While Green admits that the survey is far from complete, it does "provide a reasonable picture of the stalk configurations in use during this period (p. 94)." Appendix D in Green (1979) contains a tabular summary of this survey.

Also in Green (1979) is a discussion of the effort of standards organizations with regards to stalk controls. Included are comments on the ECE (Economic Commission for Europe, a Geneva-based UN group), the EEC (European Economic Community or Common Market), and ANSI (American National Standards Institute).

Finally, Green (1979) contains a brief discussion of human performance models for predicting activity completion times. Among them are Hick's Law for response time and Fitts's Law for the time to complete ballistic movements. Green proposes that "combining several of the psychological models with the industrial engineering data will yield the most accurate predictions (p. 140)" with respect to human performance. Since then, this has occurred, and such models are commonly applied to study human-computer interaction (Card, Moran, and Newell, 1983). (Those unfamiliar with Hick's Law and Fitts's Law should read Card et al.) Green's report goes on to make a series of tentative human factors design recommendations with respect to the design of stalk controls, though those recommendations apply to all control types and contexts, including instrument panel-mounted controls.

Green (1979) concludes with a number of proposals for future research. With respect to finding novel designs for controls, he suggests a study of custom and show car dealers and manufacturers, as well as possible MVMA sponsorship of student industrial design projects to develop new control designs. He also suggests a detailed study of the relationship between control design and accident statistics, as initially undertaken in the Perel (1976) study. He also proposed a survey of drivers in Europe and Japan to add information regarding experiences of non-American drivers with controls. Finally, a series of experiments to determine the parameters of a possible response time model were suggested, to allow engineers to properly predict driver performance in the future.

Rockwell and Roach were hired by the MVMA, the sponsor of the Green (1979) report, to critique that report (Rockwell and Roach, 1980). Interestingly, while they suggested that Green's model was too simple, internal MVMA comments were that it was too complex. Rockwell et al. noted several other weaknesses in the proposed model: selecting performance time over other criteria (e.g., eye movements, number of errors, etc.) as a measure of human performance and a lack of a dimensional analysis. Furthermore, while they suggested that performance time was not a particularly suitable criterion.

Perel's 1983 report reviews the relationship between vehicle familiarity and safety. Perel examines six sources of accident causation data, and discusses their findings. In particular, he notes that lack of familiarity with the controls of the vehicle is often a significant factor. One of his sources was the Indiana University Tri-Level Study of Accident Causation (Treat et al., 1979) which involved analysis of police reports, on-scene accident analyses, and in-depth accident investigations. In that study, 34% of the passenger car drivers had less than six months familiarity with the car, and roughly 25% of the vehicles involved had less than 2,000 miles on the odometer. Perel argues this supports his hypotheses that familiarity with vehicles and ease-of-use of controls are essential to safe driving.

Finally, a potential report of interest is de Waal and Moraal (1983). The abstract for this report (in English) says the report reviews the literature regarding ergonomic aspects of cars and trucks. (The body of the report is written in Dutch, a language in which the authors are not fluent.) It is notable that this report offers comments on the relative importance of the various ergonomic factors. According to the abstract it also tries to formulate standards for vehicular ergonomics. It would be interesting reading if this document translated.

Summary

To recap, there have been several literature reviews of human factors and controls prior to this one. The only comprehensive review pertaining to controls was Green (1979), which this document supersedes in many aspects. (Those with specific interests in stalk-mounted controls should read Green, 1979.)

- WHAT DO HUMAN FACTORS LITERATURE SUMMARIES SUGGEST? -

In terms of basic material on human factors engineering, there is a great wealth of information. Those with minimal formal course work in human factors engineering/ergonomics are urged to carefully study a common human factors textbook such as Sanders and McCormick (1987), in particular chapters 9 and 10. Another source of information designers and engineers should have a desk copy of is Military Standard 1472. Finally, attendance at a human factors short course such as the class at the University of Michigan is also strongly recommended for those seeking an introduction to human factors and the design of controls.

- WHAT DO HUMAN FACTORS LITERATURE SUMMARIES SUGGEST? -

WHAT EXPECTANCIES DO DRIVERS HAVE FOR CONTROLS?

In designing and positioning controls for cars, driver expectancies for control location, method of operation, and switch type should have a major influence on the designer's decisions. When controls are not placed where people expect them or operate differently than expected, it takes drivers longer to use them and they make more mistakes in doing so. In some instances, the design that drivers expect is not optimal from the human factors perspective when experience is ignored. When this occurs, the designer must decide how to trade off short-term performance (favoring the expected design) with long-term performance (favoring the optimal one).

Three major reports of driver expectancies are examined in detail in this section. Issues examined include the relationship between expectancy and performance, preferences for controls and location, preferred reach distances to controls, and several related issues.

McGrath (1974)

While the focus of this report is on U.S. drivers, some mention of foreign drivers must be made for the sake of completeness. McGrath (1974) reports control expectancies from a survey of 219 European (UK, France, Italy, Sweden) and Japanese drivers. Participants were given two sketches, one of an American-made and one of a foreign-made auto, and asked to mark where they expected to find seven controls. (ignition, hazard control, defroster control, cigarette lighter, washer control, wiper control, and headlight control.) All the sketches depicted left-hand-drive cars except for the "European car" sketch shown to UK drivers and the "Japanese car" sketch shown to the Japanese drivers, both depicting right-hand drive cars.

McGrath found that, generally, European expectancies did not depend upon whether the vehicle was European- or American-made. Furthermore, while most of the expectancy differences between left-hand and right-hand drive showed mirror-image location reversal, there were still some locations selected which were not simply reversed in this manner. For example, while drivers expected to find the cigarette lighter on the right panel of a left-hand drive car and the left panel of a right-hand drive car, they expected to find the defroster control on the right panel of both types of car. This indicates that driver expectancy patterns do not simply switch sides with left- and right-hand drive.

There were also general differences between nationalities regarding control locations, suggesting a fair degree of autonomy among European countries. For example, French and Italian drivers expected to find the headlight switch on a left-side stalk, while other drivers expected an outboard panel location. There were similar differences with the wiper/washer controls. Europeans expected to find these controls mounted on the stalk, while American drivers expected them to be on the left side of the panel. Each nationality has its own set of unique expectancies regarding the location of other controls, especially between panel- and column-mounting. Americans expected the hazard switch to be located on the right side of the column, while all other drivers expected it to be on the right side of the panel. Furthermore, while most drivers expected the horn to be mounted on the steering wheel hub, French and British drivers expected the horn to be stalk-mounted. These differences make it difficult to design one car ideally suited for world-wide distribution.

Anacapa Sciences (1974, 1976)

The most significant and detailed studies of driver performance and expectancy in locating controls was carried out by Anacapa. An overview of that extensive project is shown in Figure 6. The findings of this effort are detailed in three documents: an early progress report (Anacapa Sciences, 1974), a related analysis of foreign cars and drivers (McGrath, 1974, described above), and a final report that both summarizes the earlier work and describes the later work in detail (Anacapa Sciences, 1976).

Anacapa conducted four extensive control expectancy surveys, three of which concern U.S. drivers. The initial survey involved 100 of them. It is not clear which controls were tested. The progress report (Anacapa, 1974) show the data for six controls (windshield wiper/washer, defroster, hazard switch, headlights, and ignition/starter) but the project overview (Figure 6 here) refers to 8 controls and the Anacapa (1976) report text to 7.

The purpose of the survey was to identify how expectancy data should be collected. In one condition participants placed adhesive-backed dummy knobs on a blank instrument panel mounted in a 1973 Chevrolet Impala where they expected to find controls in an unfamiliar full-size American sedan. In a second condition, participants marked a sketch showing where they expected to find the same controls. In brief, the results of this survey, originally reported in Anacapa Sciences (1974), indicate the following expectancies:

PROCEDURE	CONTROL/ACCESSORY FUNCTION TESTED																													
	Ashtray	Climate Controls	Cigarette Lighter	Defroster	Door	Fan	Gear Shift	Hazard Flasher	Headlights	Heater	High-beam/Dimmer	Hood Resease	Horn	Ignition/Starter	Mirror Adjust	Odometer Reset	Parking Brake	Parking Brake Release	Radio	Radio On/Off	Seat Belt	Shoulder Harness	Steering Wheel	Tape Deck	Temperature	Turn Signal	Vent	Window	Windshield Washer	Windshield Wiper
PROBLEM INCIDENCE SURVEY *1,140 own-car drivers*		▨	▨		▨		▨	▨	▨		▨		▨	▨	▨	▨	▨		▨				▨	▨		▨	▨	▨	▨	▨
PROBLEM INCIDENCE SURVEY *342 rental-car drivers*		▨	▨		▨		▨	▨	▨		▨		▨	▨	▨	▨	▨		▨		▨	▨				▨	▨	▨	▨	▨
OWN-CAR RECALL TEST *28 U.S. drivers*				▨				▨	▨				▨	▨															▨	▨
CONTROL-LOCATING PERFORMANCE: 35-MM SLIDE PROJECTION TEST *24 U.S. drivers* *30 vehicles*		▨	▨					▨	▨					▨					▨								▨		▨	▨
CONTROL-LOCATING PERFORMANCE: ON-THE-ROAD TEST *12 U.S. drivers* *2 vehicle types plus own car*	▨	▨	▨	▨		▨	▨	▨	▨	▨	▨		▨	▨			▨		▨	▨					▨	▨	▨		▨	▨
U.S. CAR COMMONALITY	▨	▨	▨	▨				▨	▨		▨		▨	▨					▨										▨	▨
EUROPEAN CAR COMMONALITY			▨	▨				▨	▨				▨	▨															▨	▨
EXPECTANCY (IN-CAR TEST) *100 U.S. drivers*			▨	▨				▨	▨				▨	▨															▨	▨
EXPECTANCY QUESTIONNAIRE SURVEY *238 European & Japanese drivers; 2 vehicle types*			▨	▨				▨	▨				▨	▨															▨	▨
EXPECTANCY QUESTIONNAIRE SURVEY *1,708 U.S. drivers* *5 vehicle types*	▨		▨	▨				▨	▨	▨	▨	▨		▨			▨	▨	▨								▨			▨
EXPECTANCY (FIRST LOOK) *2,088 U.S. drivers* *2 vehicle types*	▨	▨	▨					▨	▨										▨								▨			▨
CONTROL-LOCATING PERFORMANCE: (PARKED-CAR, ONE-TRIAL METHOD) *2,088 U.S. drivers* *2 vehicle types*	▨	▨	▨					▨	▨										▨								▨			▨

Figure 6, Summery of Experiments in Anacapa Program

wiper/washer	- either left or right of panel, tendency toward left
defroster	- right panel
hazard flasher	- mostly on column, tendency toward right side
headlight	- far left of panel
ignition	- right side of column or right panel

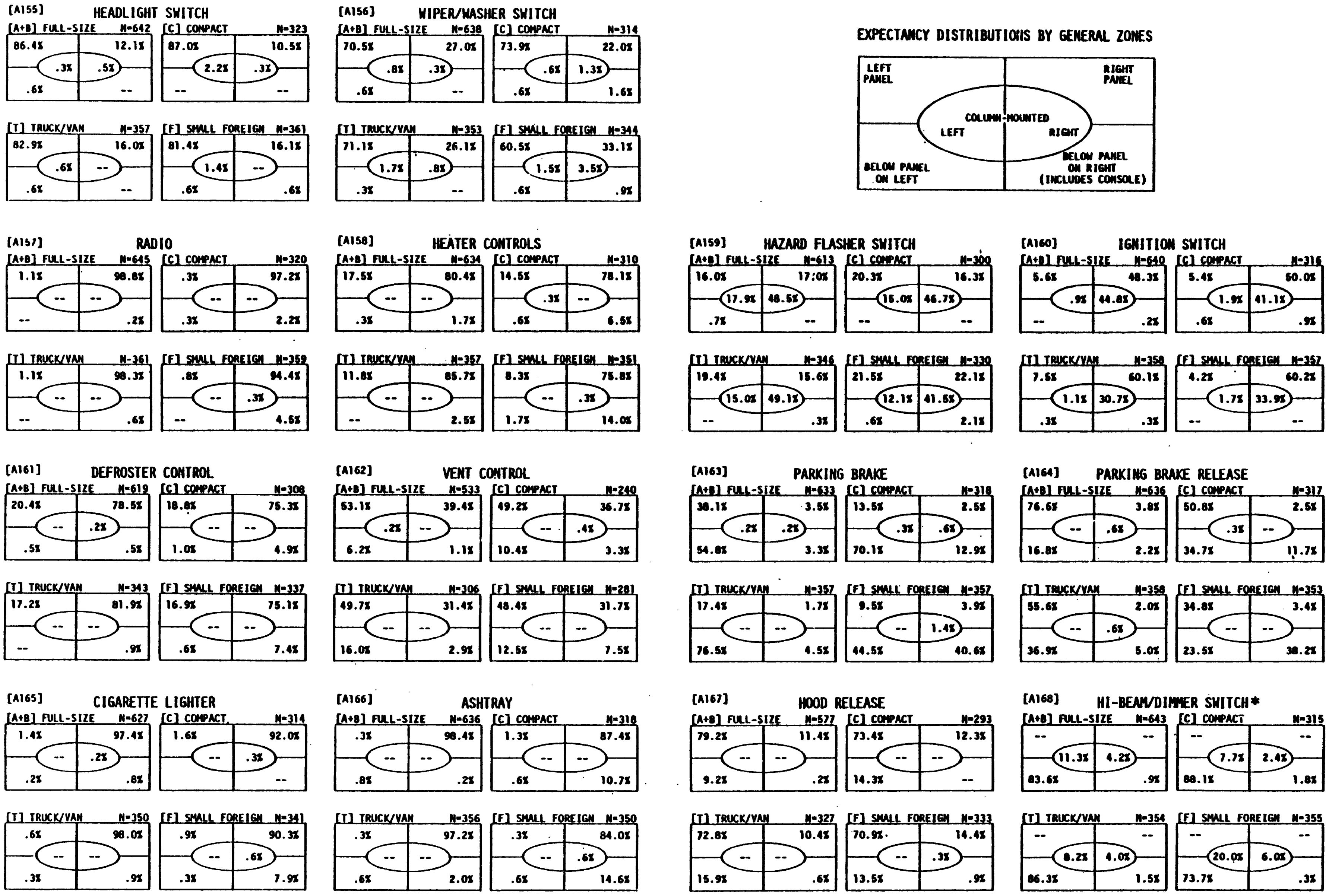
Scatter plots showing the distribution of responses for each function appear in Appendix A at the end of this report.

With regard to the methodology question, Anacapa reports, "The results generally showed that the expectancy distributions obtained by the two methods (paper-and-pencil, in-car) were sufficiently similar that the simpler pencil-and-paper method could be used for test purposes. Chi-square tests showed that the main difference between distributions were mainly from those that were forced by the differences in panel configurations. We also found that explicit instructions must be given to ensure that the subject differentiated between panel-mounted and stalk-mounted locations" (Anacapa Sciences, 1976, p. 11).

Once Anacapa had established the validity of the paper-and-pencil method, they conducted a follow-on study to identify expectancies for other controls and more accurately determine expectancies for the controls previously tested. Drivers marked the expected location for 14 controls on one of five versions of a mail-back questionnaire. They also answered a few other general questions. The questionnaire was distributed to 7,000 California drivers at Department of Motor Vehicle offices, 1,708 of whom responded. Chi-square tests revealed no significant differences between any of the sub-samples with regard to age, sex, driving experience, or between the general California driving population and the sample responding in terms of these descriptors.

There were five versions of the questionnaire. Two showed full-size American sedans, one was for compacts, one was for light trucks and vans, and one was for small foreign cars. Only the compact and foreign cars had center consoles. All of the cars were stated to have automatic transmissions except for the foreign cars.

Numerous analyses are described in the Anacapa report. For those interested in the expectancy scatter plots, they are included in the How Should Controls Be Designed section of this report. The expectancy data have also been aggregated into six categories and are shown in Figure 7.



*Responses on the panel were assumed to indicate column-mounted stalk controls and are so tabulated here.

Figure 7, Expectancy Distributions by General Zones for 2088 Drivers (Anacapa Sciences, 1976)

The **headlights** were expected to be on the far left side of the panel (about 85% of the time) in all types of vehicles tested. Drivers who owned imported cars were less likely to expect panel-mounting, suggesting the location in their own cars (often stalk-mounted) influenced their expectancies.

Also influencing expectancies was the reported frequency of use. Drivers who reported using the headlights less than once per week were less likely to expect it to be located on the left side of the panel. It is not clear what the implications of this finding are.

The **windshield wiper/washer** switch was also expected to be on the left side of the panel (by about 70% of those respondents), generally below and inboard of the lights. The distribution was more dispersed than the lights. Depending on the vehicle, expectancies for any stalk location ranged from 1-5%, usually closer to 1% and were no more than 3.5% for any side.

Over 95% of those responding expected the **radio** on the right side of the panel, even in vehicles with a center console. None of the other variables examined in this experiment had an effect on expectancies for the radio.

Expectancy distributions for the **heater** were more diffuse than for other controls. Nonetheless, about 80% of those responding expected it to be on the right side of the panel. There were statistically significant differences between vehicles; primarily a slightly greater expectancy for console-mounted heaters in small foreign cars than in other vehicles.

Expectancies for the **lighter** and **ashtray** were very similar. Typically, well over 90% of the drivers expected them to be located on the right side of the panel. For compact and foreign cars, some drivers (10 and 15% respectively) expected the ashtray on the console. Console expectancies were more prevalent in younger drivers.

Almost half of the drivers expected to find the **hazard** switch on the right side of the column. For those who expected panel-mounting, there was not agreement as to where. The type of car a person drove had a major influence on their expectancies; foreign car owners were more likely to expect panel-mounting.

There was little agreement as to where the **vent** control should be located. There was some expectancy for the lower left of the panel, but only for compacts and foreign cars. This expectation was somewhat stronger in younger drivers. Sometimes the vent is a separate control and sometimes it is part of the climate control. This mixture of responses is reflected in the data.

The **defroster** was expected to be on the right side of the instrument panel by just over 75% of those tested. There was no agreement as to where within that section it was expected. The Anacapa (1976) report describes many oddities in the data with regards to differences between various subject sub-samples. Some of them they cannot explain.

The **ignition** was expected to be either on the right side of the column (30-44% depending on the vehicle) or the right side of the instrument panel (48-60%). Column mounting was expected more often in newer cars. Panel mounting was expected more often in foreign cars.

The **parking brake** was expected to be below the panel on the left (54-76%) for all vehicle types except foreign cars where the expectancies were almost evenly divided between below the left panel (45%) and below the right (41%).

The distributions for the **parking brake release** are much more diffuse. For full-size American cars, the expectancy was for the left side of the panel (77%).

The **hood release** was expected at the very bottom of the left side of the panel by 71-79% of the drivers, depending upon the vehicle.

The **dimmer** switch was expected to be floor-mounted (73-83% depending upon the vehicle). In foreign cars, 20% of those responding expected it to be mounted on a stalk on the left side of the column. This finding was even more common for those who drove foreign cars.

From their earlier experiment (involving 100 drivers), Anacapa had concluded that it was the driver's total experience, not the vehicle they were then driving, that influenced their expectancies. Clearly, these data show the conclusion reached earlier was untrue. The vehicle a person is driving has a major influence over their expectancies.

Anacapa reports that these results reveal an "expectancy lag," a condition in which expectancies for a control configuration continue long after use of the configuration ceases in production vehicles. For example, in the 1960's, the wiper/washer switch was usually located on the right side of the instrument panel. At the time of the Anacapa study, the design practice for several years had been to place it on the left side of the panel. Nonetheless, respondents still expected the control to be located on the right. Similarly, foreign vehicles have had stalk-mounted wiper/washer controls for many years, yet drivers still expected panel-mounting of these controls. This expectancy lag is the combined result of habit ingrained over years of experience and the continuing ownership and use of vehicles long after they cease to be produced.

The final expectancy survey in the Anacapa program examined the relationship between control-locating performance and subjective expectancy for control locations. The previously collected expectancies could not be used because each individual has different expectancies and using population means would have masked the relationship of interest. As part of the final experiment, 2,088 drivers were asked to mark on a sketch the location of two different randomly selected items (from a set of eight controls and accessories) in either a 1973 Ford LTD wagon or a 1969 Toyota sedan. This was done after the subjects had participated in a performance experiment that involved searching for controls on a mockup panel in those cars.

The results are shown in Figure 8. Drivers expected to find the Headlight and Wiper/Washer controls on the left panel while the Hazard Switch was expected on the right-hand side of the steering column. Floor-mounted headlight dimmer switches were also expected as opposed to those on a stalk. Notice most of the values are within 2-5% of those from the previous experiment except for the wiper (where more drivers here expected it on the left side of the panel) and the vent (where the expectation for mounting on the right increased). Good research is repeatable and that is certainly true here.

In addition, the participants were asked to rate the strength of their expectancies on a nine-point scale. The results of this survey are shown in Table 2. The utility of the expectancy strengths is unclear.

Table 2. Control Location Expectancy Strengths (Anacapa Sciences, 1976).

		Expectancy Strength (Scale: 1=low, 9=high)	
Control	Location	Ford LTD	Toyota
Headlights	left panel	7.3	7.2
Wiper/Washer	left panel	6.6	5.4
Defroster	right panel	7.0	6.7
Hazard Switch	right column	6.6	5.4

The Anacapa (1976) study concludes with a discussion of the test procedure and suggestions for further research. One of the more interesting conclusions reached is that subjective expectancy is not necessarily an independent variable, since a subject learns control locations and develops testing expectations as experimentation continues. For this reason, Anacapa canceled their planned duplication of this experiment in actual road tests. They determined that a test buck would not offer the proper simulation either, since its atmosphere was too artificial and it tended to change the subjects' attitudes regarding vigilance (i.e. taking one's eyes off the

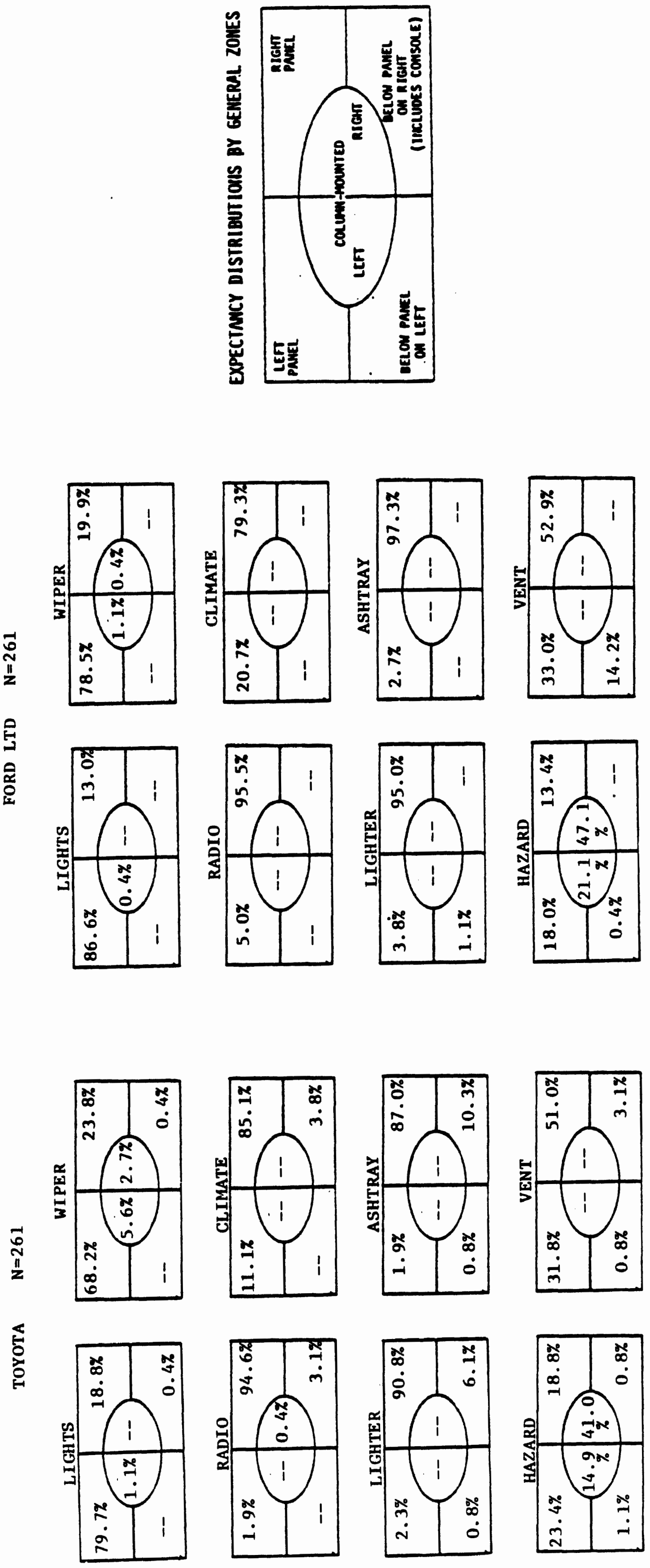


Figure 8, Expectancy Distributions by General Zones for 2088 Drivers (Anacapa, 1976) road to look for a control.) As an ideal testing situation, Anacapa proposed the use of a real car which the subject need not drive, using mock-up instrument panels.

Even though the data are over ten years old and the expectancies they describe have changed, this study should be carefully reviewed by those designing controls. The Anacapa Sciences expectancy research (and the performance work described later) is extremely well done, with clear experimental designs, substantial sample sizes, carefully collected data, and relevant and concise analysis.

Black, Woodson, and Selby (1977)

Black, Woodson, and Selby (1977) collected expectancies from 900 U.S. drivers for 10 controls (washer, wiper, cruise, headlights (on/off), headlights (high/low beam), hazard, interior fan, temperature controls, defrost/defog, and radio). Each driver was shown two boards containing 20 panel-mounted controls and 10 stalk controls. Drivers selected the switch they expected for each function and specified its method of operation, basing their decision on a picture of the car in which the controls were to be found. There were six choices: Mercedes, Honda, Granada, Chevette, Dodge, and Saab. There was a tendency to expect gaudy controls (chrome, simulated wood faces) in American cars and austere controls (dull black, large rounded corners) in foreign vehicles. Some of the results of this survey are displayed in Table 3.

For the headlights (on/off) and wiper/washer controls, subjects had strong expectancies (3:1 or better) in favor of panel over stalk mounting. When the light switch was on the panel, a round knob that was pulled was expected. Where column-mounting was considered, subjects generally weren't sure where to find the control, yet if forced to choose, the left was preferred over the right side. There was no consensus among drivers as to how a stalk control for the headlights (on/off) should operate.

The wiper and washer were expected on the panel. A round knob had the highest expectancy and was most likely to be turned clockwise for the wiper and pushed in for the washer.

For the cruise and high-low beam controls, only stalk locations were considered. (Most subjects expected the beam control to be located on the floor near the driver's left foot.) In both these cases, left stalks were favored over right. For the high-low beam switch, pulling the lever towards the driver was the preferred means of activation. Unfortunately, the basic design of a cruise control switch made the results for this category misleading. While it is conceivable that a cruise control could have one button control

Table 3. Control Expectancies (in %) from Black, Woodson, and Selby (1977)

			If Column-Mounted							If Panel-Mounted			
Control	Expected Location: Panel	Expected Location: Stalk	Where on column? Left	Where on column? Right	Where on column? IDK*	What will it look like?		How will it operate?		What will it look like?		How will it operate?	
Headlights (on/off)	89	11	35	0	55**	rotary switch	30	rotate away	24	round	78	pull out	49
						lever	30	depress rocker	20				
						rocker	20	lever up	12				
								lever toward	10				
High-Low Beam	0	100	51	--	39	lever	65	lever toward	34	--------------		-------------	
	(stalk test only)					rocker	14	lever away	13				
								depress rocker	13				
								lever up	11				
Wiper	80	20	37	0	47	lever	31	rotate away	22	round	26	rotate CW	49
						rotary switch	30	lever up	17	irregular round	14	slide right	14
						rocker	17	depress rocker	17	slider	14		
								lever toward	14				
Windshield Washer	74	26	33	7	51	end button	34	push button in	34	round	33	push in	51
						lever	32	lever toward	14	irregular round	12	rotate CW	14
						rocker	12			slider	12		
Hazard	17	83	--	73	--	pull/push or push/pull switch	82	pull out	49	NOT-IDK	34	pull out	18
								push in	31	toggle	20	move up	18
										irregular round	13	move right	13
Cruise	0	100	46	--	37	end button	34	push button in	34	--------------		-------------	
						rocker switch	19	depress rocker	19				
						rotary switch	12	rotate away	12				

* NOT-IDK = None Of These, I Don't Know

** Many of the Column Location subtotals do not add up to 100%. It is not clear why.

Table 3. Control Expectancies (in %) from Black, Woodson, and Selby (1977) (continued)

Control	Expected Location: Panel	Expected Location: Stalk	----- If Column-Mounted -----	--------- If Panel-Mounted ----------- What will it look like?		How will it operate?	
Interior Fan	100	0	—	slide	58	slide up	30
	(panel test only)			rocker	11	slide right	27
						rotate CW	11
						slide down	11
Temperature (increase temp.)	100	0	—	slide	93	slide right	60
	(panel test only)					slide up	18
Defog	100	0	—	slide	63	slide right	46
	(panel test only)					slide up	21
						slide down	10
Radio Volume	100	0	—	round	65	rotate CW	93
	(panel test only)			irregular round	31		

(push to set current speed, touch brake or accelerator to turn off), most systems have at least an on/off switch and a setting switch.

Finally, subjects expected the hazard switch to be mounted on the right side of the steering column and operated by pulling on. While Black's approach suggests an appropriate switch type and method of operation for each function, it is apparent that any final assignment of functions must involve the instrument panel as a whole. For example, the data here indicates that a button on the left stalk had the highest expectancy percentages for both washer and cruise controls, yet a combination of these controls on a single stalk is impossible.

While the Black et al. study was well-planned and executed, and the overall format of the report makes it easy to read, it contains several major weaknesses. First, in many places, the percentages don't add up to 100%. Whether this is due to missing responses on some questionnaires returned, calculation errors, or both, is not clear. The errors are too large to be due to round off. It would have been helpful to report not only the percentages, but also the actual number responding to each item. Furthermore, while summary percentages for each class of controls were given (e.g. knob 10%, lever 5%), the percentages for each design are usually not (e.g., knob #1 = 3%, knob #2 = 6%, etc.). It is this detailed data which most designers want. Finally, style and configuration of the stalks used are not reported (e.g. plain or multifunction, one- or two-stalk design). In spite of such errors and the age of these data, they are still useful, but should be used carefully.

Summary

While there have not been many studies of driver expectancies for controls, the work that has been done has been first rate. Their primary concern has been where drivers expect particular controls to be located. Except for the work of McGrath, all the expectancy studies have dealt with American drivers, who expected more controls to be located on panels and fewer on stalks. (For example, at one time American drivers expected the wiper/washer and headlight controls to be located on the left side of the instrument panel, while foreign drivers expected stalk locations.)

Only one study (Black et al., 1977) has concerned preferences for control types and direction of motion, but in many cases their analysis is incomplete. But with the passing of a decade since this study, it is unlikely that the original data can be retrieved.

The data in the literature, especially for the beam switching and wiper/washer controls, are of limited value.

Since the '70s, stalk controls have become much more common for these functions. It is therefore likely that driver expectancies for stalk controls are much greater. Expectancies for other controls may have changed as well. At this time, there is certainly the need for new expectancy data. For those interested in aggregations of the expectancies by control, that information appears in the section, entitled "How Should Specific Controls Be Designed."

The research, however, is not useless. An important lesson from this research concerns how to collect additional data. It is clear that paper-and-pencil sketches can be effectively used to collect expectancies, even for stalk controls. It is much easier to collect data in that manner than using mockups or production vehicles.

WHAT CONTROL DESIGNS DO PEOPLE PREFER?

This chapter examines studies undertaken to determine driver preferences for different secondary control configurations. Most of the studies were sponsored by the automobile manufacturers, since they have the most interest in determining customer preferences. There are eight studies discussed in this section. Most of them are concerned with specific classes of controls (e.g., headlight selector switches, multifunction control stalks, and pod controls). Only one, the Ford Best-In-Class program, deals with the design of the entire instrument panel (actually the design of the entire vehicle). As noted earlier, there are several preference studies that have been completed recently by the manufacturers. However, they consider them to be proprietary and refuse to release any details, so they are not described here.

Mortimer and Post (1973)

In the early 1970's the U.S. government was considering requiring cars be fitted with a three-beam headlight system. The low and high beams would be comparable to current low and high beams. The mid beam was a middle level specifically designed for expressway driving. Mortimer and Post (1973), as part of a study described in the human factors methods section, carried out an experiment in which 10 U.S. drivers stated their preferences for switches for three-beam systems. (Drivers did not have a chance to operate them.) The three designs tested are described in Table 4. Column-mounting was preferred.

Table 4. Switch Preferences Reported by Mortimer and Post (1973).

# Drivers Preferring	Switch Design	Method of Operation
5	Stalk	push turn signal lever away for low, middle, high
2	Stalk (but with reservations)	same as above
2	floor-dash combination	pull panel switch for low-mid pair, push for mid-hi pair; push foot sw. for beam level
1	3 posn. cycling foot switch	push down to increase; cycle is low, mid, hi, low, etc.

Kuechenmeister (1974)

Kuechenmeister (1974) had 24 General Motors employees drive a test vehicle fitted with a multifunction control for one evening each. (The left side multifunction stalk operated a turn signal, dimmer, and wiper/washer control.) A questionnaire completed after returning the vehicle revealed that the drivers felt the wiper, washer and beam-switching functions should be included on a multifunction control, but not the on/off switch for headlights/parking lights, hazard, cruise, or the horn controls. It was possible, points out Kuechenmeister, that there was a subjective bias towards what the General Motors employees thought was an "improved" General Motors product.

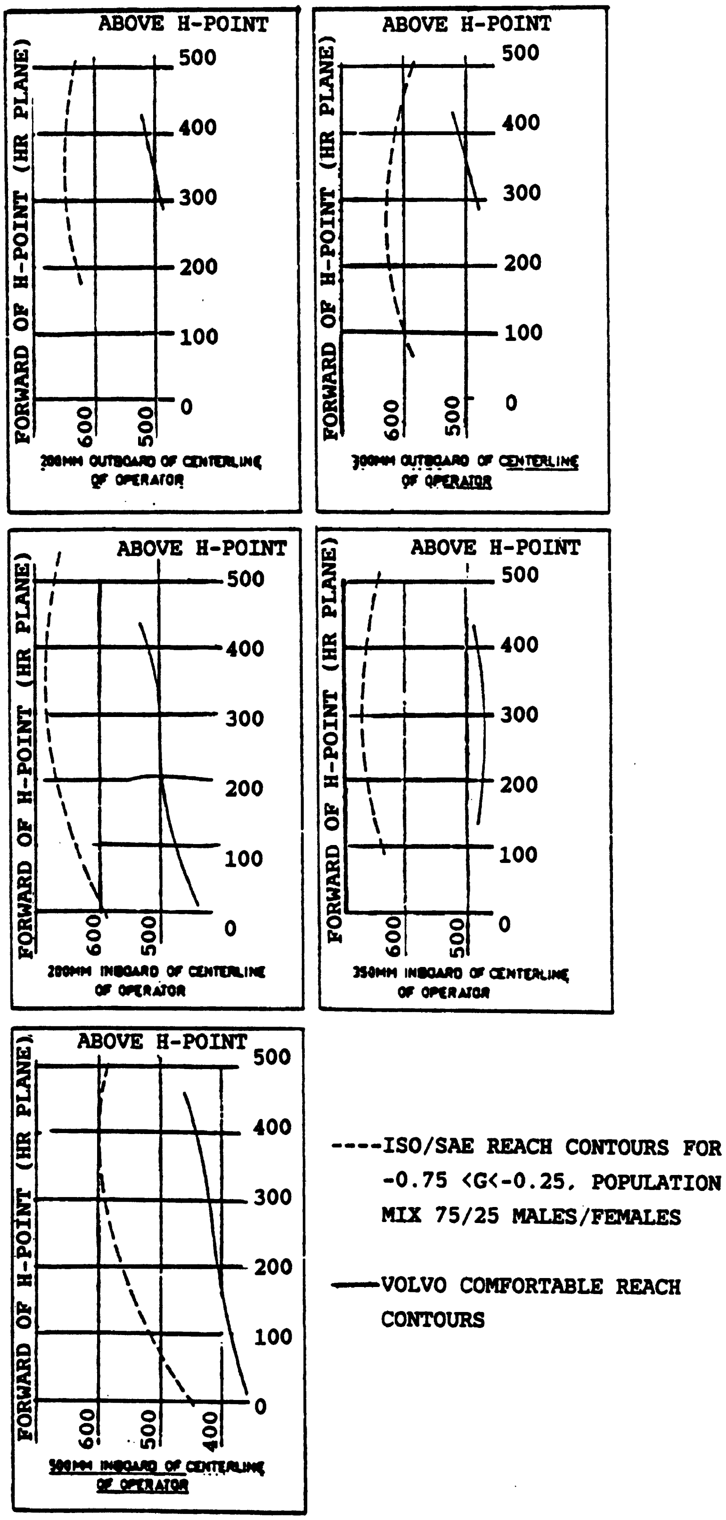
Mourant, Moussa-Hamouda, and Howard, (1977)

Mourant et al. (1977) conducted a re-analysis of the Krumm (1974) problem survey, describing responses concerning driver "likes" and "dislikes" specifically for stalk controls. As drivers listed advantages more often, Mourant, Moussa-Hamouda, and Howard (1977, p. 104) concluded, "these percentages suggest that drivers prefer more functions at fingertip reach (stalk-mounted) than in conventional locations on the dashboard."

Hallen (1977)

Very little about reach data appears in this literature review because the subject of reach is covered in another Chrysler Challenge fund project (Schneider, 1987). But no report that concerns where drivers expect to find controls should fail to mention Hallen (1977). He took a 1975 Volvo 245 with a manual transmission (G7 package geometry) and inserted rods with knobs on the end perpendicular to the face of the instrument panel. There were 15 rods (4 to the left and 11 to the right steering column). A total of 180 Swedish drivers pushed the rods as far in as possible so that the controls remained within "comfortable reach." While doing so, drivers were asked to keep their shoulders in contact with the seat back and grasp the knob at the end of the rod with three fingers.

Shown in Figure 9 is a comparison of the SAE maximum reach contours with the comfortable reach data collected by Hallen. Notice those data show that drivers prefer to have controls 100-200 mm (4-8 inches) farther aft (closer to themselves) as compared with the maximum reach contours. Combining this information with data on steering wheel location indicates a strong driver preference for controls close to the steering wheel (often within fingertip reach). This information has been ignored because at the time the data was collected control design emphasized safety, not ease-of-use. That is unfortunate because Hallen's data has a very direct bearing on contemporary design problems.



- Side view comparison between ISO/SAE maximum restrained reach contours and Volvo comfortable reach contours

Figure 9, Reach contours from Hallen (1977)

McCallum, Dick, and Casey (1982)

Anacapa Sciences had 50 luxury car owners rank-order 13 controls according to 3 criteria: number of times used, preference for convenient location, and estimated severity of consequences of an error. This was accomplished by having participants place tiles with the controls names on them in slots on a form. Participants subsequently gave their preferences for pod versus instrument panel locations for controls (after being shown sketches of proposed designs), the use of redundant radio controls, the use of an ignition keypad (instead of a key), and the placement of control buttons on the top of the pod.

Shown in Table 5 are the ranking data.

Table 5. Ranking Data from McCallum et al. (1982)

Rank	Frequency of Use	Preference for Convenient Location	Possible Danger of Error
high	Ignit.-start/stop	Ignit.-start/stop	Turn Signals
	Turn Signals	Turn Signals	Headlamps-on/off
	Ignition-unlock	Ignition-unlock	Headlamps-hi/lo
	Radio-on/off	Headlamps-on/off	Wipers-on/off
	Headlamps-on/off	Headlamps-hi/lo	Ignition -start/stop
	Radio Tuning	Wipers-on/off	Wipers-rate
	Climate	Radio-on/off	Hazard
	Radio Volume	Wipers-rate	Ignition Unlock
	Headlamps-hi/lo	Climate	Washer
	Wipers-on/off	Radio Tuning	Radio Volume
	Washer	Radio Volume	Radio Tuning
	Wiper Rate	Washer	Radio-on/off
low	Hazard	Hazard	Climate

As the reader can see, there was some consistency across dimensions as to which controls were ranked high. In many ways this data repeats what is already in the literature.

The frequency-of-use data must be used with some care. People are notoriously poor at estimating the likelihood of low-probability events, and therefore, the frequency-of-use data may be wrong, even across substantial sample sizes. For example, much work has been done on risk perception (e.g., Starr (1969), Fischhoff, Slovic, Liechtenstein, Read, and Combs (1978)). Estimates of frequencies often differ from actual frequencies by two orders of magnitude.

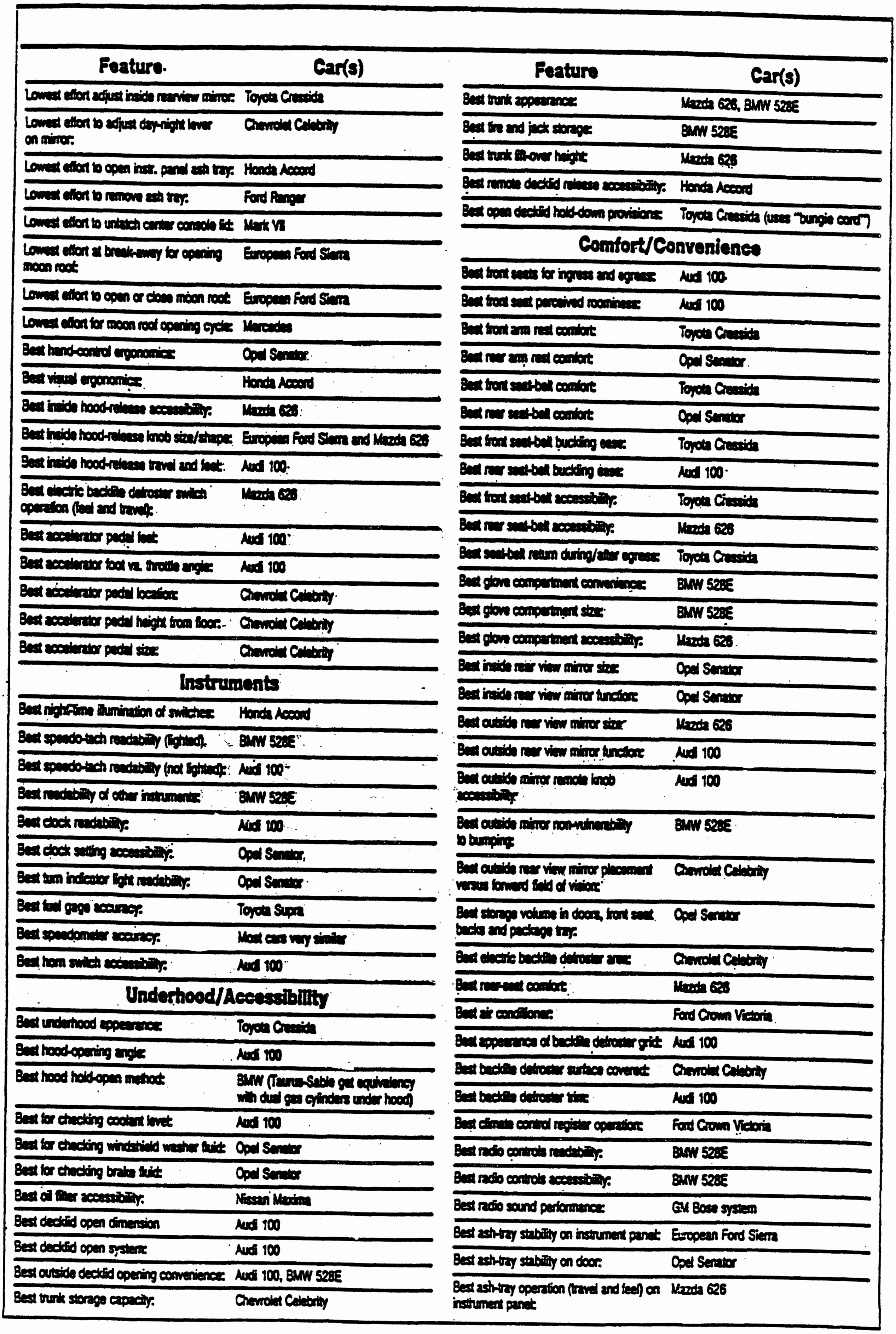
With regard to the miscellaneous questions, all participants preferred pods over conventional instrument panels. Statistically significant results were also obtained in favor of placing redundant radio controls on a pod, and against placing controls on top of the pod. Results for the other questions were not statistically significant. This is the first consumer preference study to examine pod-mounted controls, and the results seem to indicate that consumers would be in favor of a move towards more such controls.

Callahan (1986a, b, c) - (Ford Best-in-Class Survey)

As mentioned earlier in this report, most preference studies carried out by the automakers themselves take the form of clinics, customer satisfaction surveys, and marketing studies. These studies are usually limited in their scope, examining two or three specific vehicles, or surveying present owners of a certain manufacturer's vehicles. This unfortunately limits the information available to the design staff in considering design changes.

The Ford Motor Company broke away from this pattern in the design process for its Taurus/Sable model (Callahan, 1986a, b, c). (See also Ford Motor Company, 1985.) Ford spent considerable time and money to have its engineers and product planners evaluate a list of 400 customer satisfaction features obtained through the testing and questioning of hundreds of customers around the country. Features evaluated ranged from effort to remove the ashtray to clock readability. One can get a sense of the variety of items considered from Table 6, a sample page from the Automotive Industries article describing the "Best-in-Class" or B-I-C effort. Ford then had multidisciplinary internal "juries" evaluate the listed features on current U.S., European, and Japanese models, compiling a "Best-in-Class" list for all 400 of the features. U.S. vehicles won very few classes; the Chevrolet Celebrity (A-car) claiming the most with roughly 9%. European (Audi 5000) and Japanese (Mazda 626, Honda Accord) models placed highest, with these three vehicles claiming 15% - 25% of the classes.

Table 7 shows the 39 entries related to secondary controls. Controls examined include the lighter, climate control, dimmer, hazard, headlights, high beam, ignition, radio, cruise control, turn signal, washer, and wiper, and there are two "general" entries; one for nighttime illumination and an overall rating for all controls. For many controls, three attributes are examined: accessibility/location, operation (travel/feel), and size/shape.



Feature	Car(s)
Lowest effort adjust inside rearview mirror:	Toyota Cressida
Lowest effort to adjust day-night lever on mirror:	Chevrolet Celebrity
Lowest effort to open instr. panel ash tray:	Honda Accord
Lowest effort to remove ash tray:	Ford Ranger
Lowest effort to unlatch center console lid:	Mark VII
Lowest effort at break-away for opening moon roof:	European Ford Sierra
Lowest effort to open or close moon roof:	European Ford Sierra
Lowest effort for moon roof opening cycle:	Mercedes
Best hand-control ergonomics:	Opel Senator
Best visual ergonomics:	Honda Accord
Best inside hood-release accessibility:	Mazda 626
Best inside hood-release knob size/shape:	European Ford Sierra and Mazda 626
Best inside hood-release travel and feel:	Audi 100
Best electric backlite defroster switch operation (feel and travel):	Mazda 626
Best accelerator pedal feel:	Audi 100
Best accelerator foot vs. throttle angle:	Audi 100
Best accelerator pedal location:	Chevrolet Celebrity
Best accelerator pedal height from floor:	Chevrolet Celebrity
Best accelerator pedal size:	Chevrolet Celebrity
Instruments	
Best night-time illumination of switches:	Honda Accord
Best speedo-tach readability (lighted).	BMW 528E
Best speedo-tach readability (not lighted):	Audi 100
Best readability of other instruments:	BMW 528E
Best clock readability:	Audi 100
Best clock setting accessibility:	Opel Senator,
Best turn indicator light readability:	Opel Senator
Best fuel gage accuracy:	Toyota Supra
Best speedometer accuracy:	Most cars very similar
Best horn switch accessibility:	Audi 100
Underhood/Accessibility	
Best underhood appearance:	Toyota Cressida
Best hood-opening angle:	Audi 100
Best hood hold-open method:	BMW (Taurus-Sable get equivalency with dual gas cylinders under hood)
Best for checking coolant level:	Audi 100
Best for checking windshield washer fluid:	Opel Senator
Best for checking brake fluid:	Opel Senator
Best oil filter accessibility:	Nissan Maxima
Best decklid open dimension	Audi 100
Best decklid open system:	Audi 100
Best outside decklid opening convenience:	Audi 100, BMW 528E
Best trunk storage capacity:	Chevrolet Celebrity

Feature	Car(s)
Best trunk appearance:	Mazda 626, BMW 528E
Best tire and jack storage:	BMW 528E
Best trunk lift-over height:	Mazda 626
Best remote decklid release accessibility:	Honda Accord
Best open decklid hold-down provisions:	Toyota Cressida (uses "bungie cord")
Comfort/Convenience	
Best front seats for ingress and egress:	Audi 100
Best front seat perceived roominess:	Audi 100
Best front arm rest comfort:	Toyota Cressida
Best rear arm rest comfort:	Opel Senator
Best front seat-belt comfort:	Toyota Cressida
Best rear seat-belt comfort:	Opel Senator
Best front seat-belt buckling ease:	Toyota Cressida
Best rear seat-belt buckling ease:	Audi 100
Best front seat-belt accessibility:	Toyota Cressida
Best rear seat-belt accessibility:	Mazda 626
Best seat-belt return during/after egress:	Toyota Cressida
Best glove compartment convenience:	BMW 528E
Best glove compartment size:	BMW 528E
Best glove compartment accessibility:	Mazda 626
Best inside rear view mirror size:	Opel Senator
Best inside rear view mirror function:	Opel Senator
Best outside rear view mirror size:	Mazda 626
Best outside rear view mirror function:	Audi 100
Best outside mirror remote knob accessibility:	Audi 100
Best outside mirror non-vulnerability to bumping:	BMW 528E
Best outside rear view mirror placement versus forward field of vision:	Chevrolet Celebrity
Best storage volume in doors, front seat backs and package tray:	Opel Senator
Best electric backlite defroster area:	Chevrolet Celebrity
Best rear-seat comfort:	Mazda 626
Best air conditioner:	Ford Crown Victoria
Best appearance of backlite defroster grid:	Audi 100
Best backlite defroster surface covered:	Chevrolet Celebrity
Best backlite defroster time:	Audi 100
Best climate control register operation:	Ford Crown Victoria
Best radio controls readability:	BMW 528E
Best radio controls accessibility:	BMW 528E
Best radio sound performance:	GM Bose system
Best ash-tray stability on instrument panel:	European Ford Sierra
Best ash-tray stability on door:	Opel Senator
Best ash-tray operation (travel and feel) on instrument panel:	Mazda 626

Table 6, Sample Page Describing B-I-C Effort

Table 7. Ford B-I-C Categories Related to Secondary Controls

Category	B-I-C Car
All cluster & panel-mounted push buttons	Mazda 626
All cluster & panel rotary/rocker switches	Accord/626
Cigarette lighter-insert/remove/activate	Accord
Climate control detents	Saab 900
Climate control operating efforts-rotary	Saab 900
Climate control sw.-operation (travel,feel)	Saab 900
Climate control switches-size and shape	BMW 528E
Cruise control switches access	Accord
Cruise control switches operation	Ford
Cruise control switches size and shape	Accord
Dimmer switch effort - stalk	Toyota
Emergency flasher switch	Lucas
Headlamp switch accessibility	Senator
Headlamp switch size and shape	Accord
Headlamp switch operation (travel, feel)	Toyota
High beam control accessibility	Senator
High beam operation (travel, feel)	Toyota
High beam control size and shape	Accord
Horn operating effort - non-stalk	Cressida/Audi 5000
Ignition switch accessibility/location	Audi 5000
Ignition switch operation (travel/feel)	Ford
Ignition switch size and shape	Audi 5000
Night time illumination of switches	Accord
Radio control knob/push button effort	not evaluated
Radio controls accessibility	BMW 528E
Radio controls readability	BMW 528E
Turn signal switch effort	Toyota
Turn signal lever operation (travel, feel)	Starion/Toyota
Turn signal lever size	Accord
Turn signal lever accessibility	Porsche/ Senator/Accord
Windshield washer control-stalk rotary	Maxima/Accord
Windshield washer control-stalk push button	Audi 5000/ Cressida/Celebrity
Windshield washer switch access	Mazda 626
Windshield washer switch operation	Ford
Windshield wiper control-stalk push button	Audi 5000/ Cressida/Celebrity
Windshield wiper control-stalk rotary	K car/Senator
Windshield wiper dwell control-rotary	Maxima
Windshield wiper switch access	Mazda 626
Wiper switch operation (travel, feel)	Toyota/Ford
Windshield wiper switch size and shape	Mazda 626

Ford has since used these results to make its Taurus/Sable model Best-in-Class in as many of the categories as possible, and claims to have achieved that goal with approximately 80% of the features. According to Ford, full 100% B-I-C accomplishment is not possible because some of the features block each other out. In future efforts Ford plans to weight features by their importance. (Not done in the initial application to save time.)

The Taurus/Sable has proved to be a very successful model. Its success is almost certainly due to Ford's Best-In-Class approach, and indicates the importance of optimizing every detail when designing a vehicle. Such a massive collection and analysis of customer preference/human factors data is something the automotive industry has been hesitant to do in the past. It is likely there will be more efforts of this type in the future. It was reported in a recent issue of the Detroit Free Press that General Motors had conducted a similar project (code named Mona Lisa) to support the development of the new Buick Regal (Kushma, 1987).

Studies of preference continue to be undertaken, as seen by the recent Request For Quote by the BOC Advanced Design group at General Motors for a study of driver control location preferences in "pod type" (similar to the "Pontiac Fiero, Mitsubishi Galant"), "flat" (similar to the "Buick Park Avenue"), and "wrap-around" (similar to the "BMW 535, Saab 9000") instrument panels (General Motors Corporation, 1986).

Green, Kerst, Ottens, Goldstein, and Adams (1987)

The Green et al. report is the third document in the series supported by the Chrysler Challenge fund. In that experiment 102 drivers were asked to select which of 255 switch designs they preferred for each of 24 functions. That report is being written in parallel with this one. Readers seeking further details should consult that report.

Unpublished Studies

In addition to the published data, it is reasonably well known within the industry that the domestic automakers have conducted what they call "clinics" to identify driver preferences for vehicle features. GM has probably carried out more of these than the other manufacturers, though Ford is beginning to establish an active program as well.

Clinics are typically carried out by marketing consulting firms, but sometimes they can be conducted by the manufacturers themselves. Most of these clinics involve side-by-side comparisons of the competition's production vehicles and the manufacturer's proposed product. While the data from such studies can be quite valuable, emphasis on the competition's current products as the target can be misleading. Presumably, in the time between when the data are collected and the vehicle is produced, the competition's products will have changed.

Generally, four vehicles or less are examined. Issues of interest often include body styling, seat design, desired conveniences, and so forth. Sometimes, issues pertaining to human factors have also been addressed. Obviously, because only production vehicles are examined, design parameters rarely vary in a methodical manner. Furthermore, only preferences are measured, without any study of performance.

Until the last few years, clinics were rarely used as a method of collecting human factors data. Previously, the emphasis of human factors efforts was on safety, not on preference or ease of use. As government regulatory effort has declined and sales of customer-oriented foreign vehicles have risen, the emphasis of human factors has shifted towards preferences.

At a recent SAE Controls and Displays Subcommittee meeting, one such study carried out for Ford was briefly described (Farber, 1986). The study involved a comparison of four vehicles including the Pontiac 6000 and three competitive cars. The results reported problems in using the cruise and washer controls when they were located at the end of stalks. Further details concerning the sample size, test procedure, etc., were not reported, as the work was considered proprietary.

Summary

There have been several studies that have examined driver preferences for controls, mostly focusing on control types, not location. Of the studies in the literature, two are particularly noteworthy. The research of Hallen provides contours of the maximum distance drivers prefer to reach for controls. Because reach preferences are based primarily on anthropometric considerations (joint angles and limb lengths) and driver size has not changed over the last 10 years, these data are still quite useful. They were collected at a time when safety, not driver comfort, was the primary concern, and to a large extent have been forgotten. The Hallen data, taken together with the evidence on preference for beam switching controls, and the McCallum et al. work on pods, show there is a strong driver preference for placing secondary controls close to the steering wheel. While few production instrument panels are so designed now, these data suggest such designs should be much more common in the future.

Also quite noteworthy is the Ford B-I-C program. This effort provides an excellent model of how a company should go about determining if a vehicle is well designed for the customer. It also identifies the specific dimensions (e.g., accessibility, feel/travel, size/shape) on which controls should be evaluated. However, strict reliance on this method can stifle innovation as evaluations focus on the the best of what is being made at any given time to shape *future* products.

The authors do not want to go overboard in endorsing preference data as a guide to design decisions. Using driver preferences for control designs in the absence of performance data can be very misleading, especially if the preferences are based on observation of a design, not use of it. Also critical is the sequence of exposure to the alternatives. Research on visual displays has shown that drivers tend to prefer whatever design they saw last in a test series. (See McCormick, 1970; Murrell, 1969). Thus, it is not appropriate to rely solely on preference studies to make design decisions.

WHAT PROBLEMS DO DRIVERS SAY THEY HAVE USING CONTROLS?

Important sources of control usability information can be obtained by surveying drivers to find out what sorts of difficulties they have had locating and operating controls. This section combines the results of two different sources of information: reports of near-accidents, and somewhat more general problem-incidence surveys. The first type is primarily concerned with safety issues, while the second type, at times, addresses comfort and convenience questions. The use of near-accident and critical incident data has long been an established practice for addressing safety issues for aircraft (Fitts and Jones, 1947a,b) and road vehicles.

Krumm (1974)

Krumm's 1974 report describes the first of the general problem incidence surveys of control location and operation difficulties. Some 336 people on the Mall in Washington, D.C., participated in a study that involved operating various types of horns and then responding to a survey on controls. Problem incidence data for operating the horn as a function of location are shown in Table 8. Stalk-mounted and rim-mounted configurations caused problems for drivers, although the number of drivers who report having those types of horns is small (n=27). Most interesting was the connection between reports of problems and driver performance. "Excluding known mechanical problems, the percentage of "yes" responses to a question concerning difficulty in operating a horn control closely approximates the simple reaction time results of this experiment" (Krumm, 1974, p. III-7).

Table 8. Problem Incidence vs. Horn Location, (Krumm, 1974).

Horn Location	Sample Size	No. of Problems	(%)
2-spoke lever	116	5	4
360 ring	32	2	6
center	26	3	12
3-spoke pushbutton	14	3	21
stalk	18	5	28
rim	9	3	33
total	215	21	

Krumm also carried out a survey on stalk controls. A total of 415 owners of foreign automobiles were interviewed, primarily at colleges and community colleges in metropolitan Washington, D.C., and Los Angeles. Of those interviews, 392 were partially usable. Unfortunately, the survey does not appear in that 1974 report, so there is some uncertainty about what was done. Krumm discussed in some detail the difficulties encountered with adding multiple controls to a single stalk. (See Figures 10 and 11.) However, comparative data for panel-mounted controls are not provided. Thus, a comparison between the two general locations (panel vs. stalk) is not possible based on this data.

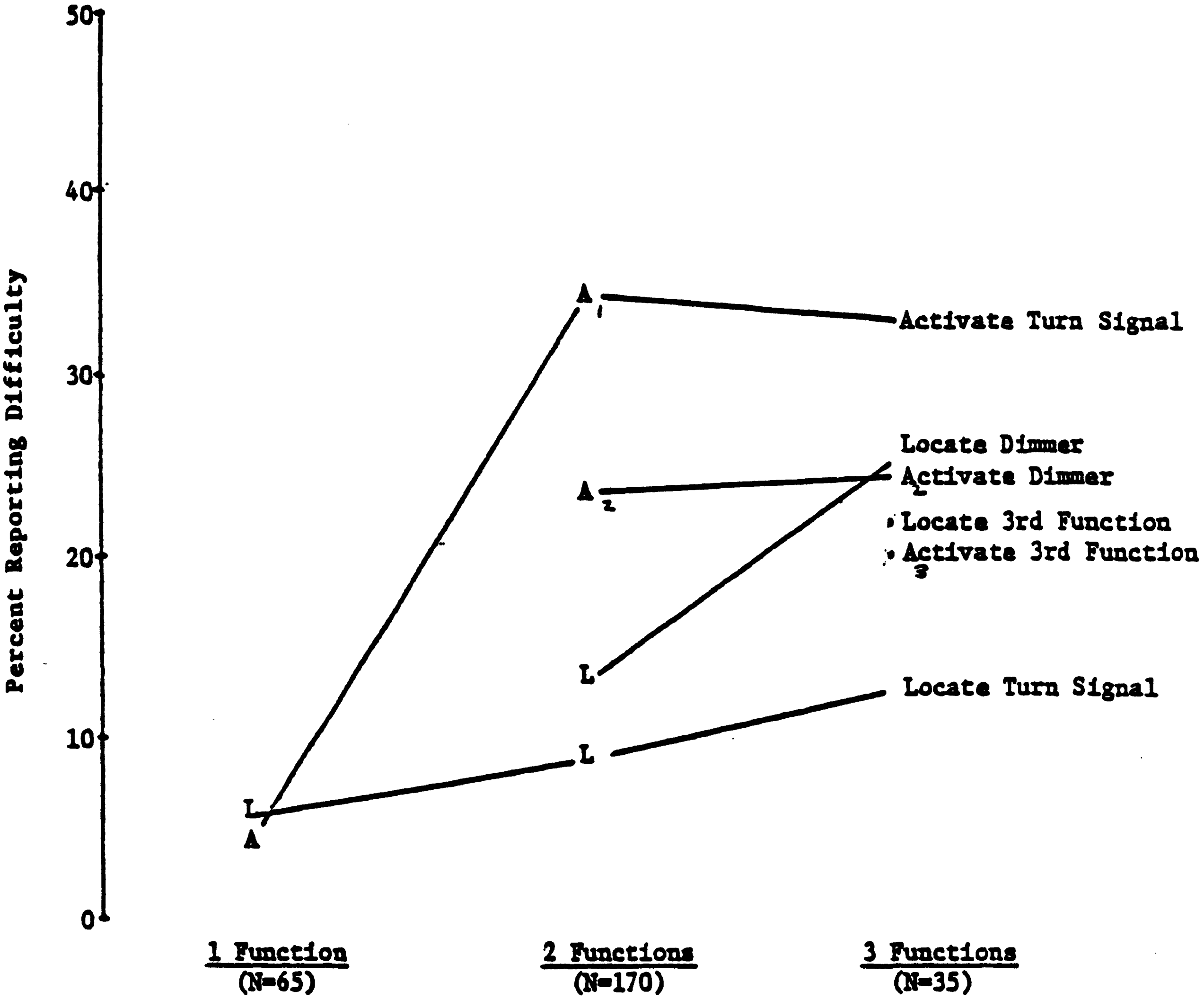
An important finding to emerge from Krumm's work is the importance of transmission type. Drivers had far more problems with stalk configurations when the vehicle had a manual transmission. (See Table 9.) Only cars with floor-mounted manual transmissions were examined, but manual shifting evidently increases the driver's difficulty in locating controls on a right-hand stalk, as well as in activating controls on either side.

Table 9.Control Problems and Transmission Type
(Configuration: Single Stalk Left, Single Stalk Right)

	Location Difficulty		Activation Errors	
Stalk->	Left	Right	Left	Right
Manual	0.0%	9.1%	6.2%	3.0%
Automatic	13.5%	25.9%	18.4%	19.9%

Source: Krumm (1974)

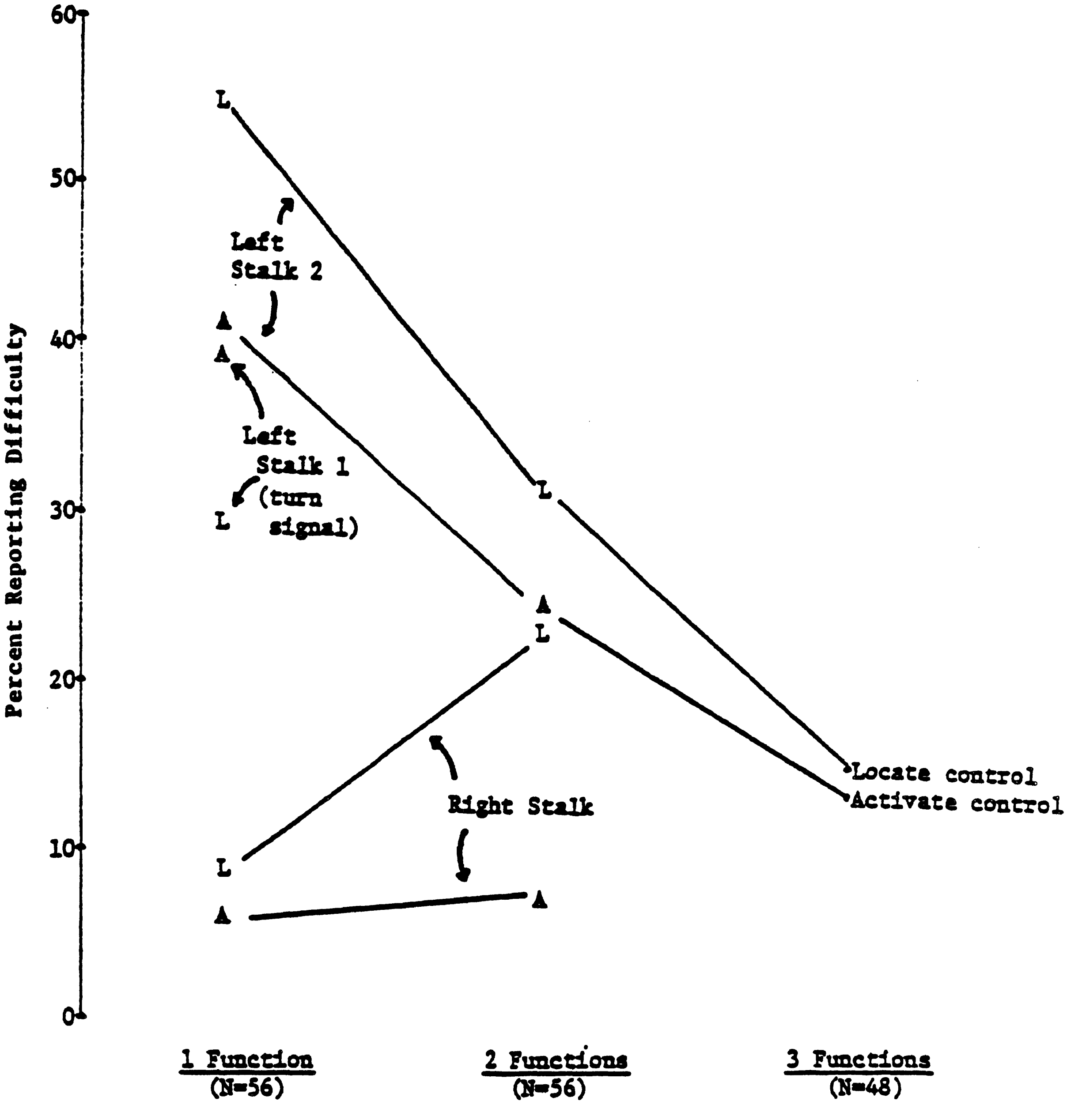
Finally, it should be noted that Mourant et al. (1977) re-analyzed a portion of the Krumm (1974) data. Eleven critical incidents (significant delays) were reported for finding stalk control locations (8 of 295 responses for the dimmer, 2 of 30 for the horn, 1 of 95 for the wiper on/off). For stalk control operation, four critical incidents were reported (2 of 95 responses for the wiper on/off, 1 of 77 for the washer and 1 of 37 for headlights on/off) (Mourant et. al., pp. 108-109). It is not known whether these rates differ from those for panel-mounted controls. Note that these critical incidents totaled 15 out of 988 individual responses concerning 7 different controls, and thus are not especially significant. Furthermore, when analyzed by vehicle type, there was an average of one incident per type, which is insignificant.



Reported difficulty in locating or activating* desired control as additional functions are added to stalk (Configuration: single stalk on left of steering column)

***Operating another control instead of or in addition to the desired control.**

Figure 10, Reported Problems vs. Number of Functions (Single Left Stalk)



Reported difficulty in locating or activating desired control function as additional functions are added to stalk. (Configuration: two stalks on left and one on right of column).

Figure 11, Reported Problems vs. Number of Functions

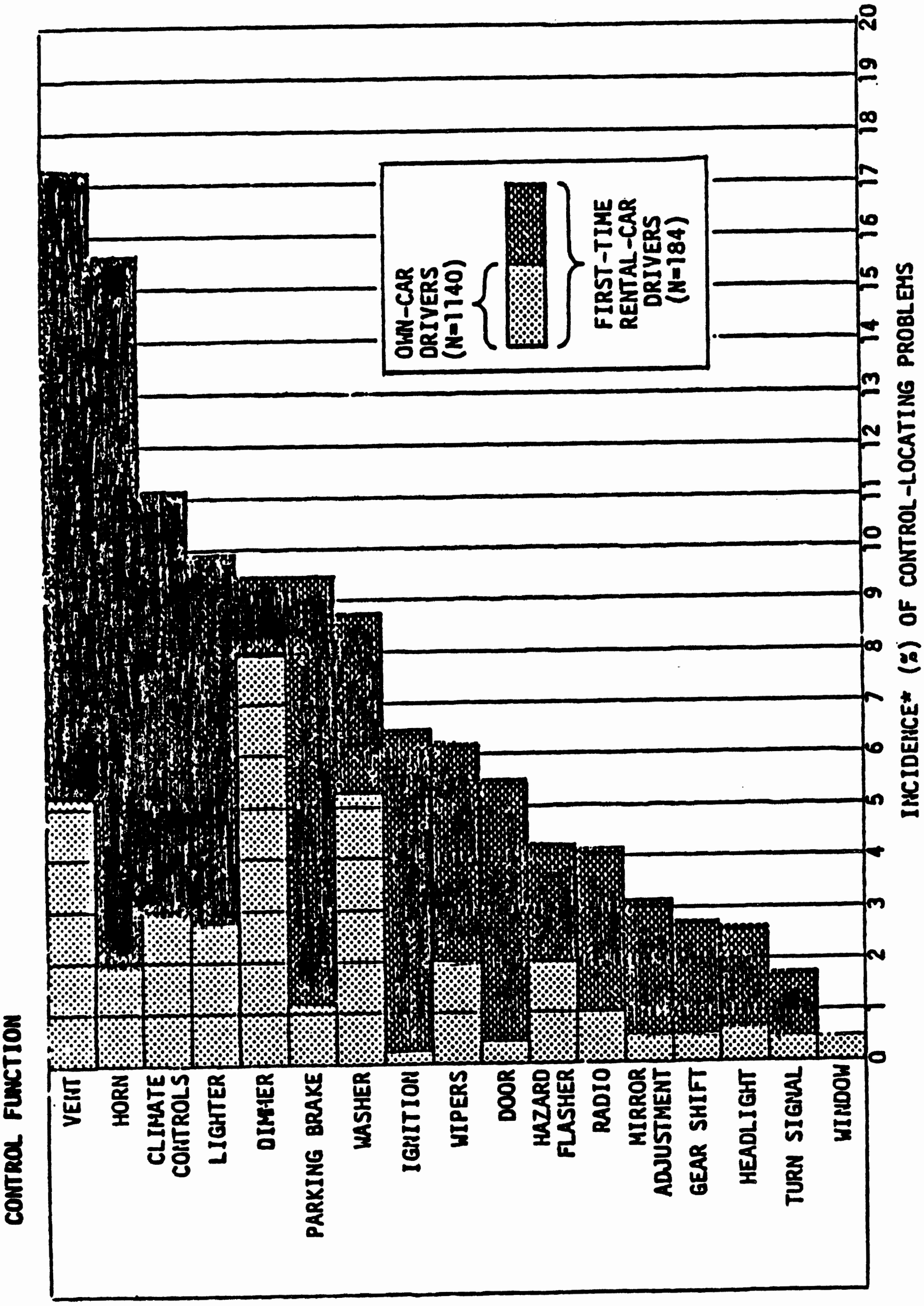
Anacapa Sciences (1974, 1976)

Two surveys of driver-reported problems with controls are reported in Anacapa Sciences (1974). (See also Anacapa Sciences (1976).) In the first, 1,140 motorists were interviewed at gas stations, California Highway Patrol inspection sites, roadside rest areas, and shopping centers about their own cars. Drivers identified which of 20 controls their cars had, how often they were used, and what problems they had locating and operating controls.

In the second, occurring at about the same time, approximately 1,900 similar questionnaires were distributed to drivers renting cars at Los Angeles International Airport. The response form used was similar to the previous experiment except that replies were to be mailed back. Of the questionnaires, 342 (18%) were returned, which is not an especially good response rate.

These two data sets were collected to get a sense of what the benefits from standardization might be. If a car was well designed, then the rate at which first time renters reported problems would be identical to what drivers report for their own cars. Unfortunately the comparison was between groups, not within subjects and the low return rate may reflect differences in the two samples. Nonetheless, data on the incidence of control locating problems between the two sets of respondents is shown in Figure 12. As expected the incidence rate for own-car drivers was lower than that for renters though the patterns of the two data sets were similar. The largest differences between own-car and rental-car drivers occurred with the vent and horn controls. Survey comments indicated that "many of these problems stemmed from unexpected configurations or appearances of these controls" (Anacapa, 1976, p. 9).

Tables 10 and 11 show these data in greater detail along with the data on operating problems, and Table 12 identifies the particular controls causing those problems for the own-car drivers. Fairly common were problems with the climate controls (in locating and operating individual switches, not the unit). Of the rental-car drivers, 9% to 10% experienced difficulties in locating the cigarette lighter, headlight dimmer, and parking brake, and the dimmer control. The dimmer was most often a problem when it was floor-mounted, even in the own-car case. When these data were collected, people were only mildly impressed by it, since the emphasis at the time was on safety. Given the current interest in ease-of-use, data of this type has much greater impact.



**Of drivers who actually used the control on the current trip, the percent who had trouble finding it.*

Figure 12, Incidence of Control-Locating Problems (Anacapa, 1976)

- WHAT PROBLEMS DO DRIVERS SAY THEY HAVE USING CONTROLS?

TABLE 10

CONTROL LOCATING AND OPERATING PROBLEM INCIDENCE RATES (OWN-CAR DRIVERS)

	OWNERSHIP PERIOD*		CURRENT TRIP**	
CONTROL:	LOCATING PROBLEMS	OPERATING PROBLEMS	LOCATING PROBLEMS	OPERATING PROBLEMS
WIPER	10.1	7.3	1.8	16.0
WASHER	8.6	9.9	5.1	11.1
HORN	9.8	12.6	1.9	10.3
TURN SIGNAL	2.1	7.4	.5	3.1
HEADLIGHT	6.9	3.5	.6	3.4
DIMMER	15.2	7.0	8.0	8.8
HAZARD FLASHER	11.0	5.5	2.0	5.9
CLIMATE CONTROLS	13.0	21.4	2.8	7.8
VENTS	17.7	15.5	5.1	8.1
RADIO	5.1	8.1	1.0	1.7
PARKING BRAKE	3.4	7.3	1.1	1.9
LIGHTER	6.8	6.6	2.7	6.8
ODOMETER RESET	5.7	3.8	3.3	3.3
MIRROR ADJUSTMENT	3.0	12.3	.5	10.6
WINDOW	2.3	10.2	.6	4.9
TAPE DECK	5.0	6.5	---	9.6
IGNITION/STARTER	7.1	5.4	.3	.7
DOOR	3.5	5.5	.4	1.4
SHIFT LEVER	1.5	8.5	.5	1.9
STEERING WHEEL	---	---	---	---

**% rates based on availability of the control.*
***% rates based on use of the control.*

TABLE 11

CONTROL LOCATING AND OPERATING PROBLEM INCIDENCE RATES (RENTAL-CAR DRIVERS)

CONTROL:	CURRENT TRIP (N=342)	ALL RENTERS* (N=342)		FIRST-TIME RENTERS* (N=184)	
	% USE	LOCATING PROBLEMS	OPERATING PROBLEMS	LOCATING PROBLEMS	OPERATING PROBLEMS
WIPER	51	6.9	8.6	6.4	7.4
WASHER	35	8.3	19.2	8.7	14.5
HORN	47	18.2	10.1	15.6	11.1
TURN SIGNAL	89	1.3	2.6	1.8	2.4
HEADLIGHT	70	3.4	2.5	2.4	2.4
DIMMER	44	6.0	3.3	9.5	2.4
HAZARD FLASHER	25	3.6	3.6	4.3	---
CLIMATE CONTROLS	82	11.0	23.0	11.1	24.8
VENTS	32	20.4	15.7	17.1	14.3
RADIO	85	3.1	6.8	4.3	5.6
PARKING BRAKE	53	8.2	6.0	9.5	5.7
LIGHTER	28	10.5	16.8	9.8	11.8
ODOMETER RESET	2	---	---	---	---
MIRROR ADJUSTMENT	69	1.7	13.2	3.1	11.7
WINDOW	77	---	5.7	---	8.0
IGNITION/STARTER	100	4.7	10.9	6.5	11.4
DOOR	100	5.3	4.1	5.4	4.3
SHIFT LEVER	99	2.4	3.8	2.7	2.7
SEAT BELTS	82	5.0	15.1	5.9	11.8
SHOULDER HARNESS	16	3.6	20.0	---	16.1

***% rates based on use of the control.*

TABLE 12, LOCATING AND OPERATING DIFFICULTIES AS A FUNCTION OF CONTROL CONFIGURATION (OWNERSHIP PERIOD)

	WIPER			WASHER			HORN		
	N	% DIFFICULTY		N	% DIFFICULTY		N	% DIFFICULTY	
		LOCATING	OPERATING		LOCATING	OPERATING		LOCATING	OPERATING
PUSH/PULL KNOB	204	10.8	7.4	178	6.7	10.7			
ROTARY KNOB	349	9.5	6.9	62	8.1	9.6			
LEVER	6	0.0	0.0	4	0.0	0.0	2	0.0	0.0
POD	5	60.0	20.0	7	42.9	14.3	18	27.8	0.0
TAB	86	10.5	8.1	50	14.0	16.0			
PUSHBUTTON	30	13.3	13.3	172	6.4	9.9	148	23.6	17.6
RING							179	6.7	15.1
1/2 RING							119	14.3	10.1
PAD							392	5.9	11.2
WHEEL CONT. PRESS							21	28.6	23.8
STEP-ON				47	19.1	12.8			
TOGGLE	26	15.4	15.4	4	25.0	50.0			
ROCKER	18	11.1	0.0	9	0.0	0.0			
THUMBWHEEL	2	0.0	50.0						
HANDLE									
CRANK									
USUAL									
DUAL/MULT.	326	10.1	7.4	330	9.1	10.3	5	20.0	20.0
ADJ. WHEEL									
BAN							131	6.9	16.0
MANUAL									
CORD									
DOORS									

TABLE 12, LOCATING AND OPERATING DIFFICULTIES AS A FUNCTION OF CONTROL CONFIGURATION (OWNERSHIP PERIOD) (CONT.)

	TURN SIGNAL			HEADLAMP			DIMMER		
	N	% DIFFICULTY		N	% DIFFICULTY		N	% DIFFICULTY	
		LOCATING	OPERATING		LOCATING	OPERATING		LOCATING	OPERATING
PUSH/PULL KNOB				956	6.8	2.7	1		
ROTARY KNOB				48	10.4	8.3			
LEVER	932	1.3	6.9	6	16.7	16.7	21	19.0	23.8
POD	144	6.9	10.4	9	22.2	11.1	185	14.6	13.5
TAB				7	0.0	0.0			
PUSHBUTTON									
RING									
1/2 RING									
PAD									
WHEEL CONT. PRESS									
STEP-ON							859	15.7	5.2
TOGGLE	1	100.0	100.0	26	15.4	15.4	4	25.0	50.0
ROCKER				13	7.7	0.0			
THUMBWHEEL									
HANDLE									
CRANK									
USUAL									
DUAL/MULT.				6	0.0	33.3			
ADJ. WHEEL									
BAN									
MANUAL									
CORD									
DOORS									

TABLE 12, LOCATING AND OPERATING DIFFICULTIES AS A FUNCTION OF CONTROL CONFIGURATION (OWNERSHIP PERIOD) (CONT.)

	FLASHER			CLIMATE CONTROLS			VENTS		
	N	% DIFFICULTY		N	% DIFFICULTY		N	% DIFFICULTY	
		LOCATING	OPERATING		LOCATING	OPERATING		LOCATING	OPERATING
PUSH/PULL KNOB	407	9.3	5.4				353	20.7	15.0
ROTARY KNOB	21	9.5	9.5	95	20.0	26.3	53	15.1	26.4
LEVER				36	5.6	19.4	197	16.8	12.7
POD	9	11.1	0.0						
TAB	42	14.3	7.1	806	13.2	21.2	224	10.3	9.8
PUSHBUTTON	178	10.7	5.6	41	9.8	14.6	9	22.2	44.4
RING									
1/2 RING									
PAD									
WHEEL CONT. PRESS									
STEP-ON							5	0.0	0.0
TOGGLE	62	19.4	6.5	16	6.3	31.3	10	0.0	20.0
ROCKER	8	25.0	0.0	1	0.0	0.0	3	0.0	0.0
THUMBWHEEL				12	8.3	33.3	6	16.7	33.3
HANDLE							19	10.5	21.1
CRANK									
USUAL									
DUAL/MULT.				28	25.0	42.9	21	23.8	28.6
ADJ. WHEEL									
BAN									
MANUAL							35	34.3	34.3
CORD									
DOORS							37	54.1	29.7

TABLE 12, LOCATING AND OPERATING DIFFICULTIES AS A FUNCTION OF CONTROL CONFIGURATION (OWNERSHIP PERIOD) (CONT.)

	RADIO			PARKING BRAKE			LIGHTER		
	N	% DIFFICULTY LOCATING	% DIFFICULTY OPERATING	N	% DIFFICULTY LOCATING	% DIFFICULTY OPERATING	N	% DIFFICULTY LOCATING	% DIFFICULTY OPERATING
PUSH/PULL KNOB				33	6.1	9.1			
ROTARY KNOB	828	4.8	8.1						
LEVER	1	0.0	0.0	504	3.2	9.9			
POD									
TAB									
PUSHBUTTON				1	0.0	0.0			
RING									
1/2 RING									
PAD									
WHEEL CONT. PRESS									
STEP-ON				451	3.5	4.9			
TOGGLE									
ROCKER									
THUMBWHEEL									
HANDLE				82	4.9	4.9			
CRANK									
USUAL							759	7.2	7.2
DUAL/MULT.	116	6.9	7.8						
ADJ. WHEEL									
BAN									
MANUAL									
CORD									
DOORS									

TABLE 12, LOCATING AND OPERATING DIFFICULTIES AS A FUNCTION OF CONTROL CONFIGURATION (OWNERSHIP PERIOD) (CONT.)

	ODOMETER RESET			MIRROR ADJUSTMENT			WINDOW		
	N	% DIFFICULTY LOCATING	% DIFFICULTY OPERATING	N	% DIFFICULTY LOCATING	% DIFFICULTY OPERATING	N	% DIFFICULTY LOCATING	% DIFFICULTY OPERATING
PUSH/PULL KNOB									
ROTARY KNOB	177	6.8	5.6				3		
LEVER							5		60.0
POD									
TAB				285	2.8	8.8	17	0.0	11.8
PUSHBUTTON							94	1.1	11.7
RING									
1/2 RING									
PAD									
WHEEL CONT. PRESS									
STEP-ON									
TOGGLE							3	0.0	33.3
ROCKER							2		
THUMBWHEEL									
HANDLE							3		
CRANK							945	1.4	10.5
USUAL									
DUAL/MULT.									
ADJ. WHEEL									
BAN									
MANUAL				713	3.2	13.5			
CORD									
DOORS									

TABLE 12, LOCATING AND OPERATING DIFFICULTIES AS A FUNCTION OF CONTROL CONFIGURATION (OWNERSHIP PERIOD) (CONT.)

	TAPE DECK			IGNITION/STARTER			DOOR		
	N	% DIFFICULTY		N	% DIFFICULTY		N	% DIFFICULTY	
		LOCATING	OPERATING		LOCATING	OPERATING		LOCATING	OPERATING
PUSH/PULL KNOB	4	0.0	0.0						
ROTARY KNOB	28	7.1	7.1						
LEVER							529	3.6	4.9
POD									
TAB									
PUSHBUTTON	50	10.0	8.0	9	11.1	22.2			
RING									
1/2 RING									
PAD									
WHEEL CONT. PRESS									
STEP-ON				1	0.0	0.0			
TOGGLE	3	33.3	33.3						
ROCKER									
THUMBWHEEL	2	50.0	0.0						
HANDLE							530	2.8	6.2
CRANK									
USUAL	2	0.0	0.0	1045	7.5	5.4			
DUAL/MULT.	3	0.0	33.3	12	8.3	25.0			
ADJ. WHEEL									
BAN									
MANUAL	3	0.0	0.0						
CORD							1	100.0	100.0
DOORS									

TABLE 12, LOCATING AND OPERATING DIFFICULTIES AS A FUNCTION OF CONTROL CONFIGURATION (OWNERSHIP PERIOD) (CONT.)

SHIFT LEVER

	N	% DIFFICULTY	
		LOCATING	OPERATING
PUSH/PULL KNOB			
ROTARY KNOB			
LEVER	225	2.7	12.4
POD			
TAB			
PUSHBUTTON	23	4.3	21.7
RING			
1/2 RING			
PAD			
WHEEL CONT. PRESS			
STEP-ON			
TOGGLE	4		25.0
ROCKER	1	0.0	0.0
THUMBWHEEL			
HANDLE			
CRANK			
USUAL	455	.9	5.5
DUAL/MULT.			
ADJ. WHEEL			
BAN			
MANUAL	291	1.7	11.0
CORD			
DOORS			

Perel (1976)

While one of the briefest reports reviewed (14 pages including the abstract), the impact of this document is considerable. Perel analyzed a computer search of police reports narratives describing accidents in North Carolina. That database was maintained by the University of North Carolina Highway Safety Research Center, and is designed to be searched using keywords.

The database included 95,879 narratives for 1974 and 19,017 for 1975. Perel looked at problems related to four aspects of vehicle design: foot controls (62 reports ignoring mechanical problems), hand controls (78), visibility (69), and lighting (104). Some of the keywords pertaining to hand controls used in the search include wiper, washer, fan, defroster, and so forth. The narratives are fairly specific in describing the problems. For example:

> "Veh [vehicle] 1 was trv [traveling] on Franklin St and [the driver] reached over to adjust the radio and veered to the rt [right] and hit V2 [vehicle 2] which was parked." (Perel, 1976, p. 5)

Shown in Table 13 is Perel's summary of hand controls problems. Notice that Perel's classification scheme (and hence the totals) can be a bit misleading. For example, 28 of the reports for hand controls relate to the horn not being heard by other drivers. For the controls listed, reports of problems concerning the entertainment unit and the horn were most numerous. In most instances, the problem was that operating a control distracted the driver. There are few instances reported where a control was not operated quickly enough (e.g., honking a horn, operating the wiper to remove material splashed on, etc.)

Despite these problems and the age of the data (11 years old), they are still worth looking at carefully. Research sponsors are strongly encouraged to support a new look at the data accumulated since Perel's examination of it.

Burger, Smith, Queen, and Slack (1977)

Burger, Smith, Queen, and Slack (1977) studied the relationship between vehicle design and accidents using a questionnaire. Problem areas investigated in the report included vision, steering, braking, shifting, seating, and controls. Drivers were asked to what degree aspects of those factors had been associated with accidents (no problem, annoying, potential danger, close call, caused accident). This data was collected because previous research had shown a strong correlation between reports of "close calls" for various conditions and accidents.

Table 13, Hand Control Problems Reported by Perel (1976)

Control	# Times	Problem
(1975 file)		
Heater	3	Distracted from driving while adjusting or turning on heater
Radio	6	Distracted from driving while adjusting radio
Tape	7	Distracted while changing tape or adjusting controls on tape player
Horn	3	Another car's horn distracted driver
	6	Did not blow horn while passing
	6	The horn was sounded as a warning and was heard but collision took place anyway
	28	The horn was sounded as a warning but it apparently was not heard
(1974 file)		
Air Cond	3	Distracted from driving while turning on or adjusting air conditioner
Lighter	2	Distracted by dropped lighter
Ashtray	2	Distracted while using ashtray
Defroster	4	Distracted while operating defroster
Wiper	6	Distracted while operating wipers
	--	
	78	

Questionnaires were mailed to 9,966 drivers in New Hampshire and California. The 3,478 returns cited 1,691 accidents or near-accidents, some of which indicated driver/vehicle incompatibilities. The number of problems associated with finding and using controls is somewhat less than those for other factors, as can be seen in Table 14. It was greater than those allegedly due to alcohol and drugs (which may be a reporting problem), and lies in the middle of the range of factors associated with vehicles. Frequency data on reported problems for several controls as a function of the degree of risk is shown in Table 15.

Given the current interest in making cars easy to use, the data in the "potentially annoying" column are particularly interesting. Notice that there are a fair number of instances where more than 10% of those responding could be annoyed by a control design. In general, drivers reported that there were more problems with finding controls than with operating them, and less with reaching for them. Most numerous were complaints about finding (15%) and operating (13%) the climate controls, finding (14%) and operating (12%) the defogger/de-icer, and finding the dimmer (12%). While problems with the horn are

Table 14. Factors Contributing to Near Accidents Reported by Burger et al. (1977)

	Extent of Contribution		
Factor	Played No Part	Contributed Somewhat	Contributed Greatly
Vehicle			
Poor Vision	2196	692	261
Steering or braking difficulties	2738	271	83
Gear shift difficulties	2989	83	8
Finding and using controls	2792	246	126
Visibility of other vehicles, pedestrians, signs, etc	1777	974	266
Driver			
Fatigue	2045	883	190
Alcohol/Drugs	2788	176	81
Disregarding driving rules	2584	410	72
Inattention	1900	1014	212
Lack of driving skills	2899	125	26
Environment			
Darkness	1876	998	197
Rain/snow/ice	1366	1260	472
Fog	1521	1247	309
Sun glare	1617	1211	252
Roadway			
Poor signs (location/readibility)	1630	1144	294
Poor road conditions	1753	999	285
Poor street markings	1638	1084	283

Table 15. Problems of Finding, Reaching, and Operating Controls. Reported by Burger et al. (1977)

		Extent of Difficulty				
Control	Activity	No Problem	Potential Annoying	Danger	Close Call	Caused Accident
Headlights	*Find*	3219	184	20	3	0
	Reach	3378	52	10	0	0
	Operate	3332	66	21	2	0
Climate Controls	*Find*	2722	531	34	0	2
	Reach	2995	301	31	0	1
	Operate	2794	458	51	3	1
Headlight Dimmer	*Find*	2926	407	78	2	2
	Reach	3073	269	57	0	0
	Operate	3019	284	83	5	0
Window Washer or Wiper	*Find*	3033	321	53	5	0
	Reach	3223	159	24	1	0
	Operate	3056	267	58	6	0
Defogger/De-Icer	*Find*	2801	490	59	6	1
	Reach	3016	293	45	2	1
	Operate	2814	418	93	8	1
Hazard Flasher	*Find*	2905	378	48	3	0
	Reach	3146	183	19	2	0
	Operate	3059	216	43	3	0
Horn	*Find*	3052	277	74	16	1
	Reach	3253	125	33	5	1
	Operate	3101	208	76	11	2
Radio, Ashtray, Lighter, Vent, Mirror, Interior Lights, Dash Lights, and Turn Signal	*Find*	2879	478	78	2	0
	Reach	3253	387	92	8	0
	Operate	2973	390	53	2	0

fewer in number, the horn must be used quickly in an emergency, so those problems are of concern. There are far more reports that the horn was associated with a near accident (close call) than any other control. Also note that while the numbers are small, there are reports that the design of a control caused an accident.

Burger, Smith, Queen, and Slack (1977) paid special attention to the relationship between the number of functions/stalks and reports of finding, reaching, and operating problems. As shown in Figure 13, reported difficulties rapidly increased as the number of functions/stalks goes from 2 to 3. In particular, there were difficulties with the horn in the '71 '72, and '76 Capri, which represented 3 of the 14 three function/stalk vehicles.

Since Krumm (1974) found that there were difficulties in locating horn controls (discussed earlier), problems with finding and operating the horn were given special attention by Burger et al. (1977). (See Table 16.) The data indicate that drivers experienced more difficulty in operating stalk-mounted horns than other designs, but fewer problems in finding it. The reader should keep in mind the operating problems are based upon responses from only 30 people, 5 of which reported some degree of difficulty.

Finally, for each of the controls examined, the report also identified which vehicles had the most and the fewest reports of problems. Why particular vehicles fared well or poorly was not considered in detail.

Mourant, Moussa-Hamouda, and Howard (1977)

Mourant, Moussa-Hamouda, and Howard (1977) carried out an extensive study of stalk-mounted controls, cataloguing existing configurations, collecting problems associated with their use, and performing a laboratory evaluation of five configurations. (That evaluation is described later in the section entitled "What Do The Performance Data Show.") In their problem survey, 405 drivers were interviewed while sitting in their own cars (31 different makes). The sample was fairly representative of the population by sex, but not by age, as it included a large number of younger individuals.

The survey results are reproduced in Tables 17 and 18. The first table describes wiper on/off and wiper speed control problems, and the second washer control problems. Note that right-hand stalks caused more difficulty than left-hand stalks, and that a hand switch activated by pushing in on the end of the column caused the greatest number of operating difficulties. Mourant et al. (1977) concluded that if functions are to be stalk-mounted, they should be added to

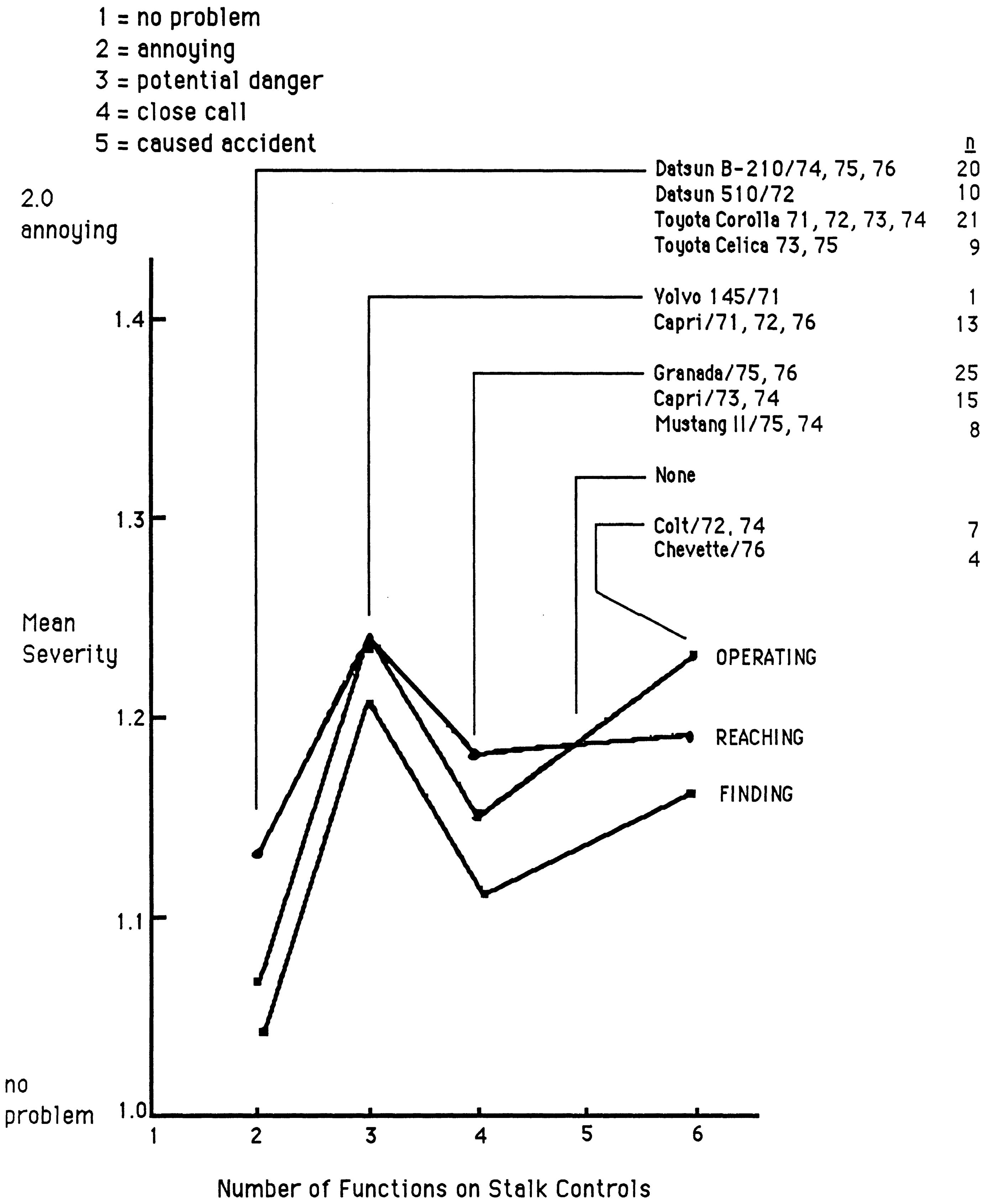


Figure 13. Control Problems vs. Number of Functions per Stalk Reported in Burger, Smith, Queen and Slack (1979). Revised in Green (1979).

Table 16 . Finding and Operating Problems for the Horn, Reported by Burger et al. (1977).

Vehicle (year)		Severity Category					Type Horn
		No Problem	Annoying	Potential Danger	Close Call	Caused Accident	
	$\overline{X}$	1	2	3	4	5	
FINDING HORN							
Cutlass (72,73)	1.24	20	4	1	-	-	2-spoke lever
BMW 2002 (All)	1.10	9	1	-	-	-	3-spoke pushbutton
Fiat 124 (All)	1.25	6	2	-	-	-	center
Capri (All)	1.07	28	2	-	-	-	stalk
OPERATING HORN							
Cutlass (72,73)	1.16	21	4	-	-	-	2-spoke lever
BMW 2002 (All)	1.10	9	1	-	-	-	3-spoke pushbutton
Fiat 124 (All)	1.00	8	-	-	-	-	center
Capri (All)	1.27	25	3	1	1	-	stalk

existing stalks, as opposed to having additional stalks installed, since multiple stalks led to greater confusion among drivers. Other conclusions drawn include: (a) labeling decreases reported problems (but not by a statistically significant amount.), and (b) there was no interaction between any of the driver characteristics (driving experience, sex, mileage, hand size, etc.) and reported problems.

The Mourant et al. study contains considerable detail regarding reported difficulty with various switch types and stalk location configurations for each function. It correctly notes, however, that drawing conclusions about a particular switch design based upon these data is difficult. While the total number of problems reported is large, the number attributable to any individual combination is small. For example, three vehicles with "1 Left, 1 Right" stalk configurations had a hand switch that, when pushed in, turned on the wiper. The driver of one of these three vehicles reported a problem finding that control, thus yielding a 33% complaint rate. Obviously, such a figure is meaningless, and only for flash-to-pass (optical horn) control are there samples of any respectable size (n=79), and in those cases the differences between designs are slight.

Treat et al. (1979) (Tri-Level Study)

Unlike the focused work of Perel (1976), the work of Treat, Tumbus, McDonald, Shinar, Hume, Mayer, Stansifer, and Castellan (1979) provides a broad overview of accidents and their causes. Data were collected at three levels. Police reports and other data were collected for accidents in the Monroe County, Indiana, area. To get more in-depth information, teams of investigators carried out on-site investigations of 2,258 accidents shortly after they occurred. Finally, 420 of these accidents were independently examined by a multidisciplinary team.

Human factors were cited by the in-depth team as probable causes of almost 93% of the accidents. (Environmental factors were probable causes in 34% and vehicle factors in 13%.) In their usage, human factors includes recognition errors (including both perception and comprehension problems), decision errors, performance errors (problems in executing correct decisions) and "critical non-performances" (e.g., falling asleep or blacking out). Hence, their use of the term is quite different from the way it is used in the rest of this review. In their analysis, human factors engineering problems are classified as vehicle factors. Shown in Table 19 is a summary of the causal factors associated with seating and controls. Notice that the numbers are fairly low, much lower than many other factors. For example, 34 accidents in the on-site investigations were certainly due to a gross failure of

Table 17. Problems of Finding and Operating the Wiper Control. Reported by Mourant et al. (1977).

Problem and Control (configuration)	Wiper On/Off												Wiper Speed							
	Switch Types												Switch Types							
	Lever Lift Up		Lever Pull Down		Hand Switch In		Hand Switch Rotate Toward Driver		Hand Switch Rotate Away from Driver		Slide Switch Right		Lever Lift-Up		Lever Pull Down		Rocker Switch		Slide Switch	
	#	%	#	%	#	%	#	%	#	%	#	%	#	%	#	%	#	%	#	%
<u>Finding Problems</u>																				
Left Stalk (1L)					5	20.0			0	0	2	10.5					3	13.6	1	4.2
Left Stalk (1L, 1R)					1	33.3														
Left Stalk (2L)									0	0										
Right Stalk (1L, 1R)	6	10.3	5	10.9			1	33.3					2	3.5	4	8.5				
Right Stalk (2L, 1R)			2	8.3																
<u>Operating Problems</u>																				
Left Stalk (1L)					1	4.0			1	5.6	0	0					0	0	0	0
Left Stalk (1L, 1R)					0	0														
Left Stalk (2L)									2	18.2										
Right Stalk (1L, 1R)	9	15.5	4	8.7			1	33.3					2	3.5	1	2.1				
Right Stalk (2L, 1R)			2	8.3																

Table 18. Problems of Finding and Operating Washer Control. Reported by Mourant et al. (1977).

Location of Control and (configuration)	Switch Types							
	Lever Pull Toward		Lever Pull Away		Hand Switch Push In		Finger Button Push In	
	#	%	#	%	#	%	#	%
Finding Problems								
Left Stalk (1L)			0	0			1	2.4
Left Stalk (1L, 1R)					2	66.7		
Left Stalk (2L)					2	18.2		
Right Stalk (1L, 1R)	5	7.6			2	5.4	1	100
Right Stalk (2L, 1R)	1	4.4						
Operating Problems								
Left Stalk (1L)			1	33.3			0	0
Left Stalk (1L, 1R)					1	33.3		
Left Stalk (2L)					0	0		
Right Stalk (1L, 1R)	8	12.1			1	2.7	1	100
Right Stalk (2L, 1R)	0	0						

the brake system, and 15 were certainly due to a vehicular view obstruction.

Table 19. Causal Involvement of Vehicle Factors in Treat et al. (1979), p.21

	Probability											
	Certain (highest level)				Probable (includes certain)				Possible (incl. certain & probable)			
Vehicle Problem	on-site		in-depth		on-site		in-depth		on-site		in-depth	
	n	%	n	%	n	%	n	%	n	%	n	%
Driver Seating & Controls	3	.1	0	0	3	.1	1	.2	11	.5	3	7
Driver Ctrls	3	.1	0	0	3	.1	1	.2	10	.4	3	.7
Anthropometry	0	0	0	0	0	0	0	0	1	0	0	0
All Veh Probs	92	4.1	19	4.5	205	9.1	53	12.6	333	14.7	106	25.2

Using these data, Treat and Romberg (1977) examined the potential reductions in accident frequency and severity from 11 vehicle design changes (improved wet-traction tires, rapid window defrost system, etc.). Possible benefits ranged from a low of .5% (two accidents out of 420) for "standardization of driver controls," to a high of 8.8% (37 accidents) for "improved brake lights." They did not believe the gains from standardization would be very large.

Summary

Most accident data bases do not code information regarding the use of controls. Even where the data does exist, information about control use is often lost because drivers are unable to report what they were doing just before the crash (i.e., they forget, they're dead). It is likely that problems associated with controls are under-reported. Nonetheless, there are three specific studies in the literature (Perel, 1976; Burger et al., 1977; Treat et al., 1979) that have identified incidents where the use of controls has been associated with accidents. The number of incidents is not very high. For the most part the evidence suggests the problem is one of use of the control distracting the driver from paying attention to the road ahead.

The literature also indicates there is a good relationship between reports of problems, near-accidents, and accidents. Where problem reports have been collected, there seems to be good agreement between studies (e.g., Anacapa, 1976 with Burger et al., 1977). Because there are far more near accidents than accidents, one would expect the literature to offer a clearer picture of those aspects of control design that minimize risk to the driver. Unfortunately, that question often has not been examined, and where it has, the number of relevant cases is small.

There are, however, a few conclusions about design that do emerge from the literature. Drivers reported approximately the same number of problems with multifunction stalk controls as with panel-mounted controls. Most control use problems (both stalk- and panel-mounted) were associated with locating and activating them, as opposed to reaching for them. In addition, adding multiple functions to stalks increased the difficulty associated with operating them. For example, Krumm (1974) shows drivers reporting difficulties rising from 6% on a 1-function stalk to 32% on a 3-function stalk. However, the trade-off ratio between adding controls to stalks and adding stalks is unknown, since Krumm also noted fewer reported difficulties as more functions were added with multiple stalks.

Horn controls should be mounted on the steering wheel spokes or hub (6.3% and 4.3% errors according to Krumm, 1974), not in the rim (33.3% errors) or on a stalk (27.7%). Finally, many drivers experienced difficulties with stalk-mounted wiper/washer controls, either in comparison with panel-mountings (Krumm (1974) or between different stalk types (Mourant et al., 1977).

Several studies have also found relatively high problem incidence rates for the climate control, in particular for operating it. While the Anacapa work shows which control types led to the fewest problems, the numbers available are the raw report totals, not the report rates. (Problems for many designs are reported more often because more cars have that design, not because they are relatively more difficult to use.)

While problem surveys can be a valuable source of information, they are a retrospective approach yielding information only about the past. Furthermore, the accuracy of problem surveys is based on driver recall, which may be susceptible to error. However, the data are easy to collect and help sensitize engineers to the problems which customers experience.

- WHAT PROBLEMS DO DRIVERS SAY THEY HAVE USING CONTROLS? -

WHAT DO THE DRIVER PERFORMANCE DATA SHOW?

One of the most effective methods for assessing alternative control designs is to have actual drivers use the controls in question. Of the many studies included in this section, about half of them were undertaken over a five-year period in the mid-1970's. The emphasis of these studies is on comparing specific alternative designs, not on developing predictive models or validating human performance theories. Most studies are concerned with the entire instrument panel and typically about eight controls, and examine performance with designs found in cars in production at the time. A few studies have dealt with a limited set of functions, either those on a single stalk, or more recently, tripcomputers.

Performance is typically measured by response time, but other measures such as error rates, glance durations, and tracking error have been used as well. Usually the studies concern work carried out in the laboratory using a simple buck, but quite a few have been done on the road. The use of high fidelity driving simulators is rare.

Malone, Krumm, Shenk, and Kao (1972)

The first performance study reported in the open literature is commonly referred to as Essex '72 after its corporate author. Appendix C of that study describes experiments concerning learning the location of controls on various instrument panel configurations, and discusses the methodology involved in performing such experiments. Trucks and buses were also studied, but discussion here will be confined to automobiles. It should be noted, however, that the other experiments indicated that there was some value in designing truck and bus controls to have layouts similar to those of automobiles.

Malone et al. conducted several small preliminary experiments to answer methodological questions. In all experiments, each of the 20 controls and displays of interest was responded to five times. Also, in each case drivers were verbally cued to operate controls and response time was manually recorded.

In the first experiment, either an unfamiliar car ('71 Oldsmobile Delta 88) or a person's own car was driven around a test track. Two groups of subjects were used; one group of four did the experiment at night, another ten did the experiment during the day. In the night condition, panel illumination was set at normal levels. As shown in Table 20, there were no statistically significant differences between day and night conditions, though drivers clearly did better in their own cars.

Table 20, Day vs. Night Comparison in Essex Study

Vehicle	Measure	Group/Condition Day	Night
unfamiliar car	RT (sec)	3.39	3.82
	Errors (#/S)	1.96	1.56
familiar (own) car	RT (sec)	1.25	1.31
	Errors (#/S)	1.25	1.31

In a second experiment conducted several weeks after the first, four people reached for several controls in their own car while it was stationary. Differences in reaction time between that condition and when they drove their own car on the test track were small. (Statistical tests are not provided.) The results of this experiment are used to argue in favor of static testing.

In another condition, an unspecified number of drivers from two groups (large-car drivers, small-car drivers) reached for controls in a small car (1971 Volkswagen Beetle). There were no statistically significant differences in performance between the two groups, suggesting that the size of the panel one is familiar with has no effect on performance. Both the Beetle and the Delta 88 (used in previous tests) had instrument panels that tended to be different (had low control commonality indices) from other cars on the market at the time.

The final preliminary experiment concerned the effect of the test order on performance. Five people were tested in the Volkswagen, then their own cars. Another five were tested first in the Oldsmobile, then their own cars. Ten were tested only in their own cars. Prior testing in unfamiliar cars had no statistically significant effect on subsequent driver performance in their own cars. There was, however, a large and statistically significant difference due to familiarity. First trial responses averaged 4.29 seconds in unfamiliar cars but only 1.42 seconds in familiar cars. Differences in the number of errors were not found.

Finally, for all conditions, Malone et al. report that performance appeared to level off at about five trials, but since only five responses were obtained for each control, it is hard to say if that is true.

Two months after this series of experiments, participants from those studies responded to instrument panels designed by Man Factors and Essex. (Those panels are described in the section on human factors methods.) All tests were conducted using mockups in the laboratory while drivers apparently performed an unspecified activity that had demands resembling those of steering ("simulated perceptual load"). There is also a reference to day and night conditions (which did not affect performance). Shown in Figure 14 are the mean response times for the first trial for each control (and display) tested for all four instrument panels.

With regard to overall differences in panel design, response time differences between the "human-engineered" panels and the panels in drivers' own cars were small. (See Figure 15.)

However, as noted before, drivers did much worse in responding to unfamiliar panels. The evidence has been used to argue in favor of following human factors principles when designing automobile instrument panels. In brief, a "human engineered" instrument panel that a driver has never used before is about as easy to use as one a driver has had extensive experience with (one from their own car).

Appendix D of Malone et al. describes another experiment concerned with evaluating alternative three-beam headlight switch designs. (See also Kao, Malone, and Krumm, 1972.) Figure 16 shows the four designs evaluated. Six drivers were tested in a crude vehicle mockup. In front of them were a column of three lights, each of which served as a signal to the driver to switch the headlights to a different setting (low, medium, high). Each beam setting was responded to 12 times. Another three lights, arranged in a row, signaled which way the driver was to turn the steering wheel.

There were no differences between conditions in simulated steering performance. As shown in Figure 16, there were statistically significant differences in beam switching times, with times being shortest for the spoke button design.

Middendorf, Dineen, and Hapsburg (1974)

Headlight switching between high and low beams was compared in a series of experiments carried out by Middendorf, Dineen, and Hapsburg (1974). The first one, involving 32 General Motors employees, examined three different designs, two column-mounted (pull/pull and pull (high)/push (low)), and one floor-mounted. Drivers were signaled by slides when to activate controls, and the response times from the signal to activation were collected electronically. Some drivers were allowed to practice operating the different designs before the test, while others were not. After practice, response times were 1.22 seconds for the foot switch and 1.06 (pull/pull) and 1.14 (pull/push) seconds for the column switches.

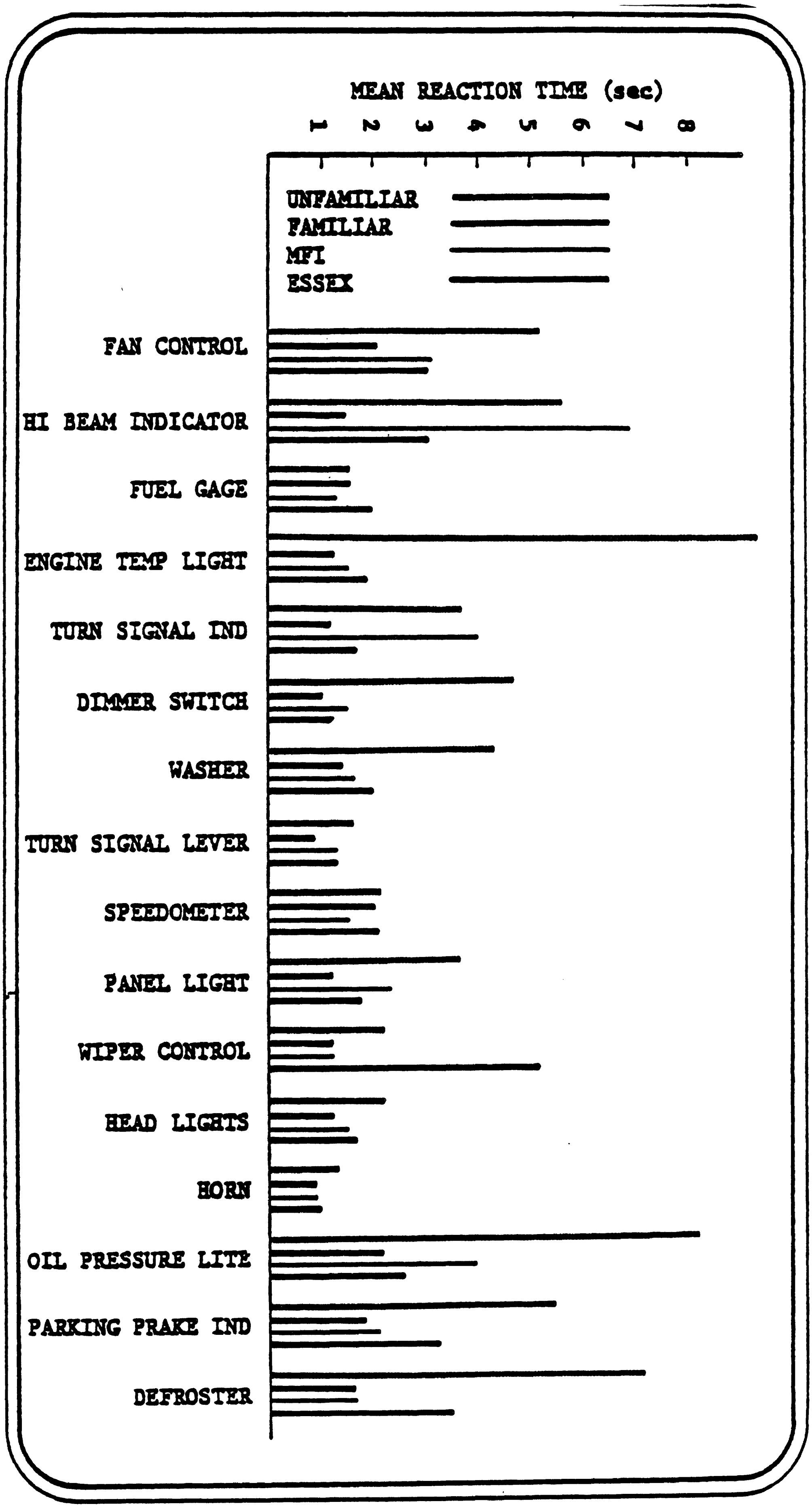


Figure 14. Comparison of first trial mean reaction times of automobile drivers responding to selected controls and displays using four alternative panels (N=10).

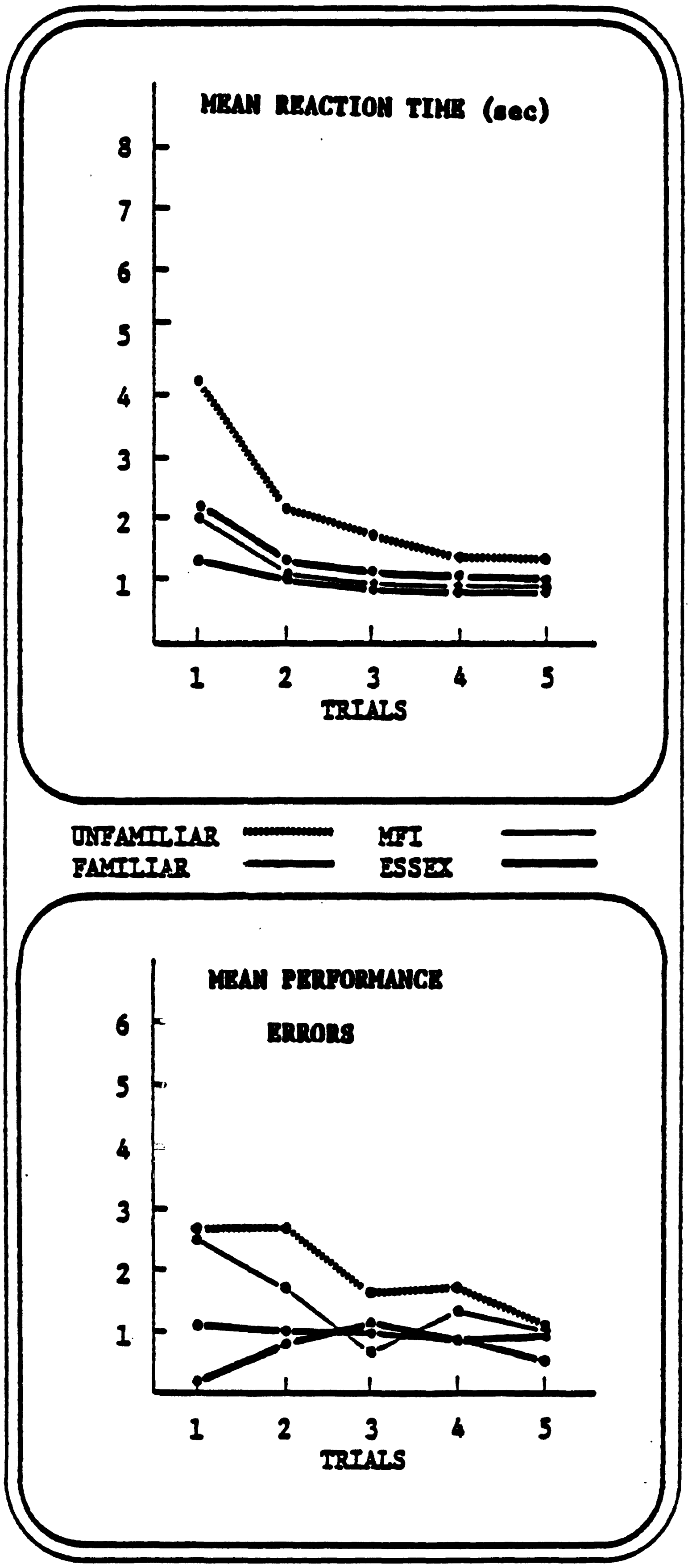
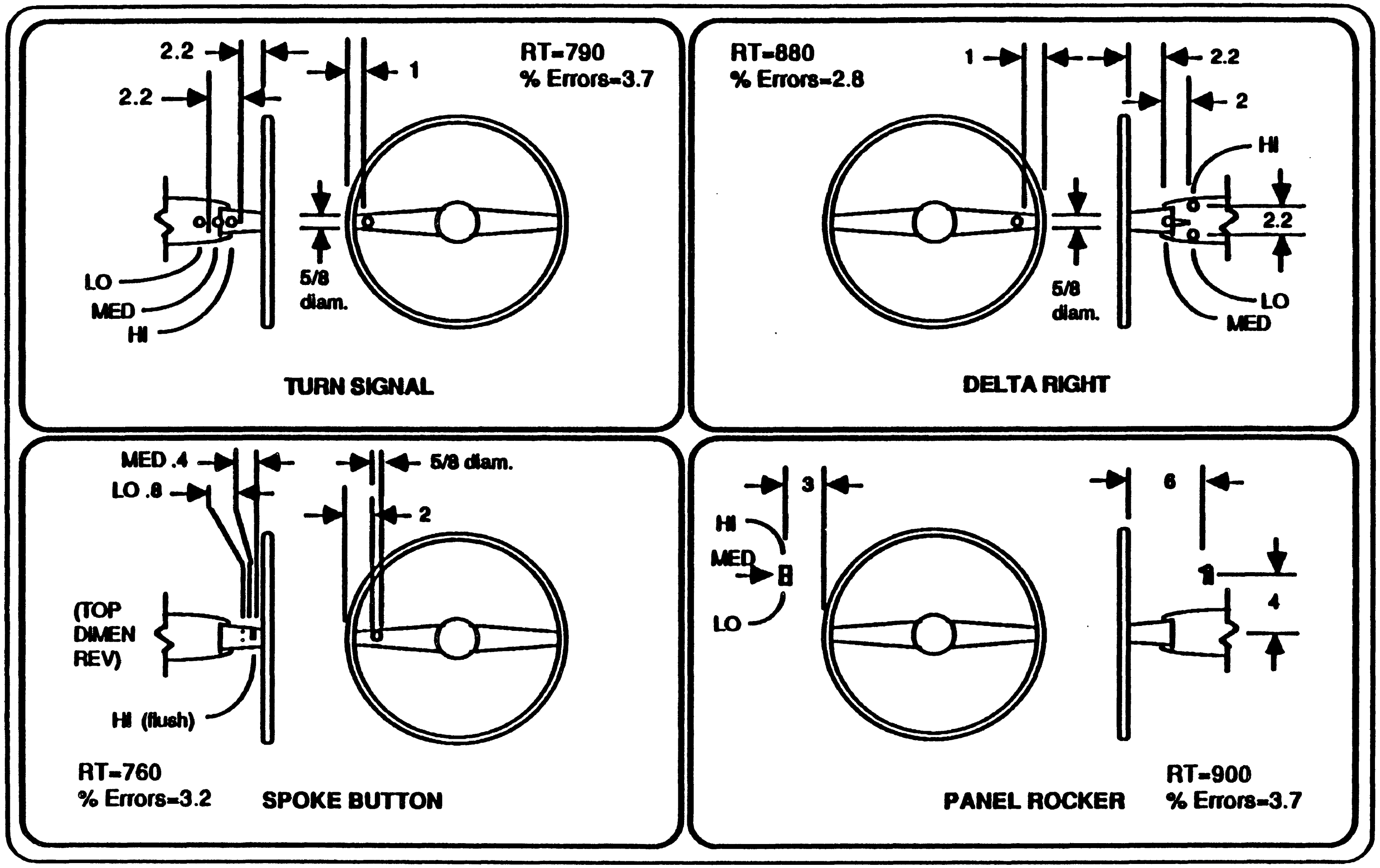


Figure 15, Comparisons of four automobile panels in terms of "learnability"



Source: Malone, Krumm, Shenk, and Kao (1972)

DIMENSIONS - inches
TOLERANCE = +/- 25%
FORCES = 10-40 oz.

Figure 16, Comparison of Four Beam Switching Systems

In a second experiment using the same protocol, 32 General Motors employees and 32 other drivers were tested operating three types of beam-switching systems. The results (see Table 21) showed no differences between designs or subject samples.

Table 21. Response Times for Three-Beam Switching Systems

	Response Time (seconds)		
Design	GM Workers (n=32)	Texas Drivers (n=64)	Method of Operation
Column Stalk	1.21	1.20	Pull toward for low, intermediate, high
Delta Stalk	1.21	1.20	Toward panel = low, toward ceiling = middle toward driver = high
Panel Stalk	1.24	1.14	Push up for low, intermediate, high

Krumm (1974)

The static procedure of Malone, Krumm, Shenk, and Kao (1972) was repeated by Krumm (1974) to assess the effect of airbags on vehicle design. Since airbags might be installed in the steering wheel hub where the horn was usually located, there was interest in how long it would take to honk the horn when it wasn't on the hub. "Multiple choice" response times were collected for operating the horn (amber signal light), the foot brake (red light) and the headlight dimmer (white light). Each of the six cars chosen had the horn in a different location. In the experiment, 336 drivers (American adults) were told to honk the horn once to obtain a "simple" reaction time. Then four "choice" response times were obtained where drivers were told to honk while steering in response to signal lights.

Drivers initially experienced a significant amount of difficulty with rim-blow and stalk-mounted horns, difficulty which persisted with the stalk-mounted horns. (See Table 22.) The average simple RT for the rim-mounted horn (in an Oldsmobile) was 29 seconds and response times to stalk-mounted horns was 10 seconds! In real driving, the actual means for these designs, especially the rim-blow horn, would have been much larger. Drivers were only given 30 seconds to respond. When they did not respond within that time, 30 seconds was recorded as the response time. Since the horn is often used to warn drivers of an immediate danger, this is an extremely hazardous design for American drivers. It is likely that these results could be duplicated today with American drivers, since there have been few changes in horn location since 1974.

Table 22. Time to Sound a Horn (from Krumm, 1974).

Control Type	Car	Mean Response Time (seconds) Initial	Choice
360 Ring	Taunus	.41	1.64
2-spoke lever	Olds Cutlass	.44	1.29
center	Fiat 124	.62	1.65
3-spoke pushbutton	BMW 202	1.96	1.86
stalk	Austin Marina	9.60	2.07
rim	Oldsmobile 98	29.00	1.61

Kuechenmeister (1974)

To evaluate a Mercedes-Benz multifunction stalk control, Kuechenmeister (1974) tested 30 General Motors employees. The stalk control was mounted in a 1972 Chevrolet wagon. Stopwatch times were recorded from when drivers were told to operate a control until their hands returned to the wheel, as well as driver errors. Two fixed sequences were used, one for practice and one for test trials. Generally, after about three blocks of 15 responses, most of the employees operated the control unit without error, and any further decreases in response time with practice were negligible. Table 23 shows where significant differences occurred. Because of its complexity, that table requires some explanation. For example, in the initial trial with no formal practice (first column), there were significant operating conflicts when the headlight on/off switch was a fore/aft lever. Specifically, the conflicts occurred when switching the headlights to low with the dimmer control. Notice the lack of significant differences by the third trial, indicating that differences between operations, functions, and switch types tend to disappear with practice, though at different rates.

The weakness of the Kuechenmeister study is that only one control configuration was studied. To draw meaningful conclusions with respect to alternative configurations of controls, more than one should be tested. Further, the rapid decrease in differences with practice is also expected, given the focus on a limited number of items which people had to learn.

Anacapa Sciences (1974, 1976)

Anacapa (1976) argued that if the location of controls is standardized, locations should be no more specific than the extent to which drivers can recall them. They had 28 drivers at a roadside rest area select which of three sketches most closely resembled the instrument panel configuration in their vehicle. Drivers then marked on the sketch where seven controls were located. Shown in Table 24 is a summary of the

Table 23, Response Time for Operating a Stalk Control

<table>
<tr><td>MEASURE</td><td colspan="12">Response Time</td><td colspan="2">Learn Trials</td><td colspan="12">Errors</td></tr>
<tr><td>CONDITION</td><td colspan="2">A</td><td colspan="2">B</td><td colspan="8">C</td><td colspan="2">C</td><td colspan="2">A</td><td colspan="2">B</td><td colspan="8"></td></tr>
<tr><td>TRIAL</td><td colspan="2">0</td><td colspan="2">0</td><td colspan="2">0</td><td colspan="2">1</td><td colspan="2">2</td><td colspan="2">3</td><td colspan="2"></td><td colspan="2">0</td><td colspan="2">0</td><td colspan="2">0</td><td colspan="2">1</td><td colspan="2">2</td><td colspan="2">3</td></tr>
<tr><td>OPERATION</td><td>Hdlts On</td><td>Hdlts Off</td><td>Hdlts On</td><td>Hdlts Off</td><td>Hdlts On</td><td>Hdlts Off</td><td>Hdlts On</td><td>Hdlts Off</td><td>Hdlts On</td><td>Hdlts Off</td><td>Hdlts On</td><td>Hdlts Off</td><td>Hdlts On</td><td>Hdlts Off</td><td>Hdlts On</td><td>Hdlts Off</td><td>Hdlts On</td><td>Hdlts Off</td><td>Hdlts On</td><td>Hdlts Off</td><td>Hdlts On</td><td>Hdlts Off</td><td>Hdlts On</td><td>Hdlts Off</td><td>Hdlts On</td><td>Hdlts Off</td></tr>
<tr><td>Knob(Panel)</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
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<tr><td>Rocker</td><td></td><td></td><td></td><td></td><td></td><td></td><td colspan="2">•</td><td></td><td></td><td></td><td></td><td colspan="2">•</td><td></td><td></td><td colspan="2">•</td><td></td><td></td><td colspan="2">•</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Pushbutton</td><td></td><td></td><td></td><td></td><td></td><td></td><td colspan="2">•</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Hdlts On/Off</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Dimmer</td><td colspan="2">•</td><td></td><td></td><td></td><td></td><td colspan="2">•</td><td></td><td></td><td></td><td></td><td colspan="2">•</td><td colspan="2">•</td><td></td><td></td><td></td><td></td><td colspan="2">•</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Turn Signals</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Wash On/Off</td><td></td><td></td><td></td><td></td><td></td><td></td><td colspan="2">•</td><td></td><td></td><td></td><td></td><td colspan="2">•</td><td></td><td></td><td colspan="2">•</td><td></td><td></td><td colspan="2">•</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Wipe Speed</td><td></td><td></td><td></td><td></td><td></td><td></td><td colspan="2">•</td><td></td><td></td><td></td><td></td><td></td><td></td><td colspan="2">•</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
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<tr><td>Hdldts Low</td><td colspan="2">•</td><td></td><td></td><td></td><td></td><td>•</td><td>•</td><td></td><td></td><td></td><td></td><td>•</td><td>•</td><td></td><td></td><td></td><td></td><td></td><td></td><td>•</td><td>•</td><td></td><td></td><td></td><td></td></tr>
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<tr><td>Wash Off</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td>•</td><td></td><td></td><td></td><td></td><td>•</td><td>•</td><td></td><td></td><td>•</td><td></td><td></td><td></td><td>•</td><td>•</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Right Turn</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Left Turn</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
</table>

A: No Formal Practice
B: Moderate Formal Practice
C: Extensive Formal Practice

• Significant @ p> 0.05 level

Kuechenmeister (1974)

recall data for six of the controls. (Data for the horn are not included in the section of the Anacapa (1974) report where the results for this experiment appear.) Three to four inch recall errors were typical for all the controls, with few differences between individual controls. (Readers interested in further details should consult Appendix B.)

Table 24. Control Location Recall Errors

Control	# Accurate (+/- .5 inch)	# Inaccurate	Missing Data	"Typical" Error (in)	Maximum Error (in)
Headlights	0	28	0	3	13
Wiper	4	24	0	2	17
Washer	3	23	2	3	17
Defroster	3	24	1	6	18
Ignition	18	10	0	5	9
Flasher	14	12	2	4	9

In a portion of the study addressing control location performance, 24 U.S. drivers were shown slides of instrument panels from 30 different cars (24 domestic and foreign 1973 model-year vehicles, 6 older models) and the driver's own car. Each driver was tested on all 30 panels (as well as the driver's own panel) twice, with panels displayed in random order. The driver was told which control he or she would be looking for, and then shown a slide of an instrument panel (projected at full size approximately 24 inches from the driver). The driver was timed from when the slide was displayed until the control was touched on the screen.

The cumulative response times from this large experiment are shown in Figure 17. Cumulative response times are a good method of reporting data, since they solve the problem of reporting an average when some response times are unusually long. Notice that the functions are well-behaved. With the exception of the potentially spurious brief responses for the flasher, none of the distributions cross each other. Speed and accuracy of response varied considerably between controls. In this test, the order of difficulty from easiest to hardest to locate was (1) radio, (2) ignition switch, (3) climate control unit, (4) headlight switch, (5) wiper switch, (6) cigarette lighter, (7) hazard switch, and (8) vent control. Anacapa Sciences (1974) noted that controls that fared poorly in this experiment (long response times, high error rates) were the same controls that people reported they had problems with in the survey of rental and own-car drivers (described earlier).

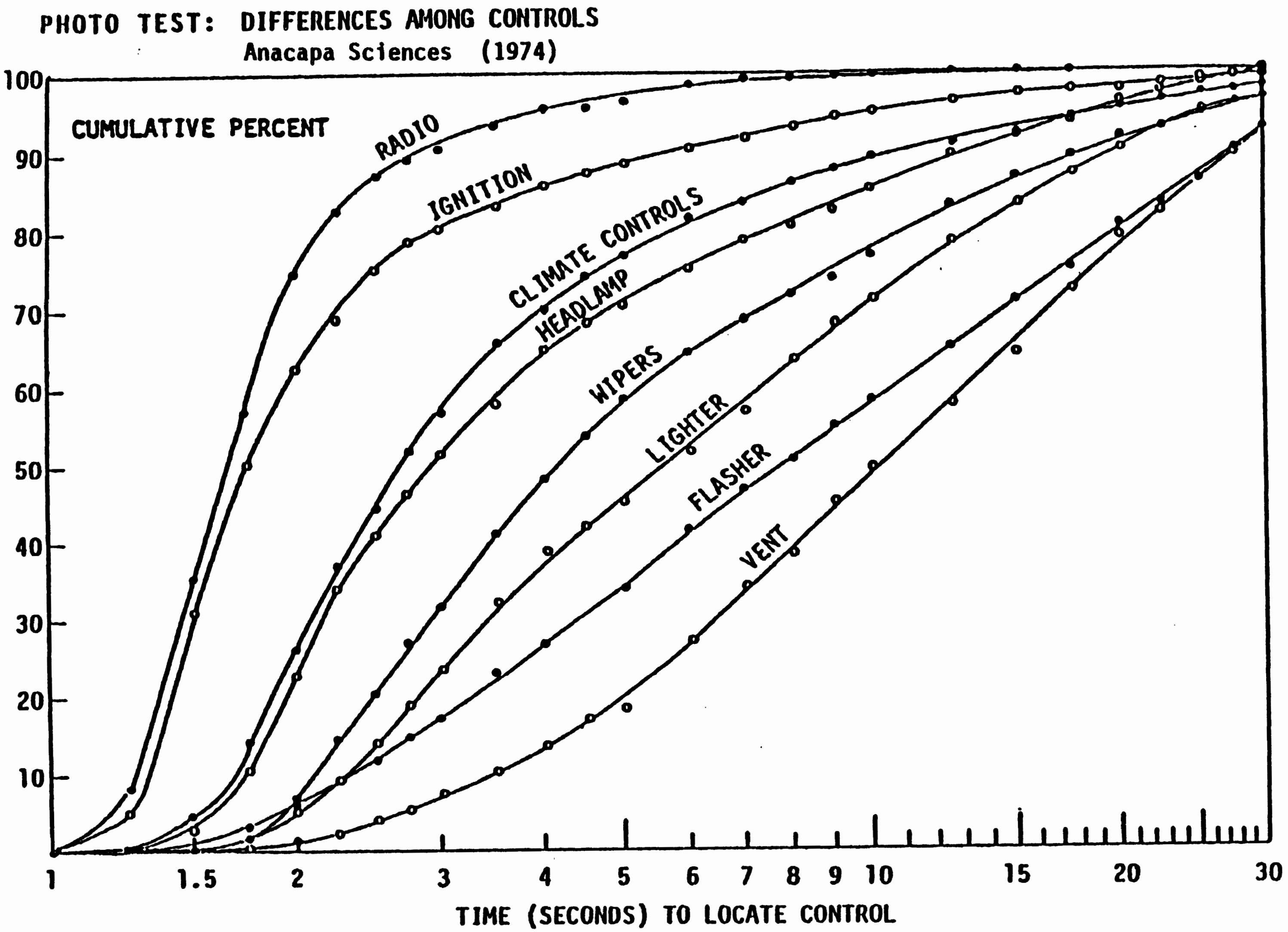


Figure 17, Cumulative Response Times for Controls

There was little difference between sexes regarding control locating ability, but Figures 18 and 19 show that older drivers were slower to respond and more likely to make mistakes than younger ones. More importantly, they nicely illustrate the high correlation (r=.85) between response time and error rate. This is relevant because some have argued that only errors, and not response times, should be collected in studies of controls. These data argue that response time is a useful surrogate measure for errors, as do the Malone et al. (1972) data.

There was also a strong correlation (r=.54) of both response times and errors with expectancy patterns from previous studies. Finally, error rates tripled when labels were covered on the controls. Anacapa (1976) reports (p. 21): "In short, when confronted with an unfamiliar instrument panel, the drivers apparently relied heavily on the labels for finding and identifying many controls, and the adequacy of the labelling system had a powerful effect on their performance." Thus, it is essential that the label be considered as an integral part of the control in question.

To validate the laboratory procedure, 12 U.S. drivers located ten controls while driving. Drivers were assigned to groups based on the similarity between the control configuration on their own car and one of three general configurations (based on the arrangement of four controls: headlight switch, wiper switch, radio, and climate controls). The test cars were a 1974 Pontiac Catalina, a 1974 Ford Torino, and each driver's own car. All tests were run on a test course consisting of two miles of a winding two-lane rural road. Except for the activation of the horn, drivers were asked only to touch each control as called out by the experimenter, and each control was responded to five times in each vehicle with times collected manually.

In general, performance in the driver's own car was best, followed by the Pontiac (high-expectancy test car) and the Torino (low-expectancy test car). The response times and error rates for the road tests of the Pontiac and Torino "were in reasonably good agreement" (Anacapa, 1974, p.3) with the lab data. Response times and error rates were both greater in the laboratory tests than the road tests, however, probably due to some effect resulting from the instrument panel being a slide projection, as opposed to an actual panel. (See Table 25.) In most cases, performance leveled out after one or two blocks of trials, and in general, response times for panel-mounted controls were less than those for stalk controls. (See Figures 20 to 30.)

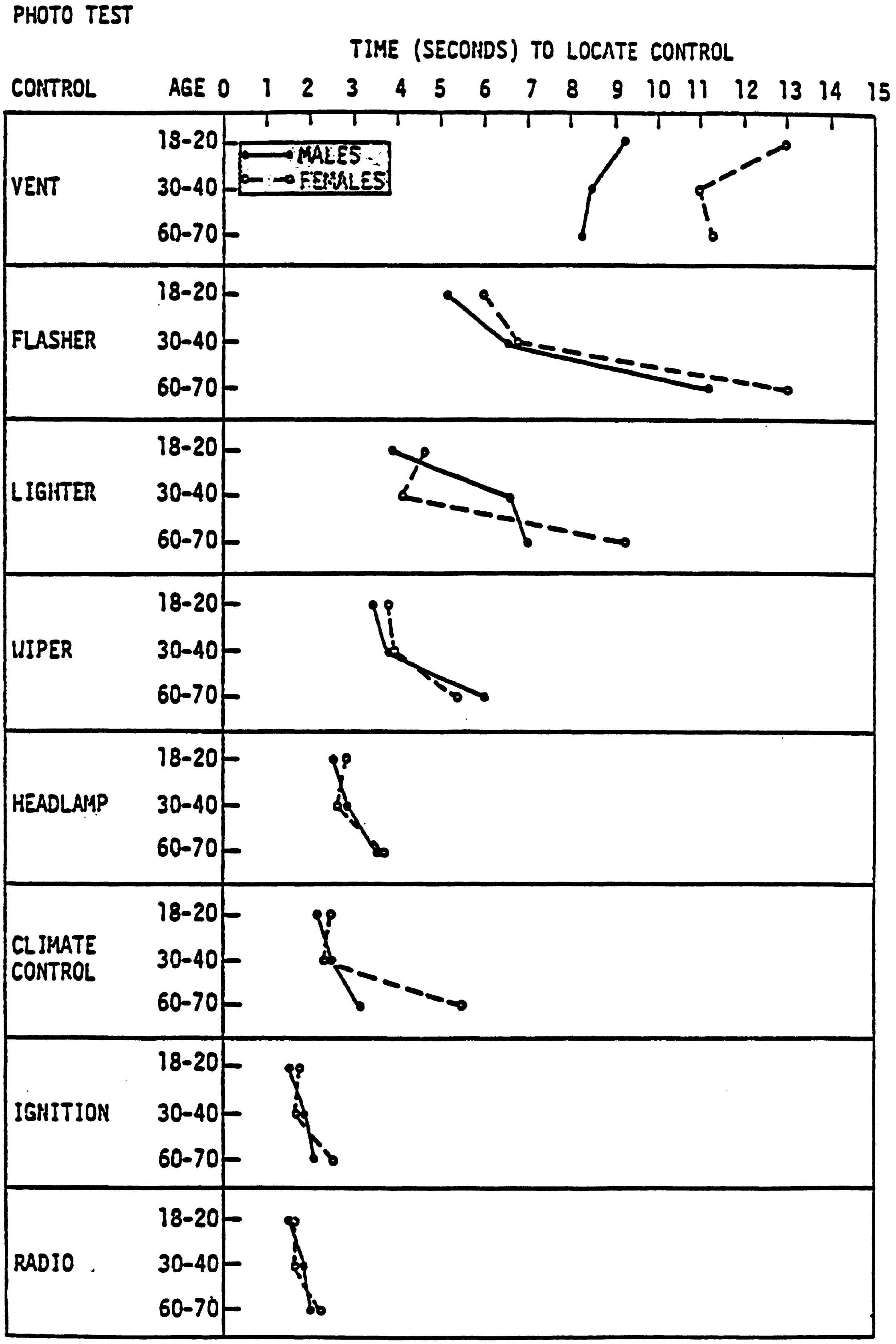


Figure 18, Time to Locate Controls by Age and Sex

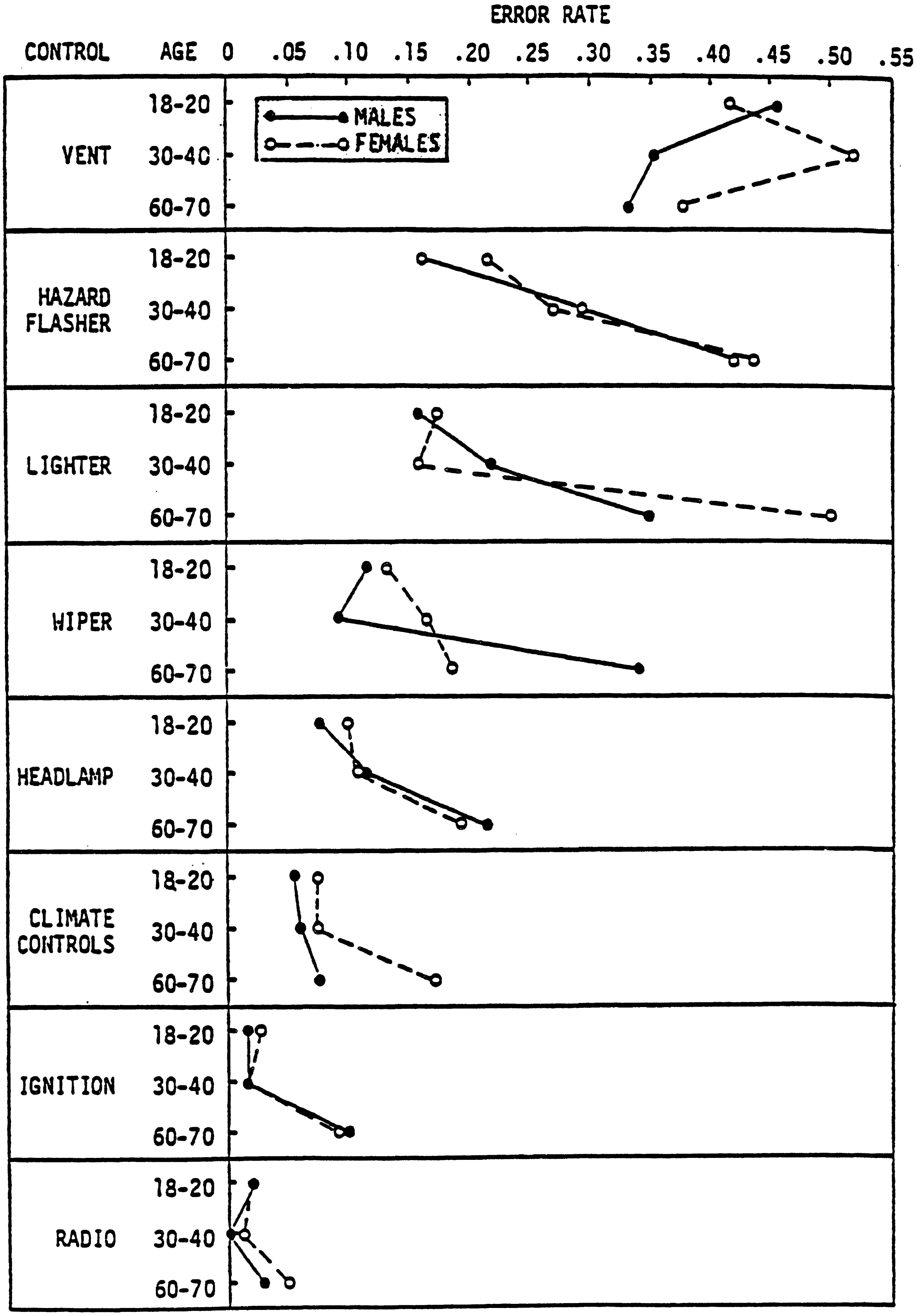


Figure 19, Errors Made in Locating Controls by Age and Sex

Table 25, Comparison of Lab and Road Test Results

Anacapa Sciences (1974)

	FORD TORINO						PONTIAC CATALINA					
CONTROL FUNCTION:	MEAN TIME		MEDIAN TIME		ERROR RATE		MEAN TIME		MEDIAN TIME		ERROR RATE	
	PHOTO	ROAD	PHOTO	ROAD	PHOTO	ROAD	PHOTO	ROAD	PHOTO	ROAD	PHOTO	ROAD
HEADLAMP	1.7	1.9	1.7	1.7	.00	.00	3.7	2.6	2.6	1.7	.00	.00
LIGHTER	12.1	6.7	7.2	5.1	.37	.00	2.5	2.8	2.3	1.8	.00	.00
IGNITION	2.3	1.4	2.0	1.3	.04	.00	1.9	1.4	1.5	1.4	.00	.00
WIPER	3.1	2.9	2.7	2.6	.00	.00	6.7	2.7	4.5	2.3	.04	.08
FLASHER	10.8	10.7	6.8	5.8	.25	.08	NOT TESTED	10.6	NOT TESTED	4.6	NOT TESTED	.08
RADIO	1.3	1.5	1.3	1.5	.00	.00	2.1	1.3	1.6	1.2	.12	.00
CLIMATE CONTROLS	2.9	1.7	2.2	2.2	.00	.00	3.5	2.0	2.8	1.7	.04	.00
VENT	NOT TESTED	10.2	NOT TESTED	3.7	NOT TESTED	.00	11.2	5.3	7.2	3.7	.33	.08

For the individual controls, one concludes the following:

1. Headlight (Fig. 20, 21)-- Performance was especially poor when this switch was located on a pod or a stalk, or in any unusual location in that area, such as under the panel.

2. Wiper (Fig. 22, 23)-- This control was found most quickly and accurately when located on the left panel (below and inboard of headlamp switch.) Poorest performance was obtained for locations on pod or stalk.

3. Hazard Switch (Fig. 24)-- This was found most quickly and accurately when it was located in the same place in the test car as in the driver's own car. In cases where the driver had no such switch in their own car, their performance was generally better when the switch was panel-mounted than when it was mounted on the steering column.

4. Radio (Fig. 25)-- Performance in using this control was adversely affected when the radio was located to the left of the steering column.

5. Climate Controls (Fig. 26)-- They were found equally well on the left or right panel, adverse effects resulted when they were located on the console.

6. Vent (Fig. 27)-- This control was located more quickly and accurately when integrated with other climate controls than as a separate ("dedicated") control.

In addition, with both test cars, there were no statistically significant interactions between the location of those controls in the driver's own car (left panel, right panel, or pod/stalk) and the location in the test vehicle. Consequently, further Anacapa work focused on expectancy based on each driver's total experience rather than the control location in their current car.

In the final driver performance study reported in Anacapa Sciences (1976), response times were collected for eight controls and accessories in a full-size American station wagon (1973 Ford LTD) and a foreign-made subcompact (1969 Toyota sedan). The instrument panels in both vehicles were removed and replaced with mockup panels. Thirty different control arrangements were evaluated in the station wagon and 15 in the subcompact. The purpose of this experiment was to assess the ability of drivers to find controls for the first time in unfamiliar vehicles.

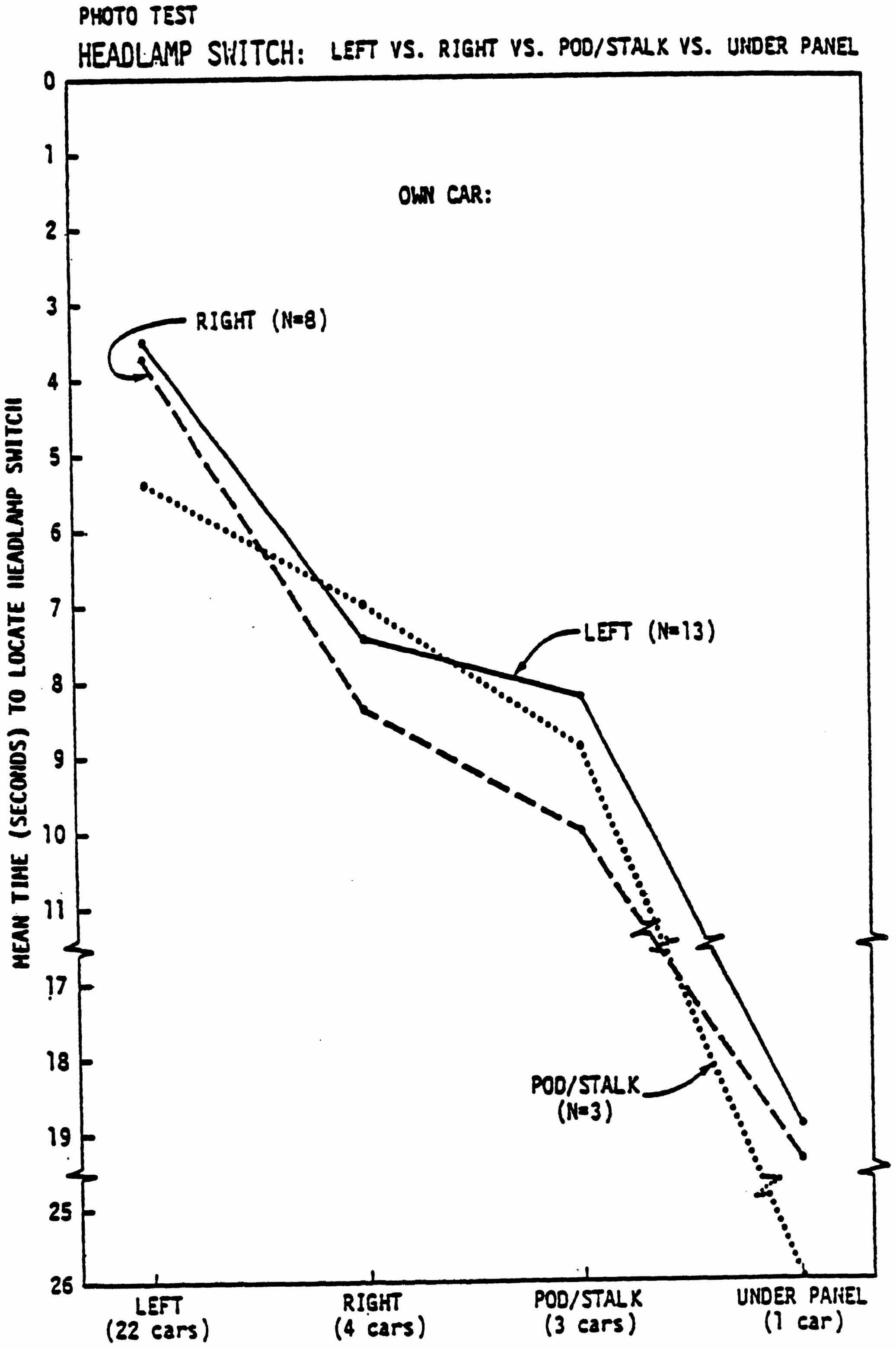
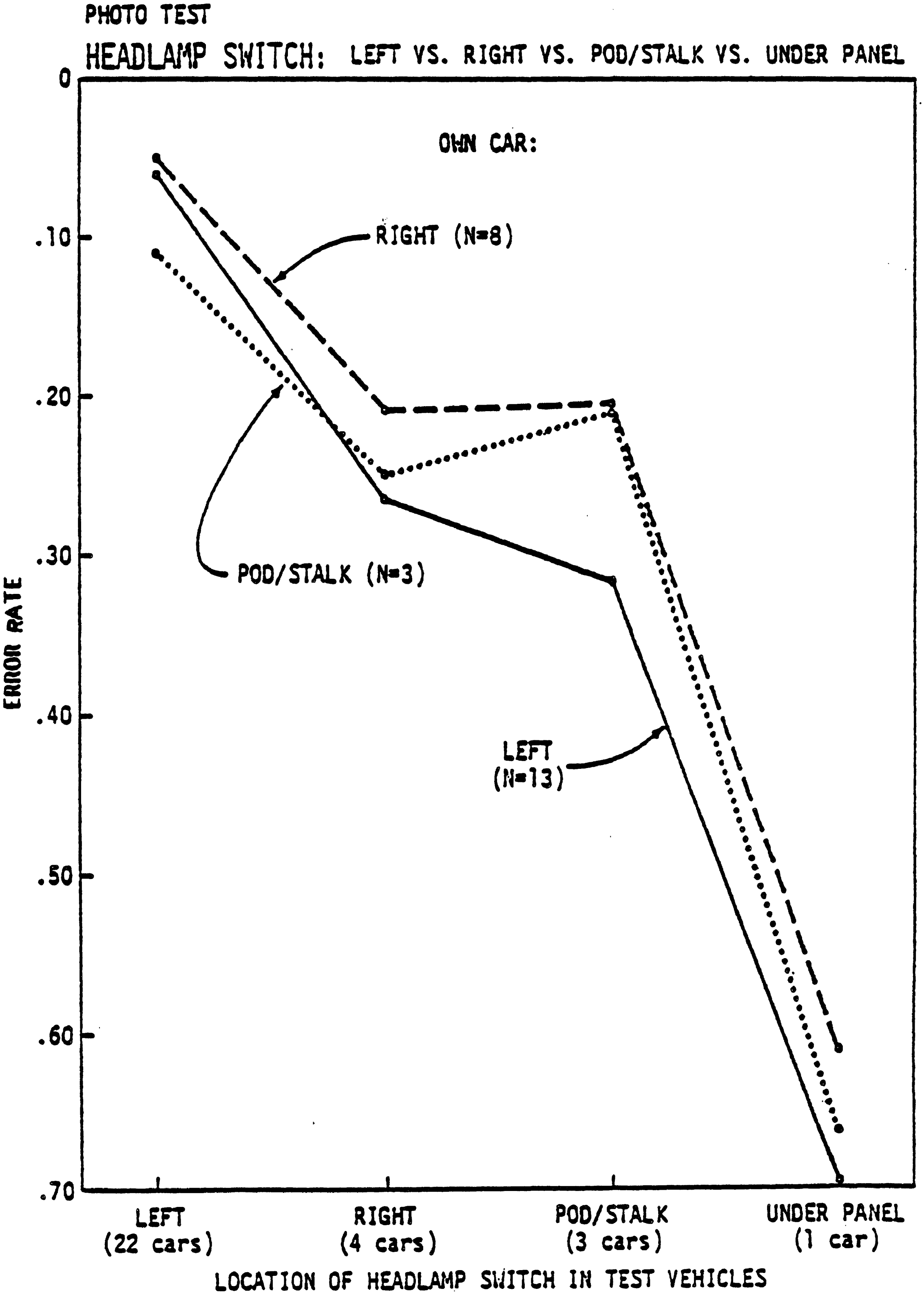


Figure 20, Mean Time to Locate the Headlamp Switch



Source: Anacapa Sciences (1974)

Figure 21, Error Probability for Locating the Headlamp Switch

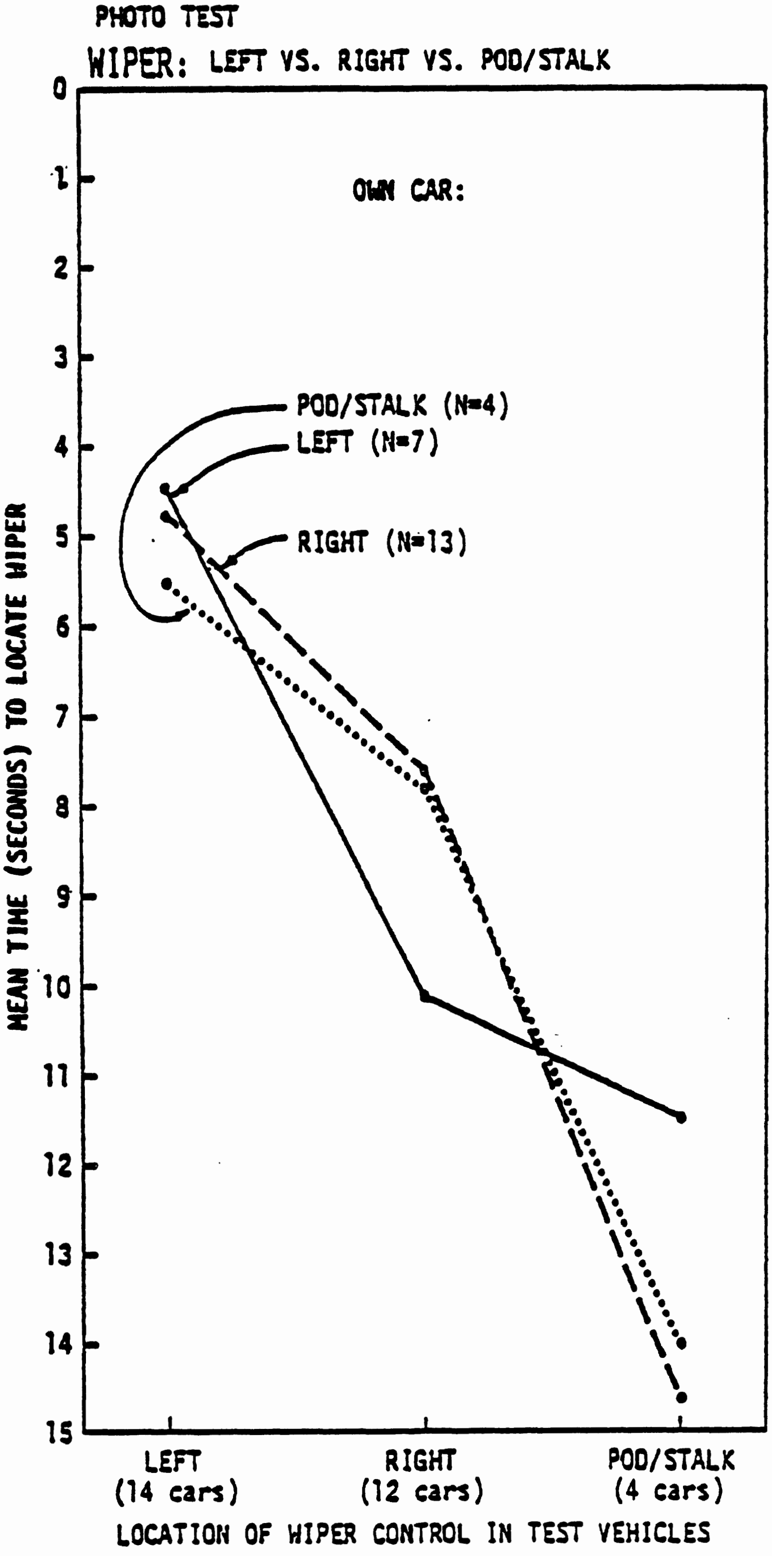
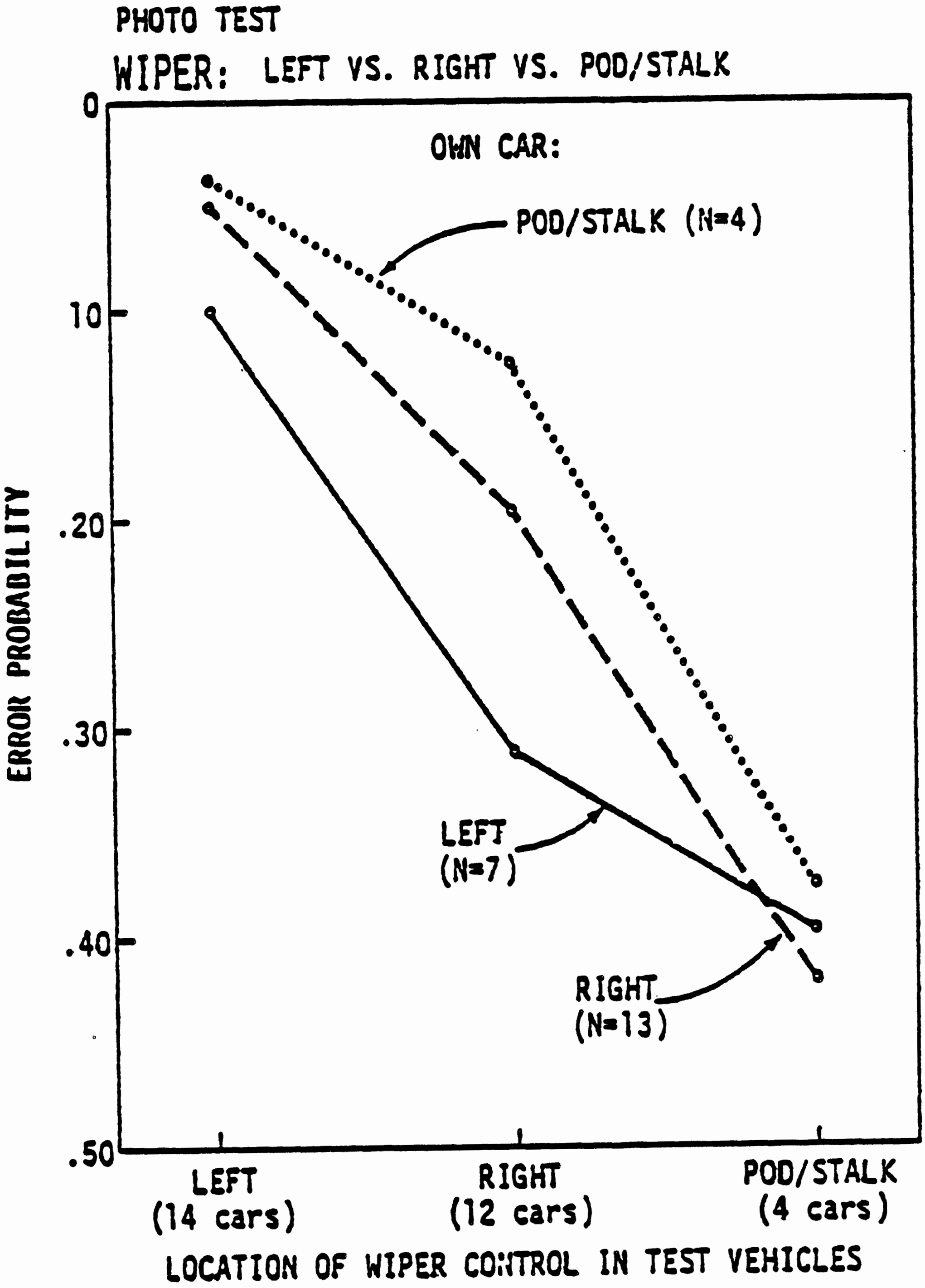
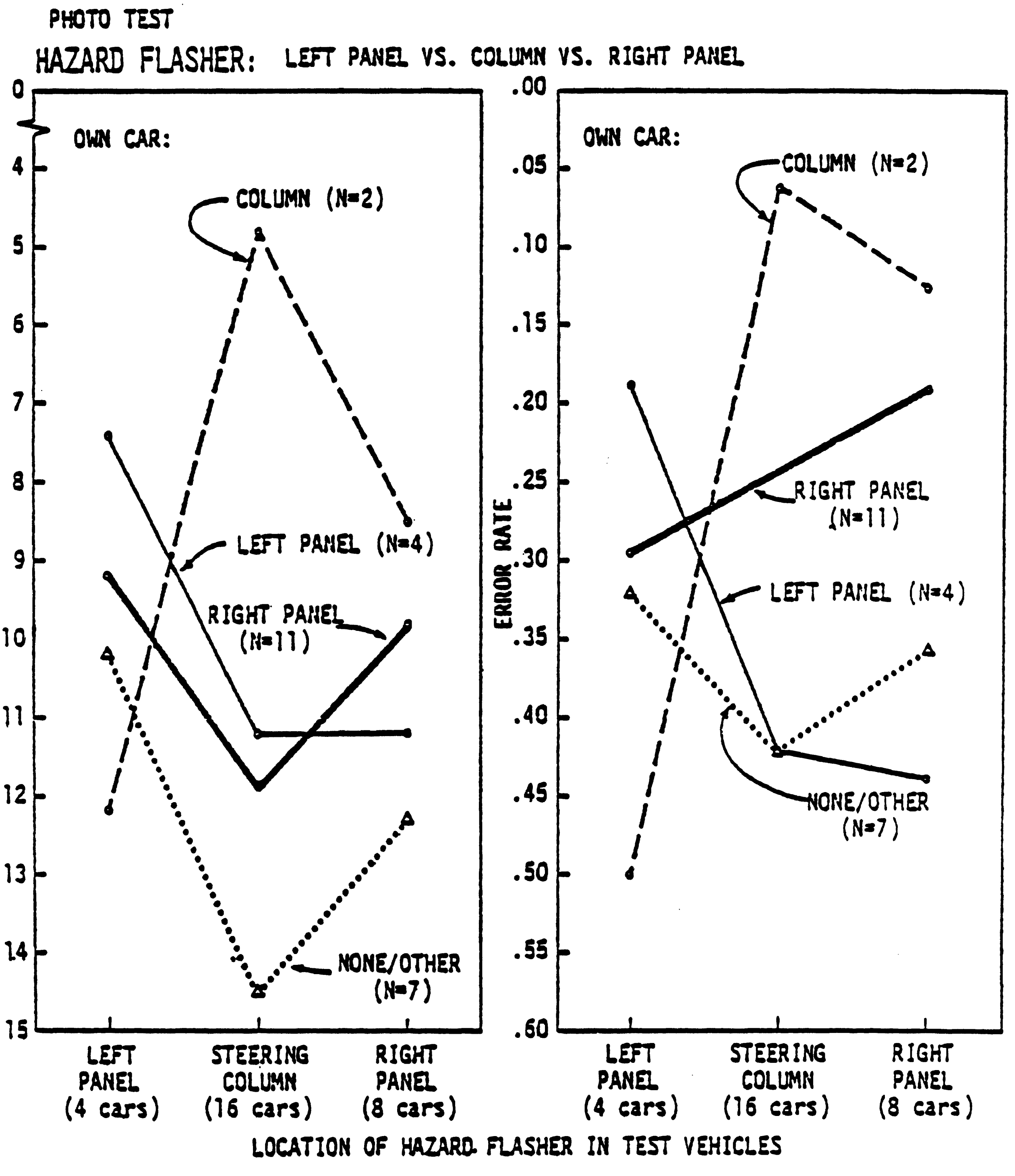


Figure 22, Mean Time to Locate the Wiper Switch



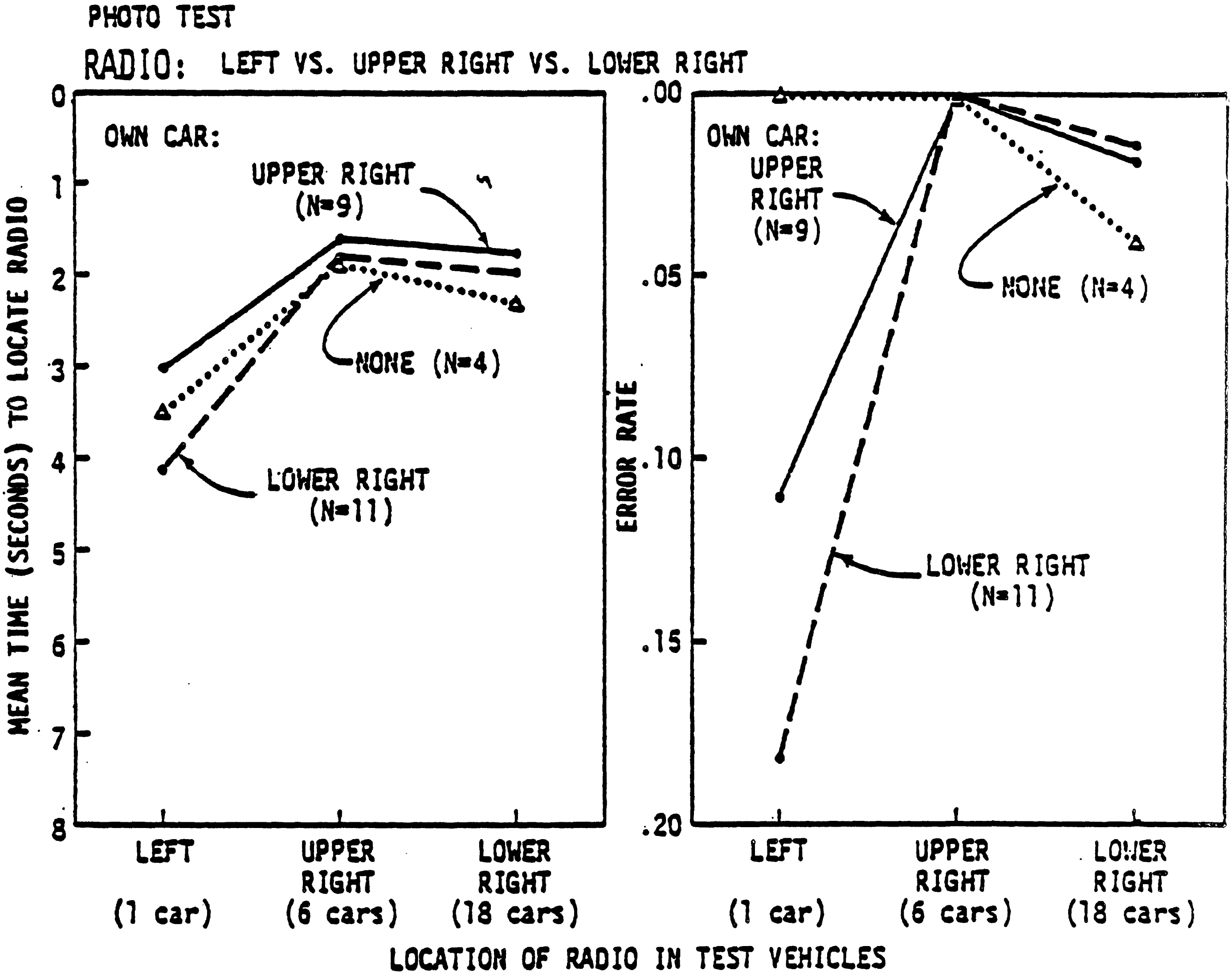
Source: Anacapa Sciences (1974)

Figure 23, Error Probability for Locating the Wiper Switch



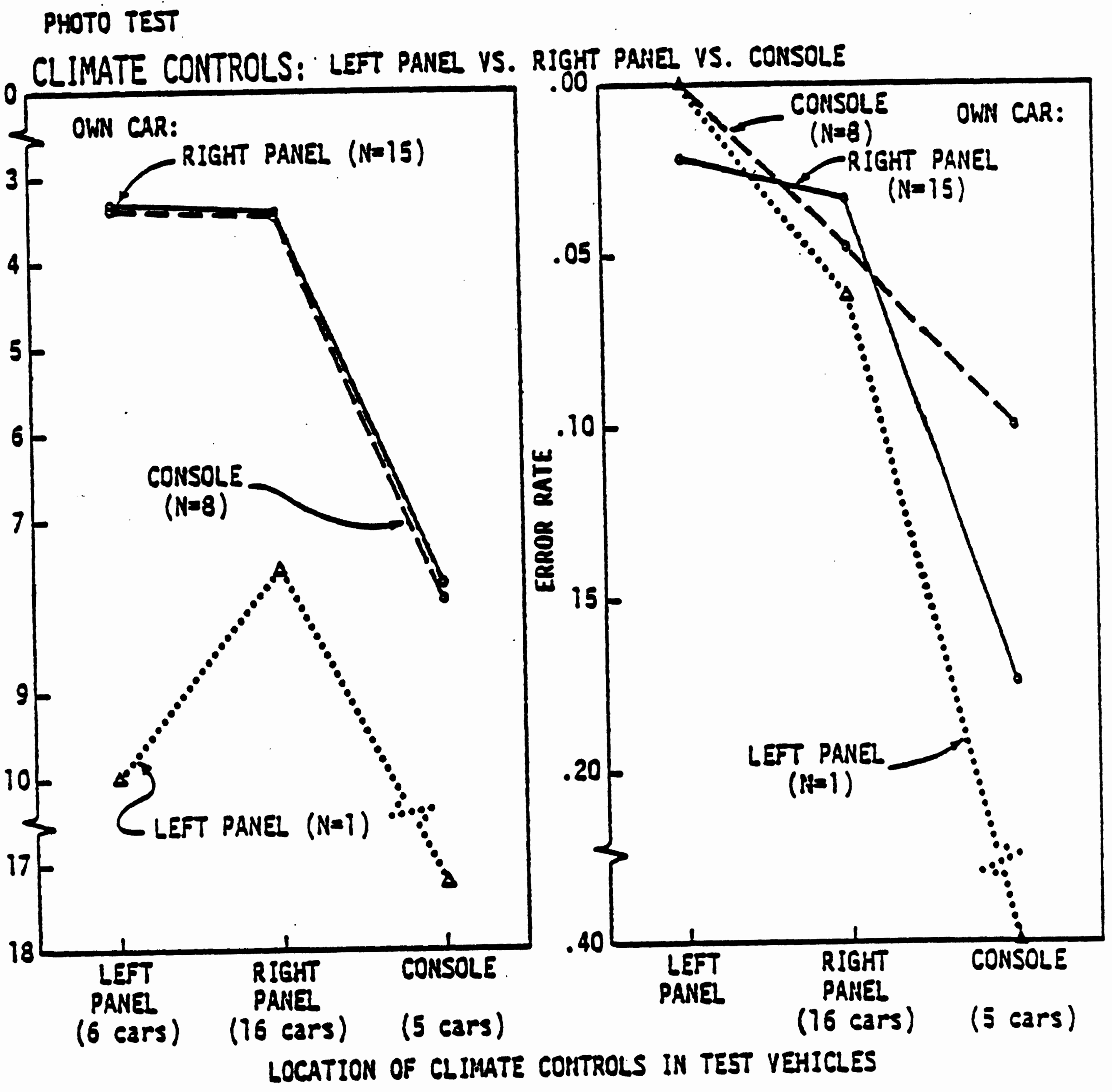
Source: Anacapa Sciences (1974)

Figure 24, Time and Errors for Locating the Hazard Switch



Source: Anacapa Sciences (1974)

Figure 25, Time and Errors for Locating the Radio



Source: Anacapa Sciences (1974)

Figure 26, Time and Errors for Locating the Climate Controls

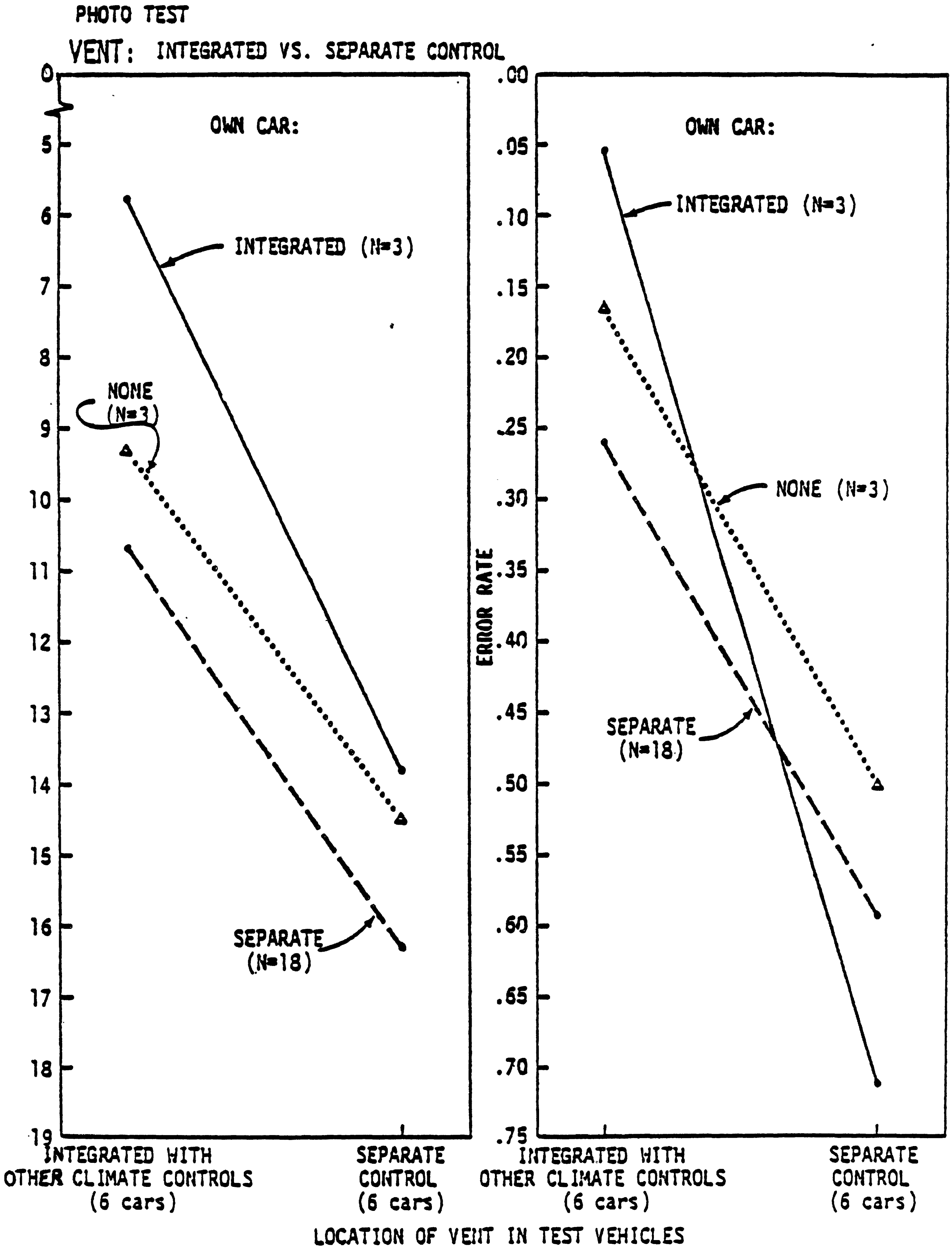


Figure 27, Time and Errors for Locating the Vent

Each of the 2088 U.S. drivers responded exactly twice, once in each car for a different control. The test sequence was fairly straightforward, with each driver's eyes fixated at a distant target while gripping the steering wheel. After naming a control, the experimenter removed a curtain covering the panel and started a clock. The experimenter stopped the clock when the driver touched the proper control. Drivers committing errors were told to continue searching (with timing continued) until the correct control was found or 60 seconds had elapsed. If the time-limit was exceeded, the driver was shown the correct location and next asked to find the ignition switch, to allow the driver to achieve a success before proceeding.

Two important findings emerged:

1. The mean time to correct a control selection error was two seconds. For the vent control, these delays approached seven seconds. It is suspected that these data underestimate the time to correct an error while driving, since in these tests the experimenter instantly notified the driver that he or she had selected the wrong control. Without this aid, it might take the driver significantly longer to recognize and correct the error.

2. The time to locate a control was linearly related to the difference between the actual location of a control and where drivers expect it to be. This is clearly shown in the "discrepancy plots" for the headlights and wiper switches shown in Figures 28 and 29. In Green (1979), these and other data suggested the application of a "five-inch rule" to instrument panel design. "As long as a control is within five inches of where drivers expect it, performance will not suffer (Green, 1979, p.29)." Anacapa Sciences argue for a seven-inch rule. This difference of opinion is due to different interpretations of where the "knee" in the discrepancy plots is located.

Further, a "by-eye" fit of these and other descrepancy plots suggests that the mean time to locate a control increases by about one second for every ten inches a control is from its expected location. This rule does not seem to hold for controls that are not in direct view of the driver, such as when a lighter is inside an ashtray. (See Figure 30.) In that case the time cost is probably three or four times greater.

These analyses show that most of the performance differences are due to uncertainty regarding in which panel section (left, right, console) a particular control will be found. Anacapa therefore argues that controls should be restricted only to an area of the panel, a specification which would be insufficient only in very large cars, where an

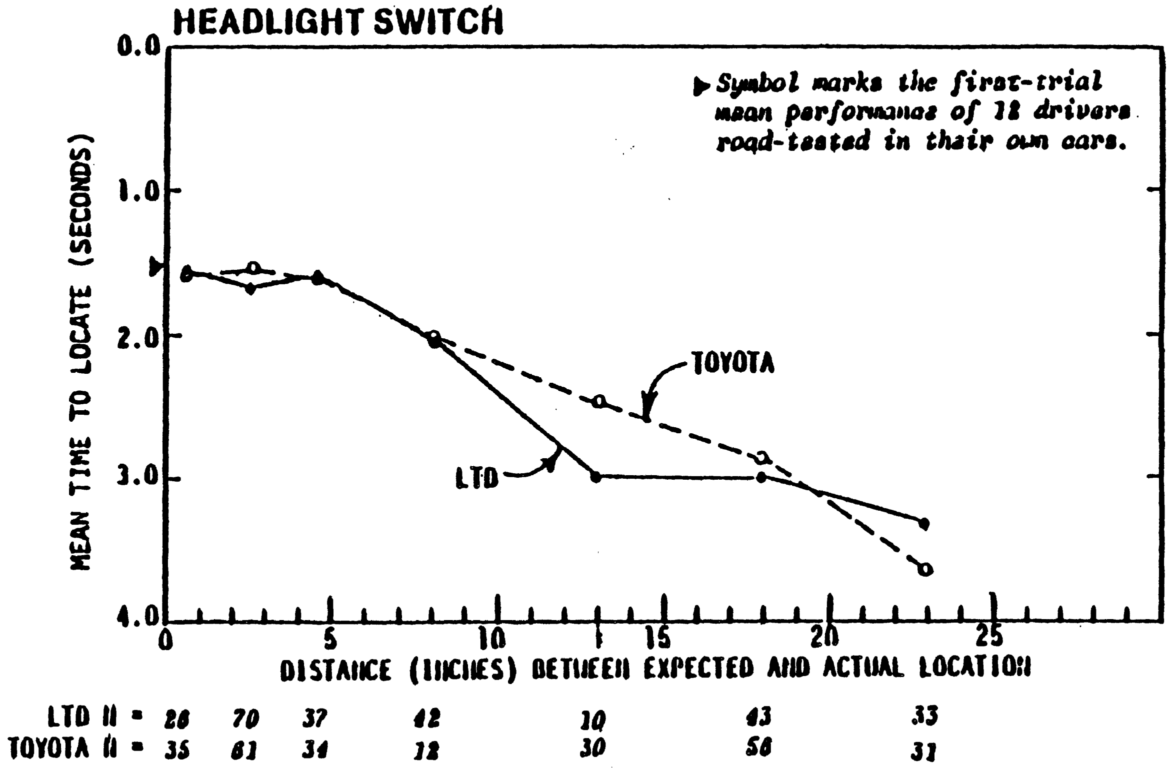


Figure 28, Mean Time to Locate the Headlight Switch as a Function of the Distance between the Expected and Actual Locations. Source: Anacapa Sciences (1976), p. 72.

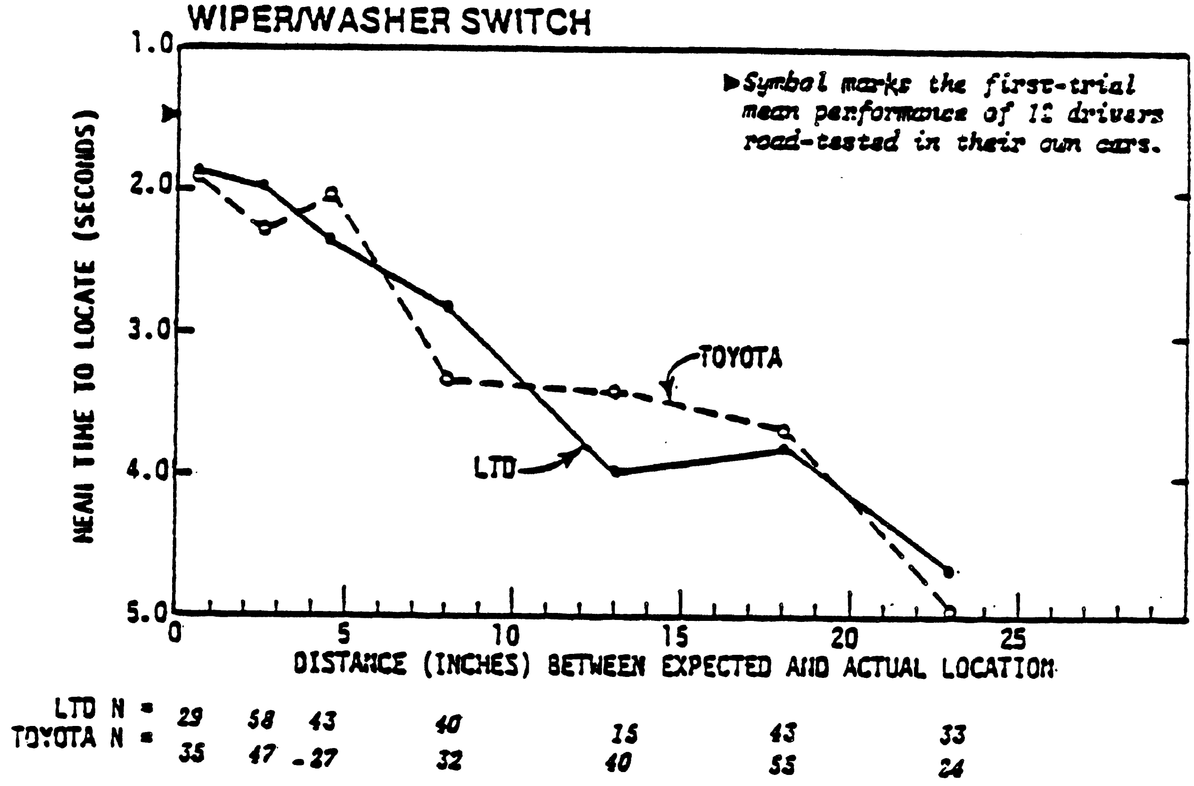


Figure 29, Mean Time to Locate the Wiper/Washer Switch as a Function of the Distance between the Expected and Actual Locations.

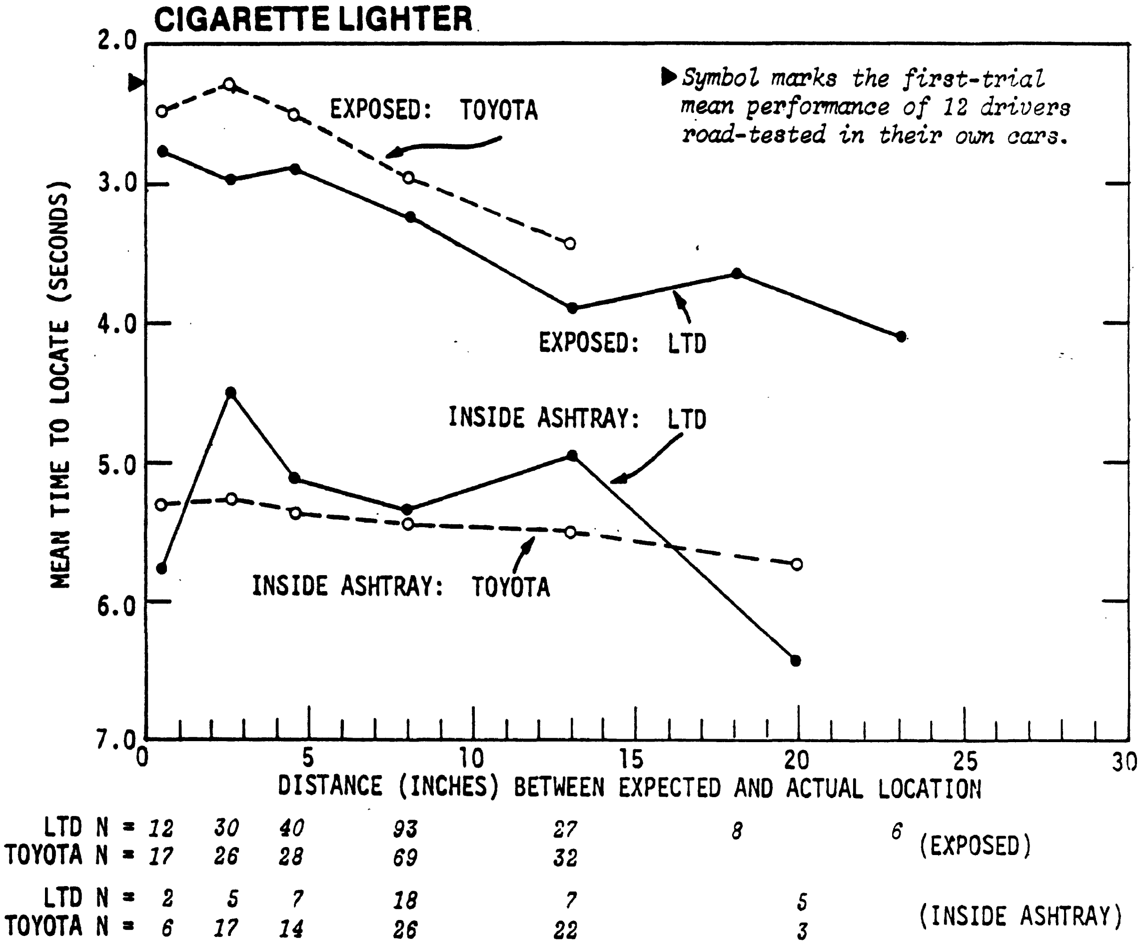


Figure 30, Mean time to locate the cigarette lighter as a function of the distance between the expected and actual locations.

abundance of panel space would facilitate violation of their seven-inch rule. It should be noted that Anacapa Sciences (1976, p. 82) expresses great caution in extending these results to column-mounted controls, as responses from drivers who expected the controls to be column-mounted were markedly different from those of drivers expecting panel-mounted controls. The authors believe, however, that once the expectation for panel- or column-mounting has been established, the "five-inch" rule will apply.

Faust-Adams and Nagel (1975)

In Australia, Faust-Adams and Nagel (1975) had 24 non-drivers reach for six controls in two cars. Each driver responded to each control 30 times in each car. The cars used were a right-hand drive 1972 Holden HQ with panel-mounted controls (representing American models) and a left-hand drive 1971 Mazda Capella RX2 with stalk-mounted controls (representing Japanese models). Response times were measured from when a slide giving the control name was shown until when the control was touched with an electrically conductive glove. The resulting mean response times for each control are shown in Table 26.

Table 26. Response Times From Faust-Adams and Nagel (1975)

	Control					
	Beam Switch	Lights On/Off	Wiper	Horn	Ignition	Handbrk
Holden						
RT (sec.)	1.76	1.63	1.74	1.46	1.68	1.94
Location	floor	on dash far rt.	on dash near rt.	steering wheel spokes	right side column	bet. seat & door
Mazda						
RT (sec.)	1.36	1.67	1.44	1.34	1.61	1.68
Location	near rt. stalk	far rt. stalk	near rt. stalk	ctr of steering wheel	apex of column & dash	bet. seats
Significant Difference	----	----	$p < .01$	$p < .01$	----	$p < .01$

The results of this Australian study favored stalk-mounted controls, as response times for them (beam-switching and wiper) averaged 300 milliseconds less than those which were panel- or floor-mounted. There was no significant difference between the response times for the lights switch (panel vs. far right stalk), because the stalk was one of two mounted on that side of the steering column in the Mazda, creating an awkward reach situation and thus distorting the times for what would otherwise be a more convenient location than the panel. In general, when two stalks are mounted on the same side of the steering column, one will be displaced from the plane of the steering wheel. Since stalk-mounting is intended to reduce movement distance and therefore movement time, mounting two stalks on one side of the column should not be considered in control design since it defeats the advantage of stalk-mounting over column-mounting. It should be noted, however, that this data was obtained from non-drivers. Driving is a skill which requires a fair deal of practice to develop proficiency, and it is questionable whether the response times of non-drivers are particularly relevant.

Kuechenmeister (1975)

Another panel- vs. stalk-mounted control experiment was reported by the Kuechenmeister (1975), in which 32 drivers were divided into two groups. In tests conducted in a 1975 Oldsmobile, one group used the standard Oldsmobile stalk (column-mounted turn signal and dimmer, panel-mounted wiper/washer); the other group used the stalk-mounted controls of a Chevette (turn signal, dimmer, wiper/washer all stalk-mounted) installed in the Oldsmobile. The timing procedure was similar to the verbal-command/stopwatch timing of

Kuechenmeister (1974), with drivers responding to each of 14 commands four times. Drivers also rated the ease of operation of the controls.

Analysis of the results showed statistically significant differences in response times resulting from panel- vs. stalk-mounted control locations, in that panel controls were responded to more rapidly overall and for each of the individual functions, although these differences decreased with practice. (See Figure 31.)

A later retest of subjects with the Chevette stalk design showed an additional improvement in performance, and the overall difference in error rates between the two designs (panel- vs. stalk-mounted) were small. (A statistical analysis of the errors is not presented.) Kuechenmeister (1975) concludes that by the fourth trial, "the differences between the two designs are 1/3 of a second or less and therefore probably not practical differences." The authors of this report disagree. At 55 mph, this translates into an increase in stopping distance of nearly two car lengths, which could well be the deciding factor in many accident situations.

Further support for a difference comes from the rating data. Drivers rated the column-mounted dimmer as easier to operate than the one in their own car (of unspecified design). They also rated the stalk-mounted wiper/washer control as easier to operate than the panel mounted design.

Mourant, Moussa-Hamouda, and Howard (1977)

Mourant, Moussa-Hamouda, and Howard (1977) undertook a laboratory experiment comparing five single left-stalk configurations mounted in a 1967 Chevrolet buck. (See also Mourant, Herman, and Moussa-Hamouda, 1980.) The stalks differed as to how the wiper and washer operated. (See Figure 32.)

Five groups of 16 drivers were tested, each group using only one stalk configuration. Drivers operated the multifunction (stalk-mounted) and instrument panel controls, while simultaneously performing a pursuit tracking (simulated steering) task in response to light signals. Video cameras were used to record where the drivers looked, the drivers' movements, and the tracking task and stimulus commands. (Tracking error was not examined in detail.) Shown in Table 27 is a summary of the results from this experiment.

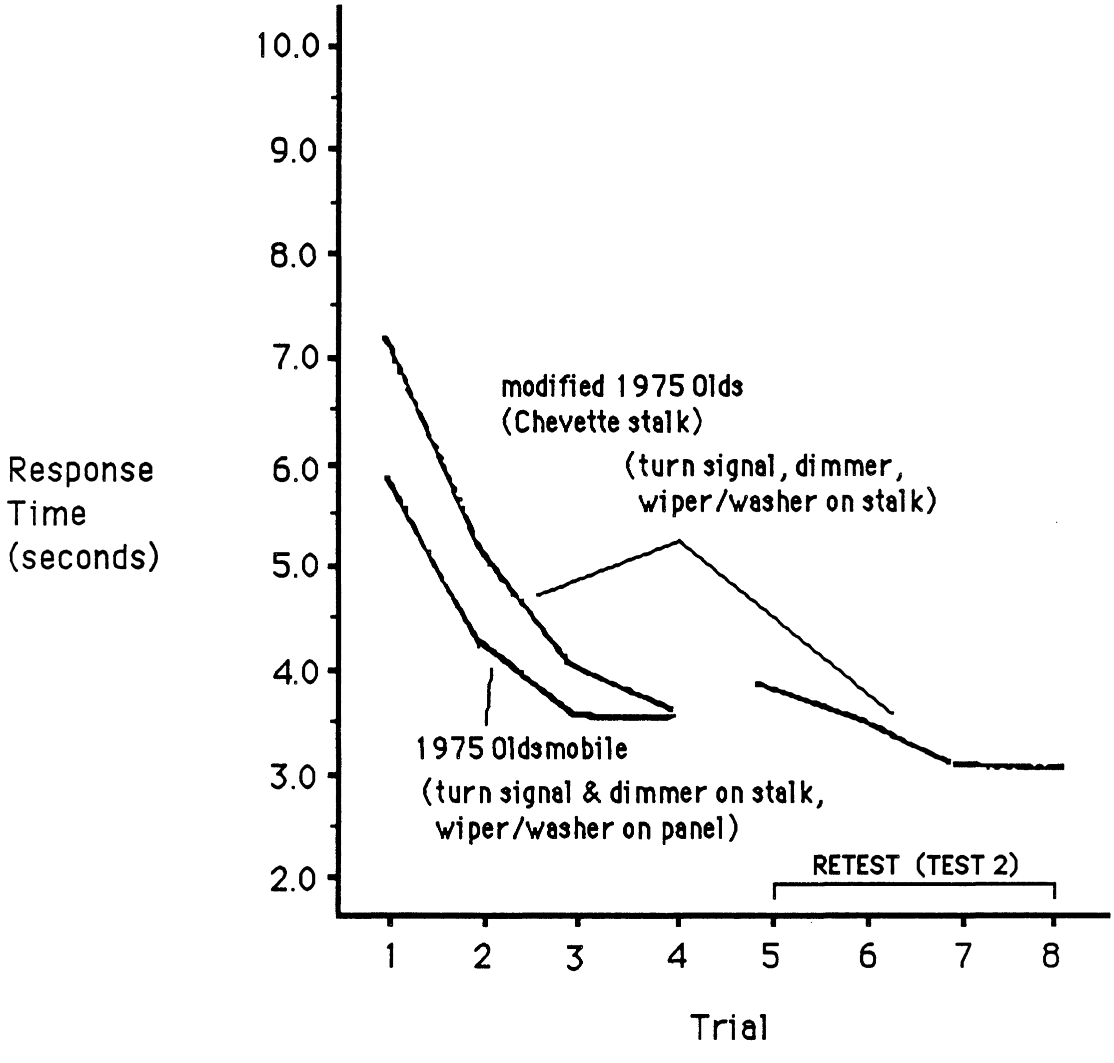


Figure 31.

Mean Response Time for Two Multifunction Stalk Controls Reported by International Standards Organization (1975).

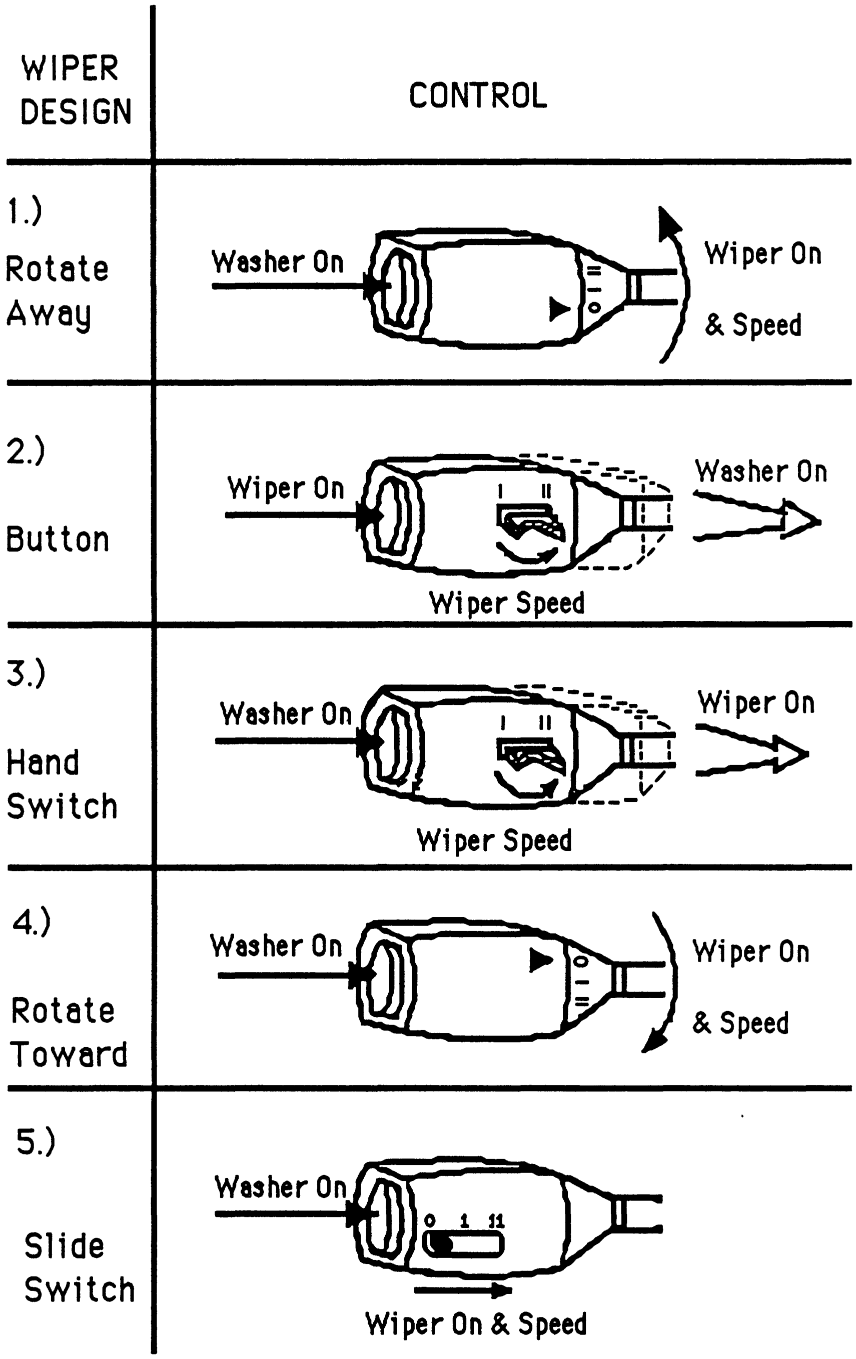


Figure 32. Controls Compared by Mourant et al. (1977).

Table 27. Mean Performance Time and Looks for the Wiper and Washer.

Experimental Group	Total Performance* Time-Wiper (Sec.)	Total Performance Time-Washer (Sec.)	Looks/100 Responses to Wiper	Looks/100 Responses to Washer
Rotate Away	.87	.81	4.5	3.0
Button	1.10	.84	27.5	9.0
Hand Switch	1.10	.99	13.5	12.0
Rotate Toward	.85	.85	6.0	4.0
Slide Switch	1.19	.86	6.5	1.0

Source: Mourant et al. (1977)

* Note: Performance time starts when the driver begins to move to the control and ends when the control has been operated.

Both rotating switches (designs 1 and 4 in Figure 32) had shorter performance times than the slide switch, while the button and hand switch designs were in the middle of the range and not significantly different from the other designs. Most likely, this was due to a genuine design advantage. However, it could reflect a performance tradeoff as tracking error was greater for drivers using rotary switches. The performance differences between wiper control designs were primarily in operation time, not movement time. Except for the poor performance of coaxial switches (e.g., when the wiper is a hand switch, see Fig. 32), there are no performance time differences between washer switch designs.

Comparisons of the direct-look frequency for each stalk configuration showed the same pattern as the performance time. The fewest looks (about 5/100 responses) were required to turn on the wiper with "rotate forward or away" configurations, and the most (18/100 responses) were required for the button configuration. Even larger and more significant differences were found in controlling wiper speed, where 37 looks/100 responses were required for the "button" design. (Speed was controlled with a rocker switch). Furthermore, Table 27 shows the correlation between direct looks and reaction times in all cases except the slide switch. The slide switch had a low direct-look count and yet took a fair amount of time to operate. This indicates that while drivers found the slide switch without difficulty, they had trouble manipulating it.

While the fingertip reach controls were used more often, and consequently their locations were better known to the drivers, this difference results mostly from the need to look while reaching for conventional panel-mounted controls. To repeat, the authors believe that the key factor is that the controls are very close to the steering wheel, not that they are stalk- or panel-mounted. Hence, these data suggest that drivers will also perform well with pod-type controls.

The Mourant et al. study is the only experiment in the literature to record all three aspects of response time for each control: reaction time, movement time, and operation time. It is unfortunate the reaction time data were not reported. Decomposition of these data offer some insight into why differences occurred. As Mourant et al. point out, "...regardless of the type of switch used to control wiper on/off and speed, drivers took about the same amount of time to move their hand from the steering wheel to touch the control" (p. 48). But, there was a slight tendency for controls requiring a more precise grip to take longer to move to, such as a hand switch. (See Figure 33.) This is exactly what a predetermined time system (such as MTM-1) would predict. Furthermore, precise grasps may require a small positioning motion (which is part of the movement time) in addition to the reach to align the hand with the object to be grasped.

For stalk controls, just over about half of the "performance time" is spent moving towards the control. The rest is spent operating it. However, for instrument panel controls with total performance times of 1.2 to 1.3 seconds, about 2/3 to 3/4 is movement time. This decomposition analysis suggests that a performance model similar to that proposed by Green, 1979 (and discussed in the literature review section of this report) could be used to predict driver performance.

To summarize the Mourant et al. research; in general, rotary stalk controls are preferable to other types, especially coaxially-mounted handswitch and button combinations. The data, with respect to performance times, also indicate that about 50% of the time required to use a fingertip control is spent moving towards it.

Elsholz and Bortfeld (1978)

A European study by Elsholz and Bortfeld (1978) asked five groups of 30 German drivers to operate the controls of an Audi 100LS, BMW 728, Citroen CX2000, Peugeot 604SL, or Renault 30TS. They recorded the number and type of errors made, and their results are contained in Table 28.

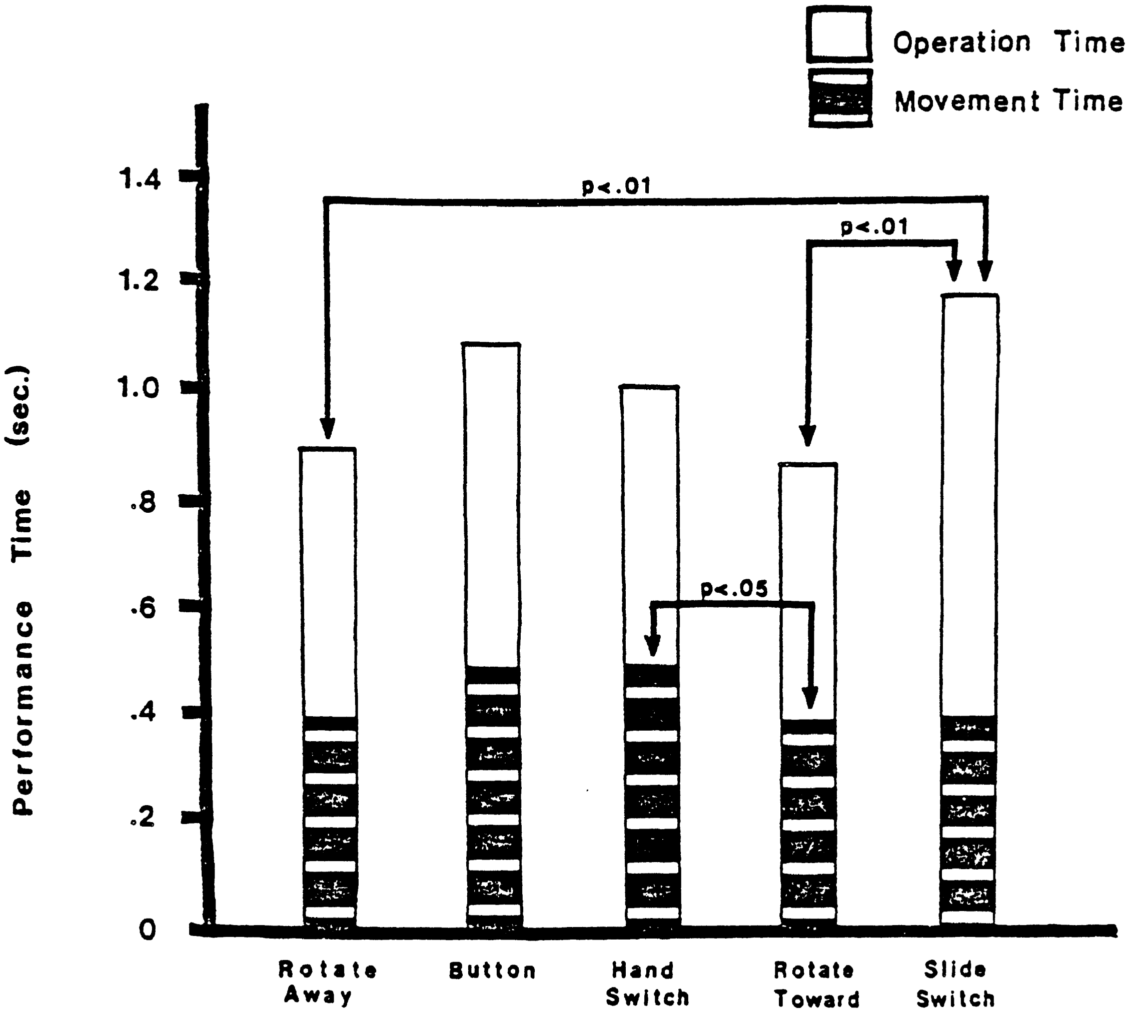


Figure 33, Performance time for the wiper (on/off and speed).

Table 28, **Control Use Errors Reported by Elsholz & Bortfeld (1978).**

Function	Control	Location	To Operate	% Unable to Locate	% Wrong Direction to Operate	% Wrong Direction to Control Intensity
Windshield Wiper	Stalk	Column: Right	Up	10	7	13
		Column: Right	Out	30	80	80
		Panel: Left		70	13	27
		Column: Left	In	63	77	77
		Column: Right	Up	7	10	63
Windshield Washer	Stalk	Column: Right	Right	10	20	23
				27	27	27
				3	13	13
		Column: Left	Up	53	83	83
		Panel: Left	Right	70	43	47
Horn	Stalk	Column: Right	Right	83	47	47
	Touch	Column: Control	Left	0	0	0
				13	0	0
				0	0	0
		Panel: Left	In	77	3	3
Turn Signal	Stalk	Column: Left	Up/Down	20	0	0
				17	0	0
				3	0	0
		Column: Right		37	0	0
	Rocker	Panel: Left		27	0	3
Parking Light	Stalk	Stalk: Left	Up	57	10	17
			Right	53	77	77
		Panel: Right	Out	73	3	10
		Panel: Left	Up	47	7	23
	Rocker			60	0	10
Headlights On/Off	Stalk	Column: Left	Up/Down	43	3	23
			Down	17	80	90
		Panel: Right	Out	73	3	10
		Panel: Left	Up	43	7	17
	Rocker			60	0	13
High Beam	Stalk	Column: Left	Left	39	46	68
				10	14	31
				17	83	93
				30	20	70
	Touch	Panel: Right	Down	67	0	0
Front Fog Light	Stalk	Panel: Right	Up	70	17	47
	Rocker	Panel: Left	Out	43	0	7
Rear Fog Light	Stalk	Panel: Right	Up	70	27	57
	Rocker	Panel: Left		63	0	50
Hazard Flasher	Stalk	Column: Left	Up	77	20	37
	Rocker	Panel: Right		77	0	40
				77	0	30
				57	0	3
				83	0	0
Parking Light	Stalk	Column: Left	Up/Down	27	0	0
	Rocker	Column: Center		90	0	0

Green (1979, p. 47) arrived at several conclusions concerning the Elsholz and Bortfeld (1978) study, and these are as follows:

1. For the windshield wiper, there were problems with right-side stalk controls that twisted or moved towards or away from the driver, but not those which moved up or down.

2. Neither a left-side stalk (push away = on) nor a left-panel control (up = on) were stereotypical modes of operation for the windshield washer.

3. Drivers had difficulty with stalk-mounted horn controls but not with "touch controls" mounted on the steering wheel.

4. Drivers had difficulty locating turn signals not operated by a left-side lever.

5. Drivers did not fully understand the control type/direction combinations used to activate the parking lights.

6. None of the headlight controls tested (left stalk - push up/down; instrument panel stalk control, right side - pull toward the driver, or left side - push up; rocker switch on the left side of the instrument panel) were easily located by drivers.

7. Similar difficulty was experienced with the high-beam controls (left stalk control - moves left or right; touch control on right side of instrument panel - push up).

8. For the front and rear fog lights, neither a stalk control nor a rocker switch was easily located by subjects. Separate control of fog lights were not fitted on most cars, particularly American vehicles, at that time.

9. Drivers experienced difficulties operating any of the five possible hazard controls (left-side stalk control - push left; rocker switch on right side of instrument panel - push down; touch control in same place - push left; left-side panel-mounted push button - push right).

10. Drivers had some difficulty locating the parking light control when it was mounted on a stalk (left side - push up or down), while a rocker switch (on steering wheel - push right side forward) was extremely difficult to locate.

The Elsholz and Bortfeld study offers many insights into the design and location of controls, and while the sample size is small and the description of procedure deficient, this report contains much relevant information in the area of automotive controls. The title and the emphasis of the body of the report on control symbols and labelling have caused many to miss the excellent research on controls it contains.

Haller, Bouis, and Heintz (1981)

This study (see also Bouis, Haller, and Heintz, 1981; Heintz, Haller, and Bouis, 1982) examines how a tripcomputer keyboard should be designed to minimize how much its use distracts drivers from looking at the road.

The description of this research is very incomplete and unclear. Apparently two keyboard designs were examined, one resembling a telephone keyboard (3x4 array of buttons with 1, 2, 3 across the top) and another referred to as a "sequence" keyboard. The sequence keyboard consisted of a top row of 4 buttons and a bottom row of two (labelled "res," "ent"). The buttons were arranged so those on the top row were under the fingers of the right hand. Four subjects, whose backgrounds were unspecified, either entered an unknown number of sequences of three- or four-digit numbers, or were selected a tripcomputer function.

For the telephone keyboard, each of the keys on the keyboard was for one of the tripcomputer functions. Digit entry followed the expected pattern. (To enter 21, push key "2," then key "1.")

To select a tripcomputer function using the sequence keyboard, the row and column of the function in an array of function names were entered. (So pressing the second button from the right might select row 2 and the third button might select column 3. Numbers were probably entered by pressing the key for the corresponding power of 10. So to enter 21, the first key on the far right (10 to the zero power) might be pressed once and the second key from the right (10 to the first power) twice.

The data were collected in a driving simulator and in an unspecified test car. The location of the keyboard and display in the vehicle were varied across test conditions. Eye fixations, tracking errors, and the time to enter each item were recorded. In general, data entry times for the sequence keyboard were longer than those for the telephone keyboard (for three-digit numbers), but the mean fixation duration and steering error were less. No statistical tests are provided. Based on their research, they indicate the sequence keyboard is preferable to the telephone keyboard. Because there is so much missing from this paper, it's difficult to know what to believe.

McCallum, Dick, and Casey (1982)

McCallum et al. summarize work carried out by Anacapa Sciences for Ford to evaluate steering-wheel mounted controls.

A Ford Thunderbird (probably an '81 or '82 model) was equipped with a prototype four-spoke steering wheel similar in shape to the production steering wheel. It had the standard cruise controls (on/off on the lower left spoke, resume/accelerate on the lower right). It was also fitted with two sets of three buttons on the upper spokes (left turn, right turn, headlight dimmer) and a row of five small buttons on the face of the hub (headlight on/off, wiper on/rate, wiper off, washer on/off).

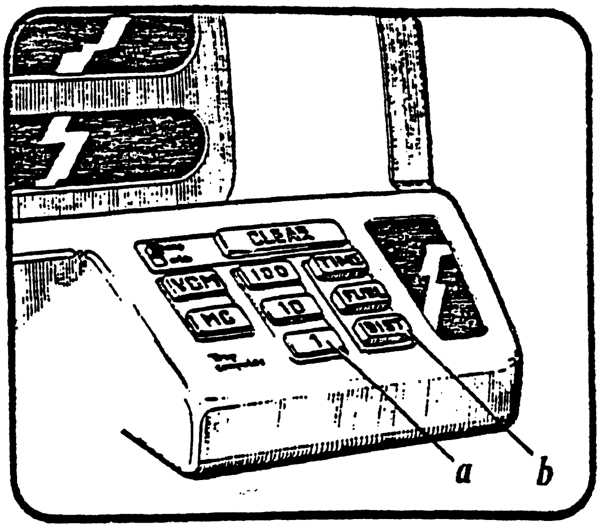
Each of 30 luxury car owners drove that car and a matched conventional car for an hour and a half. While doing so, response times and errors for using the controls were obtained, as well as driver opinions of the prototype. Unfortunately, the Anacapa report provides no quantitative data from the driver performance experiments, which makes detailed discussion difficult. It may be that work was more completely described in a previous report, but a specific reference for one is not given.

The report concluded that response times for using the turn signals and headlight dimmer were greater than those for the conventional car, and that more errors were made operating turn signals in the prototype vehicle than in the conventional car. Furthermore, drivers preferred the conventional approach of placing such controls in a stationary location, and favored push-button controls mounted within fingertip reach of the steering wheel. McCallum et al. recommend that a stalk control should be used for the turn signals and that controls should generally not be mounted on a moving surface.

Galer, Spicer, Geyer, and Holtum (1983)

Galer et al. (1983) describes the design and evaluation of a trip computer and vehicle condition display for Jaguar. While the details of the research are confidential, her paper does give some insight into what was done. Her evaluation of the trip computer examined the keyboard layout, the messages displayed, and the dialogue logic. The trip computer was mounted in a driving simulator. The keyboard, mounted just to the right of the steering wheel, is shown in Figure 34.

One hundred drivers were tested either using the trip computer alone, or with the vehicle condition display. While steering, drivers were asked to use the trip computer to answer questions, for example, "How far have we gone?" As shown in Table 29, use of the trip computer often required multiple button presses to retrieve the information desired. Also, from time to time a warning message from the vehicle condition monitor appeared on the display. A computer recorded the keys pressed while an observer recorded the keyboard use strategy.



Trip Computer Keyboard.

Figure 34, Jaguar Trip Computer

Table 29. Trip Computer Logic from Galer et al. (1983)

Button	Press #	Message		
		Test 1	Test 2	Test 3
DIST	first	DIST TRAV	DIST TRAV	DIST EMPTY
DIST	second	FUEL FOR	DIST TO GO	DIST TRAV
DIST	third	DIST TO GO	RANGE	DIST TO GO
FUEL	first	INST FUEL	FUEL USED	AV FUEL
FUEL	second	AV FUEL	INST FUEL	FUEL USED
FUEL	third	FUEL USED	AV FUEL	INST FUEL
TIME	first	TIME TAKEN	TIME TAKEN	AV SPEED
TIME	second	ARRIVAL	ARRIVAL	TIME TAKEN
TIME	third	AV SPEED	AV SPEED	TIME TO GO

The button-press error rate was about 10% under "stress" conditions (unexplained in the paper). More errors were made in responding to "multi-concept" functions such as "distance on remaining fuel" and "average speed". Error rates for the individual function, button-press times, and steering error data do not appear in her paper.

Performance apparently depended upon the strategy for obtaining information. Two strategies were used: (1) entering the required number of keypresses and then reading the display, and (2) pressing a key, reading the display, and then repeating until the desired information was obtained. Many drivers started with the second strategy but moved to the first with practice. The number of trials at which this occurred is not given.

Khadilkar (1983)

This study, commonly know as the Minicars study (after the performing organization), was carried out under contract to the U.S. Department of Transportation. (See Friedman and Schmitz for a description of the initial phase of this work.) According to Khadilkar, the objective of this study was, "...to provide NHTSA with an objective, thorough assessment...[which] can then permit NHTSA to make a rational judgment of the most reasonable approach to standardization" (p. 1-2). The study ran over budget and was never completed.

A final report was submitted but it was never approved by NHTSA. The copy of the report summarized here was received by the authors from the Chrysler Corporation. The report is not well written (filled with bureaucratese, hard to follow, messy figures, tables of hard-to-read computer printouts, etc.), the experiments flawed (the orders in which controls were tested were not properly randomized), and the analysis is incomplete (for example, no statistical tests are given). However, this report describes one of the few driver performance experiments conducted in recent years. Furthermore, because it is also difficult to obtain, it is described in somewhat greater detail than the other studies reviewed here.

Khadilkar collected data on where controls were located and how they operated in 1980 model-year cars, developed a human factors procedure for analyzing control designs, and carried out several small driver performance experiments.

The driver performance work involved four test conditions in which 20, 7, 7, and 11 drivers participated. Only two subjects participated in all four conditions making comparison across conditions difficult. The conditions can be grouped into two pairs. In one pair drivers were cued by a video monitor to operate controls. A computer recorded the times to reach for and operate controls, as well as something Khadilkar calls "release time." Also, where drivers looked was recorded (using a video camera facing the driver), so eyes-off-the-road time could be determined.

In the second pair of conditions, drivers concurrently performed a simulated steering task that required them to keep a randomly moving cursor on a hood-mounted computer display between two vertical lines. The condition involving steering followed the condition in which steering was not required.

In each pair of test conditions, two cars were used, a 1980 Chevrolet Citation and a 1980 Dodge Colt. They were selected because of the commonality of their controls with then current ('83) cars. (The Citation was conventionally configured for a post-1978 car, while the Colt had a sliding wiper switch, headlight controls on a stalk, and two hub-mounted horn buttons.)

Each test sequence consisted of 33 trials, one practice trial of turning on the ignition, and then four groups of eight trials involving alternating sequences of turning on, and then turning off, seven controls (headlights, radio, wipers, high beam, hazard, turn signal, heater). One fixed, partially random sequence was used for all four tests, and further, subjects were always tested in the Citation first.

Their conclusions are reproduced word for word as they appeared in the original report (p 5-46).

1. "Most subjects reached assymptotic performance level by the third and fourth trial" [sic].

2. The Citation (with the turn signal, wiper/washer, and dimmer on the same stalk) "was found to be confusing by some of the test subjects."

3. "Several test subjects had problem locating and operating hazard light" [sic].

4. In general, stalk-mounted controls were "touched quicker" than instrument panel-mounted controls because they are closer to the driver.

4. The horn was the easiest control to use.

5. "Most test subjects managed simulated driving task and control operation without major difficulty. However, the reaction time performance, in general did not show a nice assymptotic curve when tracking task was included. The reaction time measure recorded was certainly influenced by the load of the driving task" [sic].

6. Subjects spent more time looking away from the road (and presumably at the controls) when the tracking task was not included.

As noted previously, the data analysis is incomplete. In particular this is true for the eyes-off-the-road data (where times for each driver but not each control are provided) and for time-off-the-road and "crashes," (their steering performance measures) where again only subject totals are given.

Since the raw response times are given in an appendix to the Khadilkar report and those differences are of particular interest, mean times were computed. They appear in Table 30.

There isn't an obvious overall difference in times between the single task and time sharing conditions, which is somewhat of a surprise. There were however, major differences between the three phases of control use. The time to touch the control was the longest, followed by operating it, which in turn was followed by release time. Based on the Mourant et al. data, one is lead to believe that touching time was reaction time plus movement time. Finally, with regards to differences between controls designs, it is clear that touch times were indeed brief for stalk controls (at least the turn signal), and that drivers had problems operating the horn.

Table 30. Mean Response Times Computed from Data in Khadilkar (1983)

	------ Citation -----			------- Colt --------		
Control	Touch	Operate	Release	Touch	Operate	Release
One Task						
Headlights	2.46	.81	.60	2.48	.40	.54
Wiper	2.46	1.01	1.41	3.68*	1.61	.37
Hi/Lo Beam	2.50	.75	.68	2.55	.77	.48
Hazard	NA	3.50	NA	NA	2.79	NA
Horn	NA	1.89	NA	NA	1.89	NA
Turn Signal	1.72	1.76	1.19	1.97	.49	.78
Heater	2.53	.67	.95	4.83	.54	.37
Time-Sharing						
Headlights	2.48	.53	.56	2.83	.56	.44
Wiper	2.04	.73	.69	3.02	1.51	.39
Hi/Lo Beam	1.94	.58	.53	2.19	1.27	.41
Hazard	NA	3.66	NA	NA	3.16	NA
Horn	NA	1.89	NA	NA	2.47	NA
Turn Signal	1.96	2.30	.93	1.87	.73	.86
Heater	3.81	1.01	.86	3.40	1.44	.55

*=significantly fewer data points used to compute mean due to missing data
NA=Not Available in original data

Heintz, Bouis, and Haller (1985)

This SAE paper describes the evaluation of a general purpose information system designed to integrate the functions of the radio, cassette tape unit, tripcomputer, telephone, navigation system, climate control, and other components into a single unit. This particular study only concerns the first four functions. Heintz et al. argue that since each of these components is designed independently, the user interface tends to be inconsistent and causes problems for drivers.

Their information system user interface consisted of seven keys and presumably, a display, used to access a three level hierarchical menu system. Five were softkeys for item selection within a level, two were used to go up or down a level. A sample piece of the menu system is shown in Figure 35.

Two experiments were carried out to improve its design, both of which took place using an unspecified driving simulator. Both followed the same general format and used the same six subjects. A computer recorded both eye movements (via an electrooculogram) to determine eyes-off-the-road time and steering errors. While driving, subjects were given verbal instructions to select information system functions, for example, "Please switch the radio to station 3." Subjects were free to use either the information system to carry out the task, or conventional instrument panel controls from an unknown car. Both were present. The location of the information system and details concerning its design are not given.

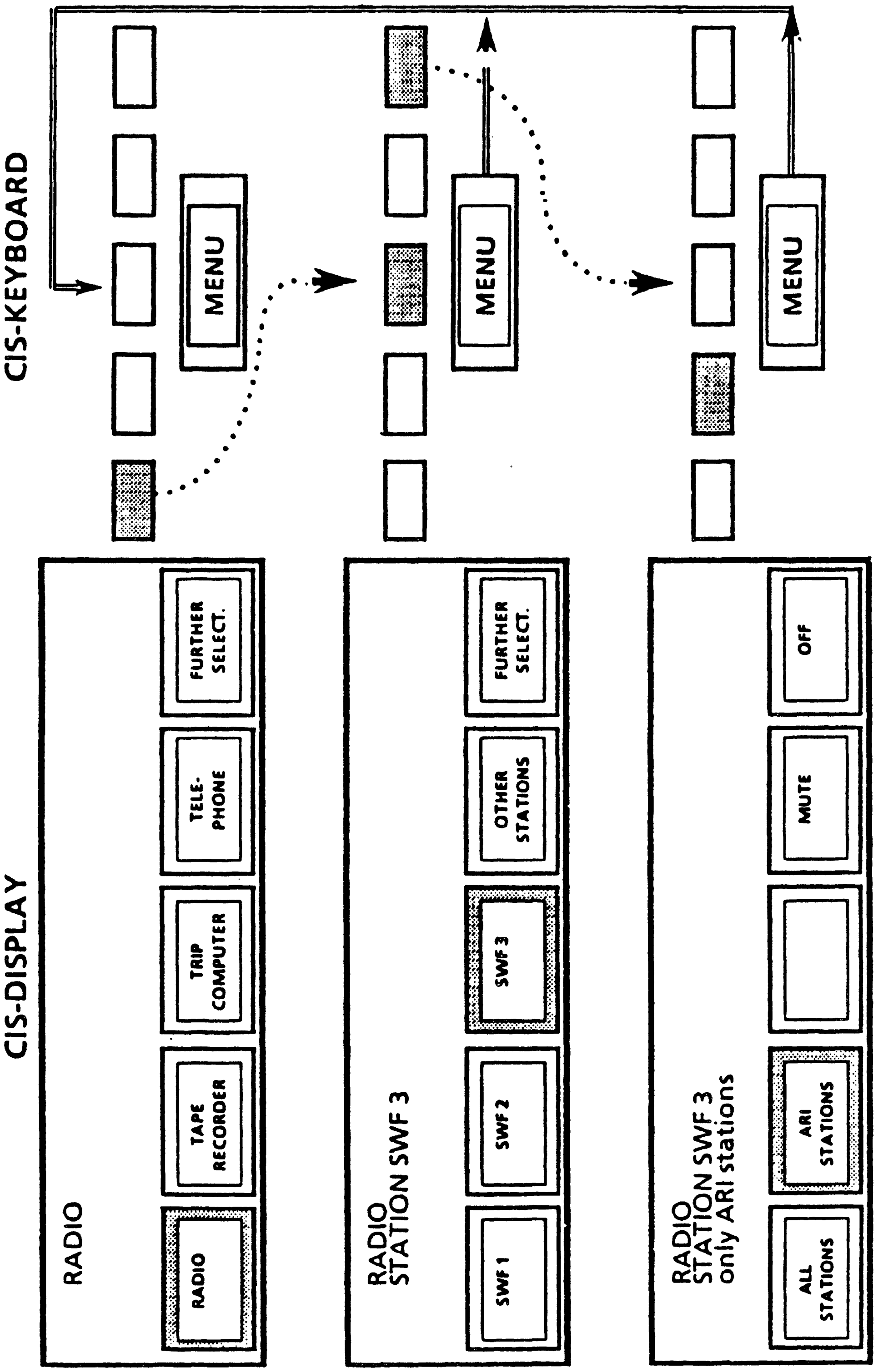
The first experiment compared a two- with a three-level menu system. The Heintz et al. paper does not state how often subjects were asked to respond. Shown in Figures 36 and 37 are the results from that study.

In the three-level version subjects chose to use the information system just as often as the dedicated controls, though use of the computerized system was more likely to lead to a correct response. In the two-level version, subjects typically were twice as likely to select the information system as conventional controls, though that ratio varied with the function selected. The ratio of correct to incorrect responses for the two conditions involving conventional controls were similar, suggesting the data are consistent. Other data (on eye fixations, steering errors) are not given in this paper.

A second experiment examined the effect of the number of choices for a menu. Three versions were developed (4, 8, and 10 softkeys, all of which also had one dedicated key for changing menu levels). Heintz et al. claim that these differences (for an unknown number of subjects) "was not a critical factor" based upon the average duration of eye fixations. Other variables are not discussed.

Heintz et al. also compare total fixation durations for conventional controls with the information system display near the tachometer (a central location) and the keyboard on the console to the right of the steering wheel. Total look durations were six seconds per selection for conventional controls and three seconds per selection for the information system. It is not clear which conditions were being compared.

Finally, Heintz et al. describe another condition in which the display was not centrally located. That change added about 300 milliseconds to each selection. Again, other data are not provided.



Menu-Version 2 of the CIS; ***Example Radio***

Figure 35, Menu System in Heintz et al.

Thus, the Heintz, Bouis, and Haller (1985) paper argues for using nondedicated controls. However, the description of the work is very sketchy. It is not known how many subjects participated, how many responses were collected in each condition, what exactly the conditions were, what the control/display unit looked like. This is unfortunate since there is considerable interest in providing such systems in future vehicles but little information on how easy they will be for drivers to use.

Jack (1985)

Another performance study is Jack (1985), which examined how orientation, labelling, and tactile coding of rocker switches influenced how likely drivers were to move them in various directions to turn features on and off. This research is typical of the kind of specific data one finds in the general human factors literature (e.g., Loveless, 1962), especially on direction-of-motion stereotypes. Most of that literature concerns knobs and levers.

In the first experiment 20 people were chosen at random as they walked by the Ford Automotive Safety Office. An unlabeled rocker switch with both a bump (bulge) and a dimple (indentation) on the face was mounted in seven locations around the driver's seat of a current model car. Direction-of-motion stereotypes were obtained by asking drivers to operate the switch in a certain manner (i.e., "Turn this switch *on.*") Performance times were not recorded. Each person responded to 36 such requests in a random order (9 function/location combinations x 4 directions). Figure 38 shows the percentage of people who selected the "bump" side of the switch for each configuration. (See the figure caption for a further explanation.)

These data confirm the linear direction-of-motion stereotypes reported in the literature; moving a control forward, to the right, or up is associated with turning something on or increase its value. (Strangely, in the United Kingdon, down is associated with on.) Particularly strong was the association of up with on and increase. Therefore, on/off controls and slide switches should be mounted on vertical surfaces and move according to that stereotype. Further, Jack shows that where a stereotype existed, adding the bump in the favored direction increased the extent to which people agreed on a stereotype.

With regard to the specific controls examined, the stereotype data show that for power window controls near the driver's door, the control should be vertically mounted (push down to lower). For the door lock, placing it on the armrest (push away to unlock) had the strongest stereotype.

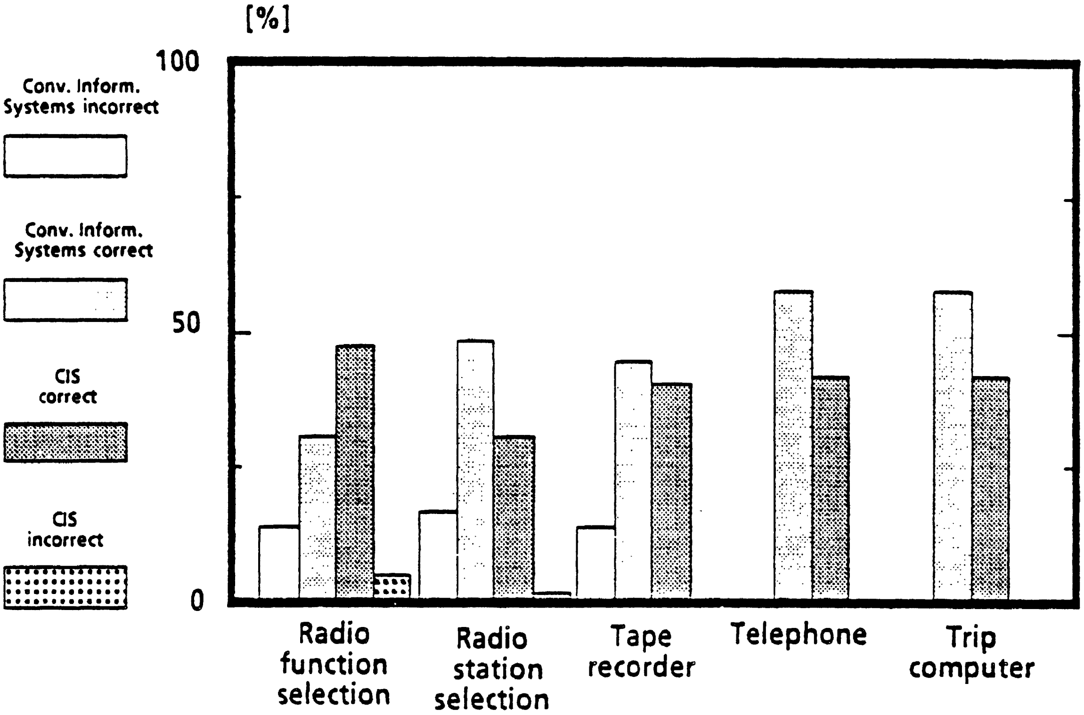


Figure 36, Proportion of Use for Conventional Information Systems and for the Central Information System (CIS) Using Three Menu Levels

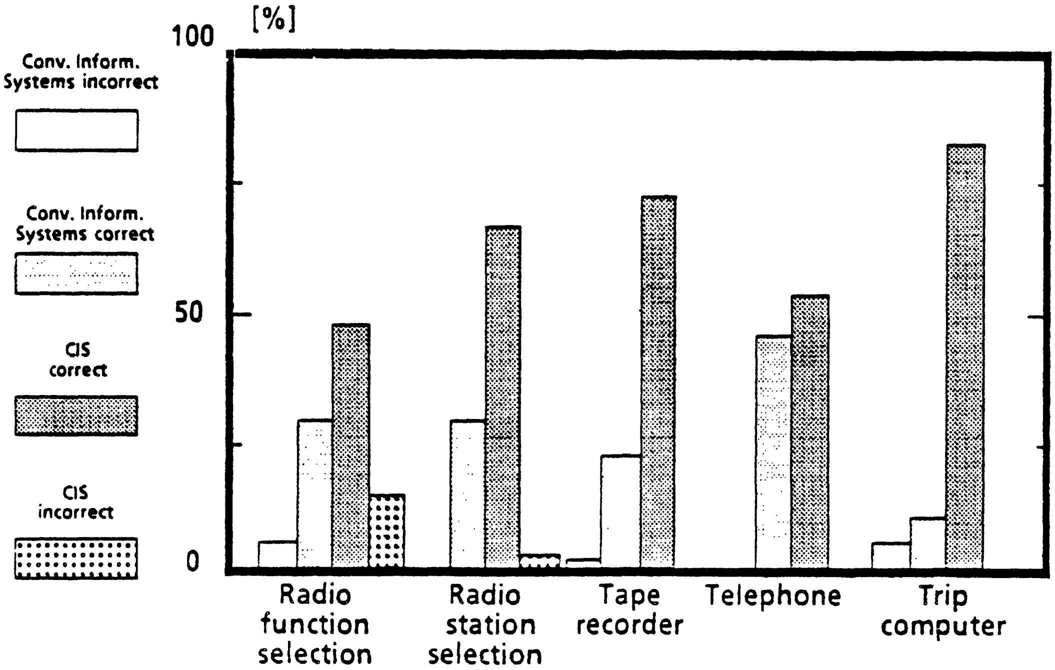
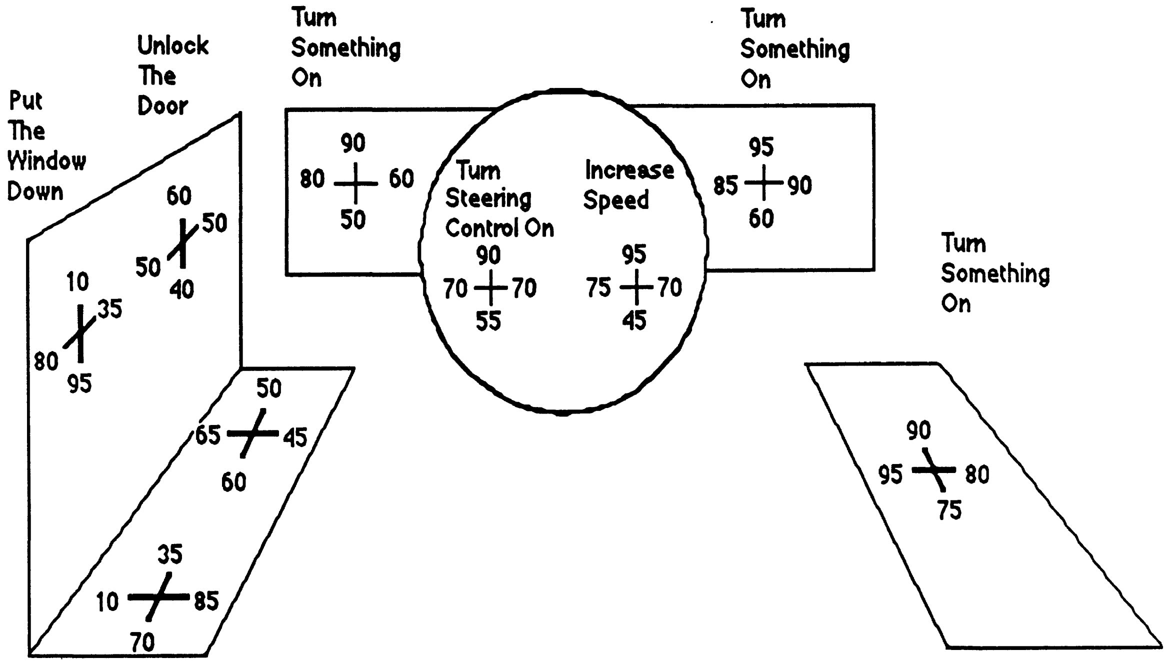


Figure 37, Proportion of Use for Conventional Information Systems and for the Central Information System (CIS) Using Two Menu Levels



Number represents percent pushing the Bump side.
(e.g. To put the window down when the switch was placed with the Bump side forward on the left armrest, 35% of the subjects pushed the switch's Bump side.)

Figure 38, Test Locations and Bump/Dimple Results from Jack (1985)

Three other small experiments (typically involving 100 drivers but only one response) were also completed. Jack found that adding the words "on" and "off" below a horizontal rocker switch (with a bump on it) increased the on-off direction of motion stereotype from 79 to 98%. However, when the distinction was a label on one face and serrations on the other, there was no clear stereotype as to which side was associated with "on". Finally, he found that for switches with one serrated face and one flat face, the serrated face was more likely to be associated with on (59% versus 41%). (The right-left stereotype for on-off was about 65-35.)

Snyder and Monty (1985)

Snyder and Monty (1985) examined driver performance in operating a touch screen CRT. Display types investigated included one with conventional, dedicated instrument panel controls and three touch-screen designs. During the experiment, 64 people drove twice over a standardized course, an hour at each time, while operating various features (select a radio station, operate the seek mode, manually tune, balance the tone, check the fuel used, average and instantaneous fuel economy, set the climate control mode or temperature, etc.) Each item was operated four times per hour. Operation times were recorded. Drivers were scored on lane-keeping, maintenance of speed, and frequency and dwell time of brake applications during the task period. Finally, eye movements were videotaped. Gaze direction (on the road, on the display) was coded by a person watching a playback of the tape who pressed a button to send a signal to a second audio track.

Snyder and Monty conclude that their methodology provided relevant information using large amounts of data, but said little regarding their results because of space constraints. As shown in Table 31, the time required to operate the touch screen (electronic) systems were double or triple the time required for dedicated instrument panel controls, and the mean number of glances away from the road (to the control surfaces) increased by a similar factor. In the authors' opinion, if these touch screen systems were fitted in production vehicles, they would present an unacceptable hazard to drivers. It is not clear how closely these systems resemble the one in the 1987 Buick Riviera. (See Ortega, Barker, Wilson, and Kruse, 1986, for a description of that system.)

Table 31. Mean Task Time and Number of Glances for Displays from Snyder and Monty (1985).

Display Type	Mean Task Time			Mean Number of Glances		
	Radio	Trip	HVAC	Radio	Trip	HVAC
Dedicated Displays	7.1	6.2	4.5	3.0	2.3	2.1
Electronic A	18.3	10.9	10.2	6.6	4.1	3.9
Electronic B	13.5	10.3	7.7	5.5	3.9	3.1
Electronic C	15.8	12.1	8.1	8.5	6.0	5.1

Summary

Much of the research on driver performance, especially the work in the 70's, is concerned with comparing stalk and panel-mounted controls (e.g., Faust et al., Kuechenmeister, etc.). There were no consistent advantages of one over the other (in terms of response time or errors) when the research was conducted. Stalk controls tend to be closer to the driver (decreasing reach time), but were at one time less expected (increasing decision time). Stalk controls are difficult to label and provide with tactile coding. Furthermore, the presence of multiple stalks or multiple controls on one stalk may lead to some degree of confusion.

Connected with the question is where secondary controls belong. The most recent comprehensive study of driver use of controls was carried out by Anacapa Sciences (1974, 1976). These experiments were extremely well done. From their data one would conclude that the lights belong on the left side of the instrument panel as well as the wiper/washer, the radio on the right side of the panel, and the climate control could go on either side. However, over the last ten years stalk controls have become much more likely and expected by drivers. For that reason, much of the Anacapa data is obsolete.

But the passage of time doesn't necessarily make all of the specific data obsolete. For example, the Anacapa data on radio location is still useful, and so too is the Krumm experiment on horn location. (Locate the horn on the steering wheel spokes or pad.)

Finally, a very popular topic in the literature is the design of trip computers and CRT-based, touch-screen information systems. The initial evidence suggests that such systems are difficult to operate, often requiring so much time to use that some designs may be dangerous.

In spite of this focus on specific controls and designs, a few general conclusions do emerge from the performance literature. Clearly, the farther controls are from where drivers expect them, the longer they take to use. Based on the Anacapa data, location times increase about one second for each ten inches a control in plain sight is from its expected location. However, deviations from the expected location don't seem to matter if they are less than five inches. It is not clear exactly how to apply this rule to stalk controls since at the time these studies took place, American drivers (used in all but one of the studies) were used to panel-mounted controls.

While expectancy is an important predictor of response time, it is primarily of concern when the driver is unfamiliar with the instrument panel. In the work of Mourant et al., movement time (from the steering wheel to the control) was about half of the performance time. For controls on the instrument panel, it was closer to 2/3 or 3/4. Furthermore, that study also showed that the design of the control itself also had a measurable impact on performance time, though it was much less. Controls that required fine movements on the part of the driver (such as small switches that were grasped), took longer to operate than controls that could be operated with gross movements (such as the turn signal). Taken as a whole, this evidence suggests that a procedure could be developed (similar to the proposal of Green, 1979) to predict control use time (for practiced conditions) from a data on movement distance and control design.

Taken as a whole, the literature suggests that drivers will do best with controls mounted close to them, controls that are similar to those they expect, and that do not require a precise grasp to operate. It is not important whether they are stalks or not. But placing controls close to the driver does not guarantee they will be easy to use. For example, McCallum et al. found that drivers took longer to use several switches mounted on the steering wheel hub than more conventional controls. The problem was the switches on the hub were very small.

A second major theme that emerges from the literature is the strong agreement of performance measures. Both the Essex '72 and the Anacapa '76 studies found good agreement between laboratory and on the road studies of the time to use controls and errors made. With regard to time and errors, the Anacapa work found a good correlation between these two performance measures (r=.85). There also is good agreement, both in the Mourant et al. study and in the Snyder and Monty work between eye fixation data (number of glances, glance durations, etc.) and various time measures. Many insist that when designing controls one should only be concerned with preventing accidents, and the key to preventing accidents is not distracting drivers from looking ahead. Most often, response time in the laboratory has been used to assess performance. These results suggest that type of experiment will predict what happens on the road.

In most of these studies, drivers are also performing some sort of tracking/steering task in addition to reaching for controls. Having such a task makes the data more believable, especially to those not trained in human factors, the primary users of these studies. For that reason, it may be necessary to include a tracking task in performance studies. On the other hand, the Khadilkar data suggest the additional task will have no effect on performance. But then, the Khadilkar data aren't very good.

A third theme that emerges from the literature is more of a reminder than anything else; generic human factors research can be used to solve automotive problems. This point is exemplified by Jack's work on direction of motion stereotypes for controls. In brief, Jack's work showed that the stereotypes in the human factors literature can be used to predict how drivers think controls should be moved to cause functions to operate.

The final theme to emerge from the performance literature is the value of a "human engineered" instrument panel. The Essex experiment compared how long it took drivers to use controls on an unfamiliar (nonoptimal) panel, a well designed one, and the one in their own car. While drivers did best using the panel they were intimately familiar with (the one in their own car), differences between it and an unfamiliar but well designed one were small. On the other hand, they did not do well on panels that were not well designed.

Thus, the main contributions to automotive design of the driver performance data are not recommendations about which specific controls are best, in spite of that being the emphasis of the research. This is because what is best depends upon what drivers expect and that has changed over the last ten years (since the last good work was done).

The most useful data concerns which factors matter, how much, under what conditions, and how new studies should be carried out. Interestingly, these issues have often been covered in pilot or preliminary studies, or the result of post-hoc analyses.

If there is a lesson to be learned from the performance literature, it is that more work on modeling performance is needed (similar to that proposed by Green, 1979). Studies concerning which of three or four controls is "best" are not very useful in the long run. Control designs change over time and after a few years the designs tested are no longer used. Further, because expectancies change with the passage of time, the results of those studies become less useful predictors of driver performance. When thinking about supporting research, sponsors need to ask how useful the data will be in five to ten years.

- *WHAT DO THE DRIVER PERFORMANCE DATA SHOW?* -

HOW HAVE HUMAN FACTORS ANALYSES BEEN USED?

There have been many studies that have examined the application of human factors principles to automobile instrument panel design. Some of them have been critiques of production vehicles of the time. Others have described how human factors principles could be applied to "human engineered" or "ergonomically designed" instrument panels, or have been applied to the design of a specific component (e.g., a tripcomputer). Finally, there are also studies in the literature that describe generally useful data (e.g., population stereotypes, frequency-of-use data, etc.) or methods. This section reviews that research as well as other potentially useful human factors methods that have not yet been applied in an automotive context.

Woodson, Conover, Selby, and Miller (1969)

The first comprehensive, nonproprietary report identifying how human factors principles should be applied to vehicle design is Woodson et al. (1969), also known as the Man Factor '69 report after the name of the company that did the work for the Department of Transportation. That report is written in a very straightforward style with many simple Do's and Don'ts. The report reviews how vehicles were designed at the time and contains a detailed commentary on which control designs conflicted with human factors design principles. That information is summarized in Green, Ottens, and Adams (1987).

This report was the first to apply task analysis in a systematic way to automobile control design. Three driving scenarios were developed from which the frequency of various driving tasks were tallied. Based on that and other data, priorities were identified for 39 controls and accessories. Each control was then assigned a value of 1 (highest, most critical, etc.) to 5 (lowest, least critical, etc.) for each of five dimensions; frequency-of-use, time criticality, precautionary (warning) value, criticality for mission success, and use by both the driver and front seat passenger. From those data the criticalities of the controls were rank ordered. (See Table 32.)

Woodson et al. also developed a partial draft design standard for instrument panels and a proposed standard panel design. Their design proposal is probably the most complete one in the literature. It covers both the general arrangement of controls and displays, and design details. Included among these details were items such as labeling, sizing, and spacing recommendations from the general human factors literature, as well as a tradeoff rationale for each control and display.

Table 32, Control/Display Priority Matrix (from Woodson, et al., 1969)

CONTROLS						
Criticality order		Frequency	Time critical	Precautionary	Mission success	Joint use
1	Steering	1	1	3	1	
4	Hi-lo beam switch	3	3	2	3	
2	Brake (primary)	2	2		1	
7	Horn	4	1	1		
5	Accelerator	1	5		1	
6	Turn signal lever	2		1	2	
3	Gear select lever	3	3	2	1	
3	Gear shift lever	3	3	2	1	
3	Clutch	3	3	2	1	
8	Window control (driver)	3		1	4	
13	Road-stop flasher switch	5		1		
10	Windshield wipe/wash switch	4	5	3	2	
11	Ignition switch	4	4		1	
9	Light controls	4		1	1	
12	De-fog/defrost controls	5	5	3	2	
19	Radio controls	5				3
15	Heater controls	5			4	1
15	Air conditioning controls	5			4	1
18	Map light control	5				2
16	Radiotelephone controls	5			3	
19	Front/rear speaker control switch	5				3
18	Glove compartment latch	5				2
19	Tape unit controls	5				3
20	Steering wheel adjust	5				
15	Master door lock switch	5		3		
15	Master window control	5		3		
15	Window control lockout switch	5		3		
14	Door opening control (driver)	5		2		
15	Individual door locks	5		3		
15	Automatic speed-set control	5		3		
14	Outside mirror control	5		2		
17	Ash tray/lighter	5				1
19	Antenna control	5				3
20	Dome light control	5				
13	Parking brake	5	5	1		
13	Steering lock	5		1		
20	Spotlight control	5				
20	Hood release	5				
20	Manual/electrical seat adjust	5				

DISPLAYS						
Criticality order		Frequency	Time critical	Precautionary	Mission success	Joint use
1	Rear view mirrors	1	1	1	2	
2	Turn signal indicator	1	3	1	2	
3	Speedometer	2	2	2	2	
6	Oil/Temp/Fuel/Gen gauges	3	3	2	2	
18	Seat belt warning light		5	1		
4	Gear select indicator light	2	4	1	3	
5	Brake failure warning light	5	1	1	2	4
15	Heater display	4	4			1
15	Air conditioning display	4	4			1
8	Radio display	3	3	5	5	1
10	Door-open indicator light	5	2	1		
12	Radiotelephone display	4	3		5	5
13	Clock	4	3			4
21	Compass	5				2
21	Altimeter	5				2
21	Outside air temp thermometer	5				2
22	Odometer	5				3
22	Grade level indicator	5				3
7	Hi-beam indicator light	3	3	2	4	
14	Engine-cold indicator light	5	3	3		
17	Parking brake-on indicator light	5	5	3		
19	Tachometer	5	5	5		3
16	Oil temperature	5	4	5	4	
20	Vacuum gauge	5	5	5	5	
20	Differential temperature	5	5	5	5	
20	Transmission temperature	5	5	5	5	
20	Head temperature gauge	5	5	5	5	
9	Defog/defrost display	4	3	3	3	
11	Temperature	3	5	3	3	
11	Fuel	3	5	3	3	
12	Generator	4	5	3	3	

NOTE: For both displays and controls, Frequency priority ratings were derived from driver task analyses, and Time Criticality values were derived from driving emergencies analyses. Both sets of ratings are preliminary only. Blank space indicates"not applicable."

Figure 39 shows where the secondary controls were to be located and Figure 40 shows the design details for a typical control. Interestingly, the Man Factors panel was basically a "pod-like" architecture. Only in the last few years has that design begun to appear in production vehicles.

Malone, Krumm, Shenk, and Kao (1972)

Several years later, Malone, Krumm, Shenk, and Kao (1972) carried out a detailed human factors analysis of instrument panel designs for cars, trucks, and buses. This study was carried out for the Department of Transportation by the Essex Corporation. (For a summary, see the 1972 SAE paper by Kao, Malone, and Krumm.) Only the work dealing with automobiles will be discussed here, although their human factors analysis of large truck instrument panels is quite interesting.

In contrast to the Woodson work, Malone et al. devoted considerable attention to current convention when they developed recommendations for a standard instrument panel. They considered guidelines for control design such as Federal Motor Vehicle Safety Standard 101 and Society of Automotive Engineers recommendations. They also considered commonality considerations with trucks and buses (based on the Regular Common Carrier Conference (RCCC) control panel concept), the ability to accommodate options, and the "right hand rule" (for trucks). (The right hand rule, a convention suggested in a report they describe (the RCCC report), states that controls operated while the vehicle is in motion should be located to the right of the steering column. The authors aren't aware of any data which supports this convention.)

Also given extensive consideration was "criticality." They view criticality as having three aspects: safety, performance, and comfort/convenience. Safety considerations include effects on driver visibility, use in emergency situations, use to avoid hazardous situations, and the degree to which errors of use produce hazardous situations. Performance considerations include items such as the likelihood of high error rates, frequency-of-use, and complexity of operations. Data relating to use requirements appear in Table 33. These data are basically subjective. The overall evaluations of secondary controls are shown in Table 34.

Man Factors, Inc.
San Diego, California

MFI 77-108 (F)

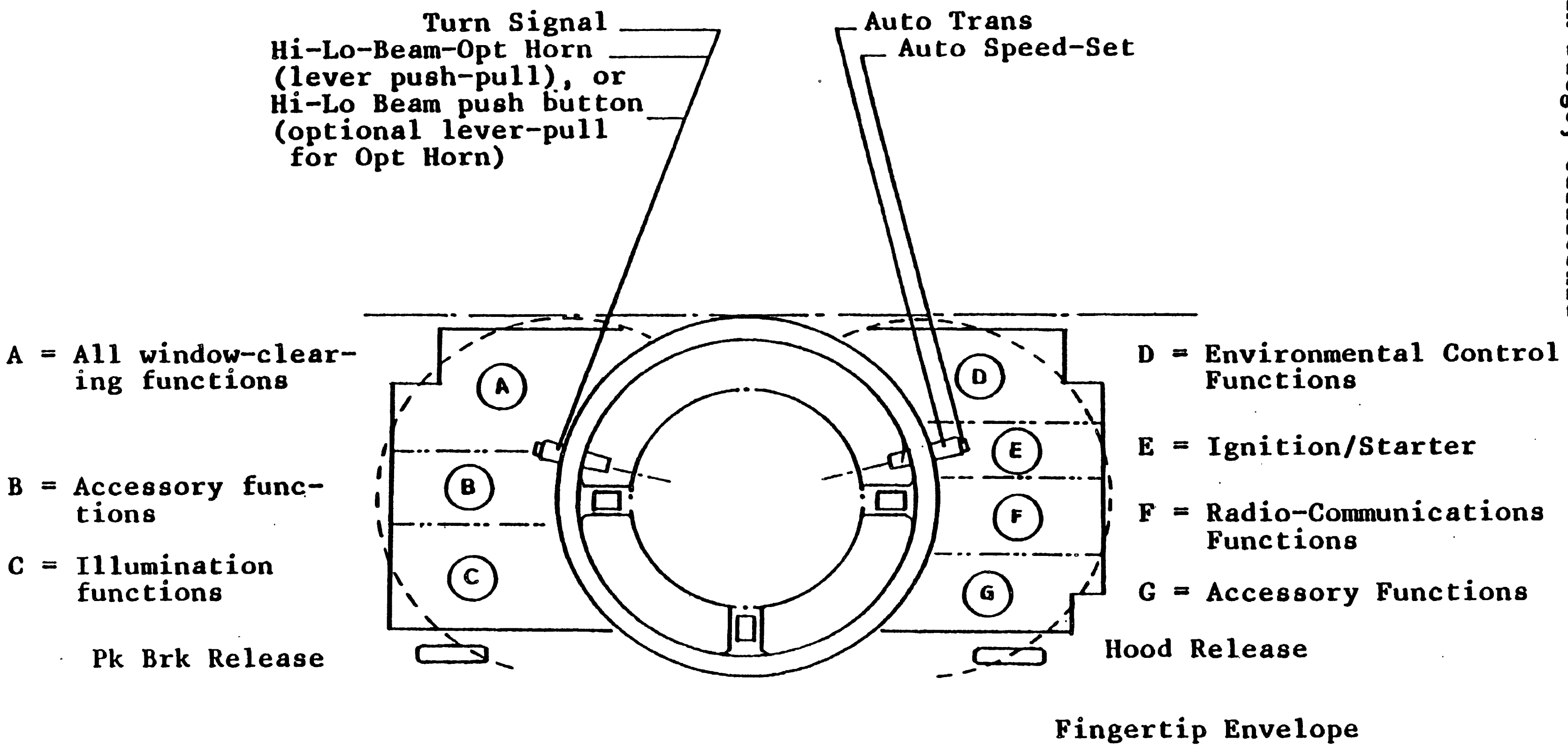


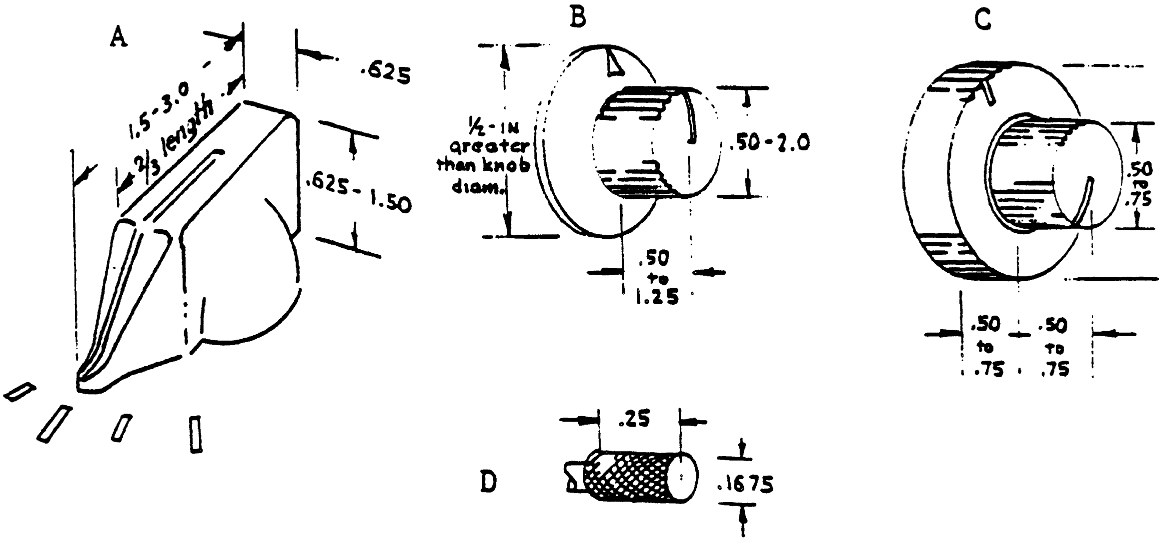
Figure 39 - Proposed Controls Location Standard Based on Trade-off Analysis

RELATED HUMAN ENGINEERING CRITERIA	TRADE OFF RATIONALE
1. Similar (standard) positional relationships between a control and the controlled element should be maintained in all equivalent work stations where feasible. 2. Displays should be located centrally (as near eye level as is feasible) with controls arranged about the periphery to preclude possibility of hands covering critical displays while operating a control. 3. Controls which may be used in an emergency should be located close to the normal line of sight. 4. Most-often used controls should be located near the normal line of sight. 5. Controls which might be operated inadvertently with undesirable consequences should be separated from one another. 6. Controls which may have some position (spatial) relationship to the element they control should be located so there is a positional identification reinforcement (e.g., windshield clearing control near windshield etc.)	1. Windshield clearing controls are placed at the top of the panel near the windshield; light switches near the bottom of the panel since headlights are low on the vehicle. 2. Windshield wipers often have to be operated quickly (emergency) further emphasizing the need for this control to be near the normal line of sight. 3. Radio controls were given priority over environmental controls since they probably will be used more often. In the future, more extensive communications may be provided, further emphasizing the frequency of use priority. 4. Light switches and windshield clearing controls are widely separated based on experiences in which lights were turned off instead of turning on windshield wipers. Parking brake and hood release controls are separated in a similar fashion. 5. Locations suggested reflect general practice indicated by vehicle survey.
Ref: HEL S-6-66; MIL-STD-1472; Morgan, et al, Human Eng Guide; Woodson-Conover, Human Eng Guide.	Location Worksheet No. 2

Figure 39, Proposed Controls Location Standard Based on Trade-off Analysis (cont.)

SUGGESTED DESIGN STANDARD: CONTROL COMPONENT DESIGN (Cont'd)

(values in inches)



A - Detented switches should utilize a pointer style handle with dimensional limits shown.

B - Continuous-turn (potentiometer) switches should utilize a round knob such as shown above (with or without skirt).

C - Stacked knobs must be differentiable one from the other. The dimensional relationships proven satisfactory are shown above.

D - The smallest continuous-turn knob which is practical is illustrated above. Such knobs should be knurled to provide adequate gripping surface.

Note: B and C should have knurled surfaces to provide secure gripping surface.

Figure 40, Accessability Worksheet No. 11

RELATED HUMAN ENGINEERING CRITERIA	TRADE OFF RATIONALE
1. Pointer style knobs should be used on detented, selector type controls. 2. Round style knobs should be used on potentiometer type switches which require more than one complete turn. 3. Surface serration or knurling is recommended to improve the gripping characteristics of rotary switch controls. 4. All knob type control handles must be designed for ease in gripping. Concentric, stacked knobs must have sufficient size difference to insure ease in operating each knob independently. Ref: GDA 63-0894-1	1. Dimensional ranges shown have been determined through many experimental studies, and provide for optimum manipulation as well as identification.

Figure 40, Accessibility Worksheet No. 11 (cont.)

Table 33, Control User Requirements from Malone et al. (1972)

Control	Normal Operation Vehicle State	Frequency	Duration	Complexity
Ignition	Stopped	Low	Discrete	Low
Cruise Control	Moving	Moderate	Moderate	High
eadlights	Any	Low	Discrete	Low
High-Low Beam	Moving	High	Low	Moderate
Parking Lights	Any	Low	Discrete	Low
Wiper	Any	Low	Moderate	Low
Washer	Any	Low-Mod.	Low	Low
Temperature	Any	Moderate	Moderate	High
Air Conditioning	Any	Moderate	Moderate	Moderate
Fan	Any	High	Moderate	Moderate
Defrost	Any	High	Moderate	Moderate
Hazard	Any	Low	Discrete	Low
Heater	Any	High	Moderate	Moderate
Fresh Air	Moving	Moderate	Low	Moderate
Horn	Any	Moderate	Low	Moderate
Turn Signal	Any	Moderate	Low	Moderate
Radio	Any	Moderate	Low	Moderate
Lighter	Any	Low	Moderate	Low

TABLE 34

Criticality Values for Passenger Car Control

	Safety				Performance					Comfort conven.
					Critical to performance					
Control	Visib.	Emergency	Avoid Hazards	Errors Cause Hazards	Vehicle	Driver	High Error Rate	Freq. Use	Complex ops	comfort conven.
Wheel tilt				X		X	X			
Ignition		X								
Starter					X				X	
Auto speed						X	X	X	X	
Headlights	X			X		X				
Panel lights						X				
Hi-lo beam	X		X	X		X	X	X	X	
Parking lights			X							
Rear window				X						X
Wiper	X		X			X				
Washer	X		X			X				
Temperature										X
Air conditioning										X
Fan							X	X	X	X
Defrost	X					X		X	X	
Mode						X	X	X	X	X
Rear window defog	X					X	X			
Hazard			X	X						
Gear select		X			X			X		
Horn			X	X			X	X		
Turn signal			X	X				X		
Top up/down				X						X
Park brake rel.					X					
Hood latch				X						
Choke					X					
Map lite										X
Elec window										X
Rear view mirror				X						X
Radio										X
Clock										X
Lighter										X

Using that information, each control was assigned to one of seven criticality levels. The assignment was subjective, not objective. Definitions of those levels and those controls assigned to the top three are shown in Table 35.

Table 35, High Criticality Controls in Cars (Malone et al., 1972)

Criticality Level	Description	Controls
1	Standard equipment a major effect on safety and high error rate with critical error effect and critical effect if function is not provided	Headlights, High Beam, Wiper, Wash, Hazard, Horn, Turn Signal, Gear Select
2	Standard or optional and moderate effect on safety and high error rate	Wheel Tilt
3	Standard or optional and moderate effect on safety with none of above	Ignition, Parking Lts, Rear Window Defrost, Top Up/Down, Hood Latch
4	Minimal effect on safety - major effect on driver performance	no examples given
5	Minimal effect on safety - major effect on vehicle performance	no examples given
6	Minimal effect on safety or performance, major effect on comfort	no examples given
7	Minimal effect on safety or performance - major effect on convenience	no examples given

This analysis resulted in the creation of an "ideal" panel (the Essex panel). (See Figure 41 for the panel and Table 36 for the design rationale.) At the time this panel was designed, not much thought was given to the use of controls mounted on stalks, pods, or steering wheel spokes.

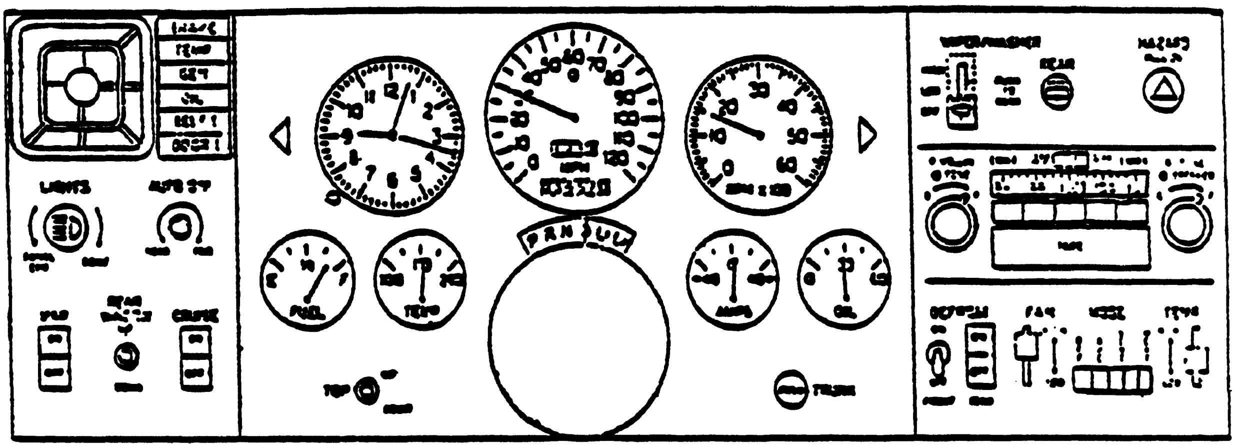


Figure 41,
Drawing of "Essex" Car Panel
Malone, Krumm, Shenk, and Kao (1972).

Table 36, Control Arrangement Rationale Given by Malone et al., 1972

Control	Location	Grouped With	Arrangement Within Zone	Rationale
Horn	Steering Col.	--	Center Hub	Con., Prio*
Gear Shift	R. Side Col.	--	--	Con., Prio.
Turn Signal	L. Side Col.	Cruise	--	Con., Prio.
Headlight	Far Upper Left Panel	Panel, Parking	Separated	Con., Prio.
Parking Light	Far Upper Left Panel	Headlight	Separated	Con., Prio.
Hi/Lo Beam	Left Side on Floor	--	--	Con., Prio.
Hazard	Far Upper R.	--	Separated	Con., Prio.
Wiper	Upper R Panel	Washer	Central	R. Hand
Rule			Separated	Separate from Lts, Priority
Washer	Upper R Panel	Wiper	Within Wiper	R. Hnd Rule Priority
Panel Light	Upper L Panel	Headlight	Separated	Convention, R.H. Rule, Priority
Cruise	L. Side Col.	Turn Signal	--	Con., SAE

*Con=Convention, Prio=Priority

Nevett (1972a)

Both of these initial studies note that frequency-of-use is an important consideration in designing controls. In the reliability section of Nevett's paper, a table is included on the "numbers of switch operations taken from instrumented proving laboratory cars." (See Table 37.) The text refers to "operational life levels of switched functions measured on instrumented cars over a period of some years." No other information is provided. Because of where they appeared, these data are not well known.

Table 37, Frequency-of-Use of Controls (Nevett, 1972a)

Control	Operations/1000 miles
Trafficator Switch (Turn Signal)	1380
Horn	456
Dip Switch	440
Ignition	419
Headlamp Switch	140
Wiper Switch	99
Screenjet (Washer)	48

Mortimer and Post (1973)

In contrast to the focus on the entire instrument panel, Mortimer and Post (1973) report a human factors analysis of 13 different beam switching methods. They assembled a collection of 44 statements (e.g., "It should not be possible to inactivate the headlamps inadvertently."), from which 40 were used in the final analysis. Those statements came from lists of design criteria that appeared in Woodson et al. (1972), Malone et al. (1972), and their own ideas. Statements were presented to five members of The University of Michigan Highway Safety Research Institute, Human Factors Group. They categorized each of those statements and assigned weights to them (4 = essential, 3 = primary, 2 = secondary, 1 = tertiary, none of these=0). By rating how well proposed designs complied with each statement and then summing the ratings across evaluators, alternative control designs could be scored. The final number had a range of 0 to 100. (See Mortimer and Post, 1973, for the calculation details.)

The five Human Factors experts used this method to examine 13 alternative designs for three-beam headlight switches. In those analysis, it turned out that the critical difference was not whether some of the controls were stalk- or column-mounted, but rather whether they permitted beam switching to occur in a single motion. The descriptions and ratings of each control design appear in Table 38.

Table 38, Designs Rated by Human Factors Experts in Mortimer and Post (1973)

DESIGN	RANK	FINAL RATING	ACTUATOR (ON/OFF)			BEAM PAIR			BEAM SELECTOR		
			LOCATION	SWITCH TYPE	POSITION	LOCATION	SWITCH TYPE	POSITION	LOCATION	SWITCH TYPE	POSITION
A	9	73	left panel	CW rotary	off/park/ head	left panel	pull/push knob	high-mid/ high-low	floor	push/pull stalk	
B	10	72	left panel	CW rotary	off/park/ head	left panel	pull/push knob	high-mid/ high-low	column left	pull/pull stalk	
C	8	77	left panel	CW rotary	off/park/ head	left panel	pull/push knob	high-mid/ high-low	column left	pull/push stalk	
D	5.5	89	left panel	pull/push knob	off/park/ head	floor	push/push button	high-mid/ high-low	column left	pull/pull stalk	
E	5.5	89	left panel	pull/push knob	off/park head	floor	push/push button	high-mid/ high-low	coloumn left	pull/push stalk	
F	7	85	left panel	pull/push knob	off/park head	column left	pull/push stalk	high-mid/ high-low	floor	pull/push button	
G	4	97	left panel	pull/push knob	off/park head				column left	3 position stalk	low = rear, mid = middle, hi = away
H	3	98	left panel	pull/push						delta stalk	up = hi, down = mid, away = low
I	12	70	left panel	CW rotary	note 1 below				floor	push/push button	
J	13	66	left panel	combined lever	pull positions: off, park, head				floor	push/push button	
K	1.5	100	left panel	pull/push knob	off/park head				column hub	3 interlocked pushbuttons	left button = low, middle = mid right = hi
L	1.5	100	left panel		off/park head				panel left	3 interlocked pushbuttons	top = hi, middle = mid, bottom = low
M	11	71	left panel		off/park head				floor	push/push button	light pressure alternate between hi & low, heavy pressure = mid

NOTE 1: off/park/L-M or M-H
left = L-M, right = M-H

This report is noteworthy because it is one of the few attempts to rigorously quantify the factors which are important in using controls and displays; and to use them for making design decisions. Its main weakness is the absence of any performance measures against which the weights of the various factors can be compared. In spite of this drawback, this study deserves further attention.

Woodson and Selby (1975)

Woodson and Selby (1975) examined the merits of using various fixed-seat control layouts with adjustable foot controls and instrument pods as alternatives to the standard fixed-panel, adjustable-seat design. Part of the research program was a human factors analysis of several versions of such a design in which controls are packaged in modules placed left and right of an adjustable (fore and aft) steering wheel. The modules move fore and aft approximately three inches relative to the fixed seat. The advantages and disadvantages of these versions were scored by judges on 10 dimensions (crashworthiness, styling flexibility, styling, operability, and so forth). Of the seven options considered, providing adjustable pods (in addition to an adjustable pedal assembly and steering wheel) was ranked third best. Not providing an adjustable pod and designs without an adjustable steering wheel were ranked higher. Interestingly, late model Camaro Berlinettas have adjustable pods.

Simmonds (1976a, b, c)

The three Simmonds documents were produced as part of an International Standards Organization effort to develop standards for stalk controls. While the delegates to the ISO Technical Committee responsible for controls are supposed to act as independent experts, they often are advocates of their employers, generally vehicle manufacturers. For that reason, discussions within ISO Committees are more political than they should be. The work of Simmonds is an interesting effort to make decisions about standardization on a scientific basis.

The Simmonds (1976b) document provides several items necessary to make those decisions. Shown in Table 39 are frequency-of-use data from five sources of widely varying quality. Based on that, Simmonds also made an "overall" estimate for the frequency-of-use of each control. Note that no data is provided for either climate controls, or for the radio, a panel component that is operated quite often. Much more of this type of data needs to be collected.

Table 39, Frequency-of-Use of Controls - Simmonds Data

(Thousands of operations during the first 80,000 km)

Control	VW (1)	BDF (2)	Chrysler (3)	Lucas (4)	Ford (5)	Overall
Lights on/off	2	5		2.6	7.0	5
Beam select	200	4		2.3	5.1	3
Horn	10	2	2.1	2.6	3.1	3
Wipers	30	5	4.5	12.3	9.2	10
Washers	30	5		5.0	2.9	3
Turn signal	200	10		29.3 L 38.6 R	71.2	30.0 L 40.0 R
Hazard	2	1		0.2		.2
Park brk rel		8			13.7	14
Headlamp washer	1	5		0.9		1
Hood release		2			0.6	0.6
Belt release		8			32.0	32
Cruise control		2				1
Optical Horn	200	2	2.7	3.5		3
Front fog lamps	1	1		1.3		1.3
Rear fog lamps	1	1		0.7		0.7
Gear selector		10			245.0	245

Notes:

(1) VW numbers are estimates.
(2) BDF numbers are estimates on a 1 to 10 scale, not 1000's of operations.
(3) Chrysler (UK) data are extrapolated from a single vehicle development used for 20,000 miles.
(4) Lucas data are from 300,000 miles over 12 months from 7 development cars.
(5) Ford (Europe) data are 50th percentiles from 71 customer cars in the UK, Germany, and Scandinavia for one year. Belt releases are assumed equal to door openings. Beam selector operations includes optical horn. Gear use is estimated from clutch operations.

By almost an order of magnitude, the gear selector was the most frequently used control followed by the turn signal and restraint release. Other high frequency-of-use controls included the parking brake and the wipers.

Also included in Simmonds (1976b) are data on the duration of use of each control. (See Table 40.) The amount of information provided is quite limited.

Table 40, Duration of Use of Controls - Simmonds Data
(Time "on" as a percentage of engine running time)

Control	Chrysler	Lucas	Ford	Overall
Lights on/off	5.9	28.	38.6	30.
Beam selector	10.6	2.		5.
Wipers	8.3	11.	7.	9.
Washers		1.		1.
Turn signal		18.	10.	15.
Hazard		0.2		0.2
Front fog lamps		1		1.
Rear fog lamps		2		2.

Simmonds also provides ratings on the need for immediate action and the danger from inadvertent operation for each control. The horn and wipers were identified as controls that needed immediate operation by the driver. The parking brake, main lights on/off. turn signal, hood release, and belt release were controls that created a danger if they were inadvertently operated. (See Tables 41 and 42.) How these data were obtained is not clearly explained. It is the authors' guess that they are from votes of 10 members of ISO Technical Committee 22.

Table 41, Need for Immediate Action - Simmonds Data

Control	Rating											Median	
	1	2	3	4	5	6	7	8	9	10	Mode		Overall
Lights on/off			3	3		6	1	2		1	6	6	6
Beam selector	2	1	1			3	3	5	1	1	8	7	7.5
Horn			1		1	2	3	2	1	8	10	8.5	9
Wipers	1		2		1	2		4	3	5	10	8	9
Washers	1	1	1	2	6	2	1	3	1		5	5	5
Turn signal				1	1	2	5	5	2	2	7.5	7.5	7.5
Hazard	2	1	1	4	3	4		1		1	4,6	5	5
Park brk rel.	2	4	2	1	3						2	2.5	2
Headlamp wash	2	5		2	2			1			2	2.5	2
Hood release	5	4		2		1					1	1	1
Belt release	1		1	1	2	3	2	4		3	8	7	7
Cruise ctrl	5	2	1	1	2	3	2	4		3	8	7	7
Optical horn	2		1	2	4		2	1	6		9	6	7
Front fog	2	2	1	5	1	2	1				4	4	4
Rear fog	2		1		5	2	3	1			4	4	4
Gear selector	3	2	1		2	2	1	2	2	2	1	6	6

Table 42, Danger from Inadvertant Operation - Simmonds Data

Control	---------- Rating ----------											Median	
	1	2	3	4	5	6	7	8	9	10	Mode		Overall
Lights on/off				1		3	1	1		4	10	7.5	8
Beam selector			1	1		1	2	3	1	1	8	7	7.5
Horn	1	2	4	1			1				3	3	3
Wipers		2	3		1			3	1		3,8	5	5
Washers		3	3	1	2	1					2.5	3	3
Turn signal					1		3	4	1	1	8	8	8
Hazard		2	3		3	2					3,5	4	4
Park brk rel		1			1		2	1	2	3	10	8.5	9
Headlamp wash	4	3	2								1	2	1.5
Hood release	1					1	1	2	2	3	10	7.5	8
Belt release			1	1				3		2	8	8	8
Cruise crtl.	3		1	1	2	1			1	1	1	4	4
Optical horn	2	2	1	1			2	1				4	4
Front fog	1	1	1		1							2.5	2.5
Rear fog	1	1	1			2				2		6	6
Gear selector						1						6	6

Finally, Simmonds (1976a) (see also Simmonds, 1976c) pulls these data together in a single table (43) that he uses for making decisions. To calculate error likelihoods, the joint frequency-of-use for each control pair is computed by multiplying the marginal frequencies. (See Table 44.) These values were multiplied by the conditional confusion likelihoods (subjective, configuration-specific estimates on a 1-to-10 scale, see Table 45). Simmonds summed these values across all possible pairs of controls to compute a total error score for several control configurations. What is important about these data is not the specific recommendations offered by the Simmonds document as much as the application of a formal quantitative procedure for making decisions, as opposed to an off-the-cuff opinion. Should an approach like this be genuinely considered, it should be modified to yield a figure of merit by weighting errors according to their "cost." (Turning on a turn signal is much less dangerous than applying the emergency brake.)

Table 43, Error Frequencies for Controls

Intended Action ↓ / Possible Error →		Freq. of Use^1	Side Lamps		Head Lamps		Flash (opt. Horn)	Dip		Horn	Turn			Wipe			Wash	Emergency Brake	
			On	Off	On	Off		To High	To Low		Left	Cancel	Right	1	2	Off		On	Off
Proportion of Time Error Possible^2			60	40	70	30	100	(60)^3	(40)	100	90	10	90	95	98	7	100	99	1
Side Lamps	On	4		I	-	-	I	-	-	I	I	I	I	D 3.8	D 3.9	I	I	D 4	D 0.04
	Off	4	-		-	-	-	-	-	I	I	I	I	D 3.8	D 3.9	I	I	D 4	D 0.04
Head Lamps	On	4	-	D		D	-	I	-	I	I	I	I	D 3.8	D 3.9	I	I	D 4	D 0.04
	Off	4	-	-	I		I	-	-	I	I	I	I	D 3.8	D 3.9	I	I	D 4	D 0.04
Flash (optical horn)		(6)	I	D 2	-	D 1.5		-	-	-	I	I	I	D 4.7	D 4.9	I	I	D 4.9	D 0.05
Dip	To High	5	I	D 2	-	D 1.5			-	-	I	I	I	D 4.7	D 4.9	I	I	I	D 0.05
	To Low	5	I	D 2	-	D 1.5		D		-	I	I	I	D 4.7	D 4.9	I	I	D 4.9	D 0.05
Horn		2	D 1.2	D 0.8	D 1.6	D 0.6	I	D 1.2	D 0.8		D 1.8	D 0.2	D 1.8	D 1.9	D 2	D 0.1	D 2	I	D 0.02
Turn	Left	35	I	I	I	D 10.5	I	D 21	I	I		I	D 31.5	D 33	D 36	I	I	D 36.6	I
	Cancel	70	I	I	I	D 21	I	I	I	I	D 63		D 63	D 66	D 69	I	I	I	I
	Right	35	I	I	I	D 10.5	I	D 21	I	I	D 31.5	I		D 33	D 36	I	I	D 36.6	I
Wipe	1	(8)	-	I	I	D 2.4	I	D 4.8	-	I	I	I	I			D 0.6	I	I	I
	2	(2)	-	I	I	D 0.6	I	D 1.2	-	I	I	I	I	-		I	I	I	I
	Off	10	-	I	I	D 3	I	D 6	-	I	I	I	I	-	I		I	I	I
Wash		3	-	I	I	D 0.9	I	D 1.8	-	I	I	I	I	I	D 2.9			I	I
Emergency Brake	On	(1)	-	I	-	D 0.3	-	I	I	-	-	-	-	D 1	D 1	I	I		D
	Off	(1)	-	I	-	I	-	I	-	I	-	-	-	-	-	-	-	D	

'D' represents possible danger, 'I' inconvenience, and '-' no real consequence.

Source: International Standards Organization, 1975

Notes:
1. Values are based on data collected for 71 cars in normal use in Germany, Sweden, Finland and the U.K. for one year. The frequencies listed are 50th percentiles at 80,000 km, reduced by a factor of 1000.
2. The proportion estimates are relative to the time the engine is running.
3. Figures in brackets are estimates.

Table 44. **Confusion Likelihood for Two Configurations of Controls.**

Proposal A

	Possible Error	Side Lamps	Headlamps	Optical Horn	Dip	Horn	Turn	Wipe	Wash	Emer. Brake
Intended Action	Side	L(P)	L(P)	L	L	L	L	R	R	R/L
Side Lamps	L(P)							2		1
Headlamps	L(P)	10						2		1
Optical Horn	L	4	4					2		1
Dip	L	4	4					2		1
Horn	L	4	4		10		10	2	2	1
Turn	L		10		10			2		1
Wipe	L		2		2					
Wash	L		2		2			10		
Emer. Brake	R/L		1					1		

Total Relative Error Number = 1865.7

Proposal B

	Possible Error	Side Lamps	Headlamps	Optical Horn	Dip	Horn	Turn	Wipe	Wash	Emer. Brake
Intended Action	Side	L	L	L	L	L	L	L	L	R/L
Side Lamps	L							10		1
Headlamps	L	10						10		1
Optical Horn	L	10	10					10		1
Dip	L	10	10					10		1
Horn	L	10	10		10		10	10	10	1
Turn	L		10		10			10		1
Wipe	L		10		10		10			
Wash	L		10		10			10		
Emer. Brake	R/L		1					1		

Total Relative Error Number = 4344.5

Note: L = control located on the steering column to the left of the reference plane.

L(P) = control located on the instrument panel to the left of the reference plane.

R = control located on the steering column to the right of the reference plane.

1. These subjective estimates do not represent "official" estimates (neither of the author nor ISO) but rather values generated for discussion only.

Source: ISO, 1975.

Anacapa Sciences (1976)

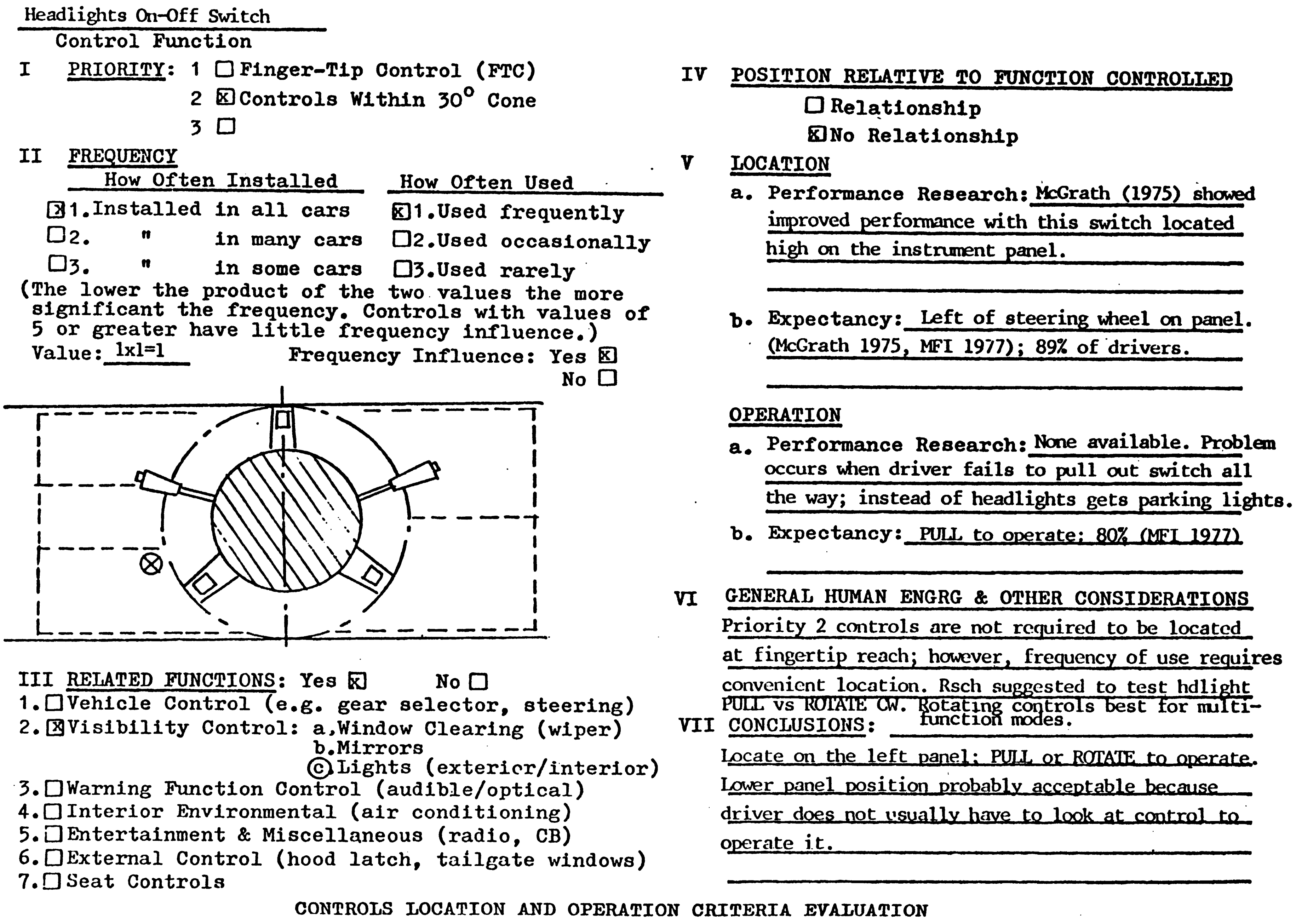
As part of the expectancy survey desribed earlier, Anacapa included questions about the frequency-of-use of controls. Shown in Table 45 are data from the 1708 drivers who mailed back the questionnaire. The Anacapa report includes data tabulated by vehicle type (e.g., large American sedan, light truck, etc.) but since the differences between vehicles were small, those subtotals have not been included here. The item with the highest frequency-of-use was the radio, with 76% of those responding saying they use it at least daily. Just over half of the drivers say they use the headlight switch daily and almost half reportedly use the vent daily.

Table 45, Frequency-of-Use of Controls/Accessories - Anacapa (1976)

Control	------------- Frequency									------------------			
	once/day or more		once/wk or more		once/m or more		Seasonally or more		rarely or never		not in my car		Total
	N	%	N	%	N	%	N	%	N	%	N	%	N
Headlight	918	55	645	38	73	4	2	0	43	3	0	-	1681
Wiper	52	3	370	23	716	44	41	3	464	28	2	0	1645
Radio	1279	76	160	10	30	2	2	0	102	6	106	6	1679
Heater	89	5	245	15	518	31	117	7	673	40	24	1	1666
Defroster	77	5	223	13	481	29	78	5	726	44	74	5	1659
Lighter	323	19	91	5	30	2	0	-	983	60	247	15	1674
Ashtray	482	29	105	6	62	4	0	-	982	59	45	3	1676
Hazard	58	4	64	4	154	9	1	0	1120	67	265	16	1662
Vent	812	48	346	21	157	9	41	2	272	16	51	3	1679

Black, Woodson, and Selby (1977)

One of the clearest and most concise human factors analysis of control design is contained in Black, Woodson, and Selby (1977). They divided controls into three priority levels based on their frequency-of-use, requirements for viewing the controls, and a critical incident analysis. In their analysis, potential hazards which required the operation of a control were described along with the outcomes (e.g., wet spray from passing truck obliterates driver's view of road, a serious accident could be the outcome). Those functions associated with the greatest potential hazards were window clearing (wiper/washer and defroster/defogger) and warning control (horn, turn signal, optical horn, headlight, hazard light). Also considered were the difficulties associated with coordinated operation of each control in conjunction with other controls and displays. Black et al. provide a single summary page for each control studied. That summary includes research results, expectancy for location and duration of operation, and a subjective estimate for the frequency-of-use. (See Figure 42



Headlights On-Off Switch
Control Function

I PRIORITY: 1 ☐ Finger-Tip Control (FTC)
2 ☒ Controls Within 30° Cone
3 ☐

II FREQUENCY

How Often Installed	How Often Used
☒ 1. Installed in all cars	☒ 1. Used frequently
☐ 2. " in many cars	☐ 2. Used occasionally
☐ 3. " in some cars	☐ 3. Used rarely

(The lower the product of the two values the more significant the frequency. Controls with values of 5 or greater have little frequency influence.)

Value: 1x1=1

Frequency Influence: Yes ☒
No ☐

III RELATED FUNCTIONS: Yes ☒ No ☐
1. ☐ Vehicle Control (e.g. gear selector, steering)
2. ☒ Visibility Control: a. Window Clearing (wiper)
    b. Mirrors
    ⓒ Lights (exterior/interior)
3. ☐ Warning Function Control (audible/optical)
4. ☐ Interior Environmental (air conditioning)
5. ☐ Entertainment & Miscellaneous (radio, CB)
6. ☐ External Control (hood latch, tailgate windows)
7. ☐ Seat Controls

IV POSITION RELATIVE TO FUNCTION CONTROLLED
☐ Relationship
☒ No Relationship

V LOCATION

a. Performance Research: McGrath (1975) showed improved performance with this switch located high on the instrument panel.

b. Expectancy: Left of steering wheel on panel. (McGrath 1975, MFI 1977); 89% of drivers.

OPERATION

a. Performance Research: None available. Problem occurs when driver fails to pull out switch all the way; instead of headlights gets parking lights.

b. Expectancy: PULL to operate; 80% (MFI 1977)

VI GENERAL HUMAN ENGRG & OTHER CONSIDERATIONS

Priority 2 controls are not required to be located at fingertip reach; however, frequency of use requires convenient location. Rsch suggested to test hdlight PULL vs ROTATE CW. Rotating controls best for multi-function modes.

VII CONCLUSIONS:

Locate on the left panel; PULL or ROTATE to operate. Lower panel position probably acceptable because driver does not usually have to look at control to operate it.

CONTROLS LOCATION AND OPERATION CRITERIA EVALUATION

Figure 42. Sample Analysis Page from Black et al., 1977

for an example.) That frequency estimate was obtained by multiplying the installation probability (1 = all cars, 2 = many, 3 = some) by the frequency-of-use if installed (1 = frequently, 2 = occasionally, 3 = rarely). While this computation has its shortcomings, the manner in which the suggested locations and methods of operation emerge from the evidence is fairly straightforward.

Based on their work and the literature, Black et al. suggested a future draft for Federal Motor Vehicle Safety Standard 101. (See Figure 43). Their proposal was extremely detailed, and includes precise human engineering minutiae (knob sizes, etc.). Its style (do this, don't do this), is similar to that of Woodson and Conover (1970). Interestingly, they propose that the defroster (front and rear), gear select, high-low beam switch, horn, beam flasher, ignition, turn signal, ignition, and wiper/washer all be within fingertip reach of the steering wheel, which they define as a seven-inch radius about the wheel center.

More specifically, their recommendations are as follows:

1. Wiper: Use a rotary selector switch/knob on fingertip reach panel pod to the left of the steering wheel near the top of an extended panel. This switch should be illuminated. (Recommended further testing of pod- vs. stalk-mounted control.)

2. Washer: Mount on button in center of above-mentioned rotary knob.

3. Headlight High/Low: Use fore-aft motion of a left-side stalk (Forward = High, Mid = Low).

4. Ignition/Starter: Use key switch (rotary) on panel.

5. Defrost/De-Fog: Place on single button on panel with other windshield functions (e.g. wiper/washer).

6. Cruise Control On/Off: Use button on end of right-hand stalk.

7. Audible Horn: Mount push buttons on steering wheel spokes.

8. Optical Horn: Place on left stalk, pull toward driver.

9. Climate Controls: Mount in upper right panel (cluster of four).

10. Radio: Mount in lower right panel, control knobs on both sides of frequency display

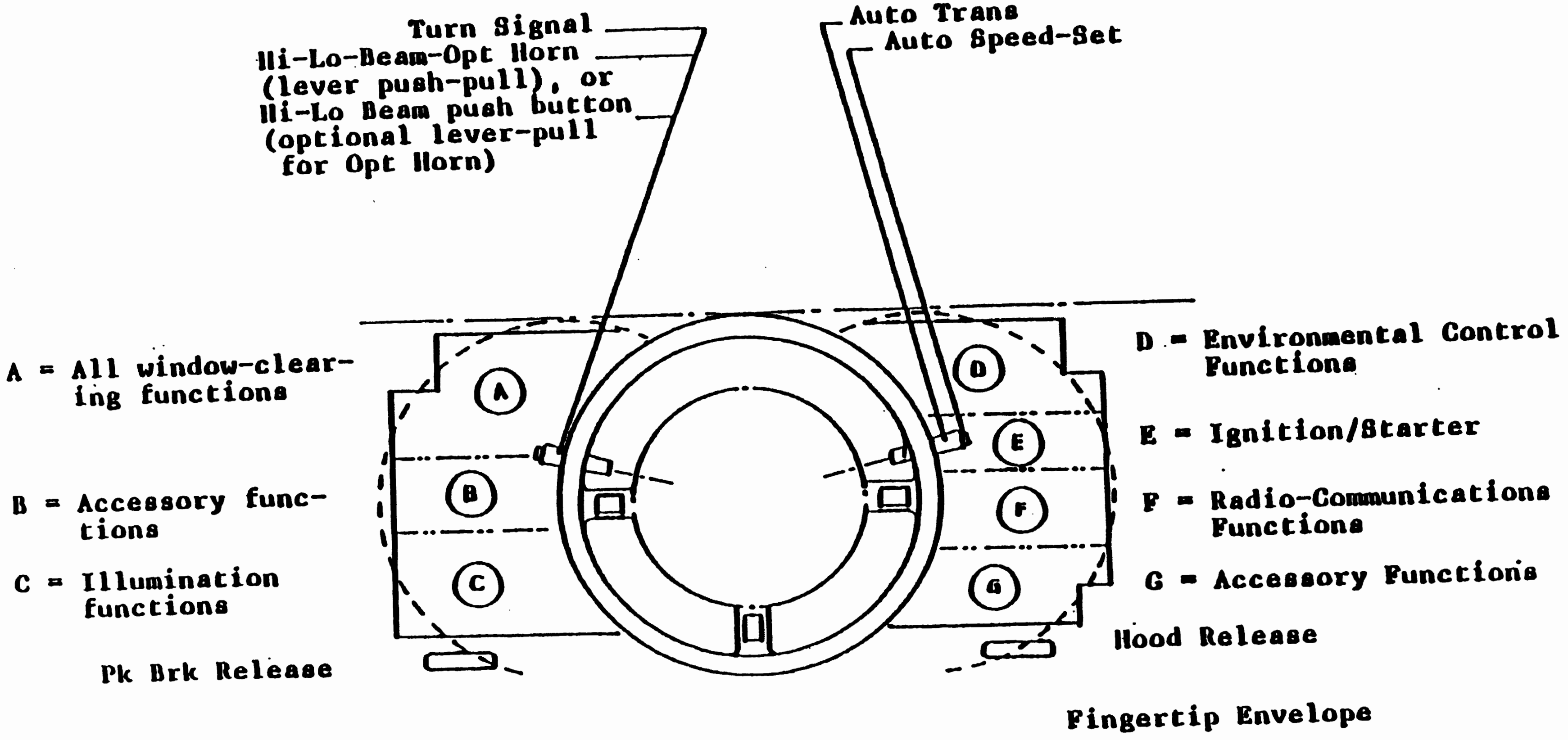


Figure 43, Proposed Controls Location Standard of Black, Woodson and Selby (1977).

11. Headlights/Parking Lights: Use left panel knob (pull on or rotate on).

This report contains many detailed recommendations about control size, shape, and so forth that are carried over from the Man Factors '79 report. Readers interested in those details should refer to the original report.

Green (1979)

Included in Green (1979) is a set of "suggestions" for the design of controls. (MVMA, the sponsor, thought the word "recommendation" was too strong.) Unlike some of the other reports described in this section, Green did not use a scoring system to reach conclusions.

His decisions were based on four general considerations: frequency-of-use, sequence, importance of the action, and functional grouping. In addition, the accident evidence, expected location, driver performance, and problems reported were also considered.

Green recommends the following:

1. Audible Horn: Active area should be both the steering wheel hub and spoke faces. Sounding the horn should flash the headlights.

2. Headlight Beam Switching and Optical Warning: This function should be on a left stalk. It was not clear if beam switching should be forward=high, pull towards driver=low, or, pull towards driver to toggle the beam setting. Flashing the headlights should also honk the horn.

3. Turn Signal: Left stalk, up for right turn, down for left.

4. Wiper/Washer: Green proposed two candidate designs for the wiper/washer with the final decision based on further research. One possibility was to use a left stalk. Twisting it would increase wiper speed and pushing the end button would operate the washer. The second possibility was to use a right stalk. Lifting it up would increase wiper speed. Pushing an end button or possibly pulling it towards the driver could operate the washer.

Friedman and Schmidtz (1981)

Friedman and Schmidtz (1981) (see also Khadilkar, 1982) describe, in very general terms, a human factors analysis of controls they carried out. They refer to compiling a "workbook," which was never released. From that information motor vehicle controls were classified into three categories:

"S" Controls - Those controls which may require quick activation while the vehicle is in motion in order to avoid a situation that may potentially result in an accident. Among them are the horn, turn signal, dimmer, wiper/washer, optical horn, and hazard light.

"F" Controls - Those "non-S" controls that are clearly identified by a high frequency-of-use when the car is in motion. They include automatic gear selector, radio, ashtray/lighter, and climate control.

"R" Controls - Those controls which are not generally used when the car is in motion or not having a particularly high frequency-of-use. They include the headlights on/off switch, the parking brake, and the ignition.

Further details concerning their analysis are not provided.

Green (1984)

Green (1984) describes the preliminary design of the TM-3 tripcomputer from the human factors standpoint. That product was planned to be standard equipment on the 1987-1/2 Lincoln Continental. Since the product is not yet on the market, the design data are still confidential. In brief, it lists the functional requirements of the product, the target population, the conditions of use, and general ease-of-use guidelines. There were five design iterations. Each proposal is described in detail (down to the level of switch legends and message wording).

In addition, the report identifies product-related research needs. However, the most important recommendations concern how the design process might be improved. A major mistake in this program was that no funds were allocated for testing users during the design phase. Thus, decisions about how keys should be labeled and messages worded were based upon the opinions of engineers and not the performance of users. The use of many small-scale studies to obtain empiric user feedback (often involving just 6-10 subjects) early in design is common in the computer industry. That approach should have been followed here. If such studies are to be carried out, then software to rapidly prototype user interfaces is needed. Again, this is a commonly done in the computer industry, and is critical if interfaces are to be easy to use. To the best of the authors' knowledge, these recommendations have not been carried out.

Saunby, Farber, and Jack (1986)

Throughout this review, the methodologies used by various experimenters in the course of their work have been described in some detail. They range from the mundane to the extremely elaborate, but a common point to all is that computers have little to do with the actual human factors data collection in them. They are nearly always used in the analysis of the collected data, but the process of collecting data is usually relegated to an experimenter using paper and pencil.

Saunby, Farber, and Jack have developed a computer program that collects and scores the data used for human factors evaluations. This program is written in BASIC for an Apple II computer. The menu-based program collects four types of information: identification data, objective data, expert judgment data, and descriptive data. The questions are presented one at a time on the computer display, along with the allowable responses. The checklist for displays, containing 107 questions, takes 10 minutes to administer. It addresses five topics: visibility, identification, analog-specific features, digital-specific features, and warning light features. The 154-question checklist for controls takes 25 minutes. For controls, the four areas addressed are ease-of-use, findability, setting verification, and the grouping of look-alike controls.

For each control and display the program computes a figure of merit (0.00 = fails to conform, 1.00 = fulfills human factors criteria). That figure is based upon the weighted responses to the questions about each control and display. The weights were set by the authors of the program based on their opinions. A flowchart for a typical question sequence for displays is shown in Figure 44. (They do no give an example for controls.)

The standardized scoring procedure allows comparison of scores between vehicles to identify the suitability of varying designs. The authors caution that the checklist is by no means exhaustive, and should be used in combination with other information to arrive at conclusions. The program has not been validated against performance data and there is no data on between-user reliability. Furthermore, the authors point out that the methodology was developed for individual components (e.g. speedometer, headlight on/off switch) and is not suitable for more complex systems. (e.g., climate control system.)

On the other hand, Saunby et al. identify the potential this system has for teaching new human factors personnel about the application of human factors principles to automotive design. The checklist and scoring procedures clearly demonstrate the level of detail involved in such analyses, and could be used to educate personnel in other professions about the human factors field. There are not enough human factors personnel in the industry to handle all the problems that need their attention. This program serves as an electronic surrogate.

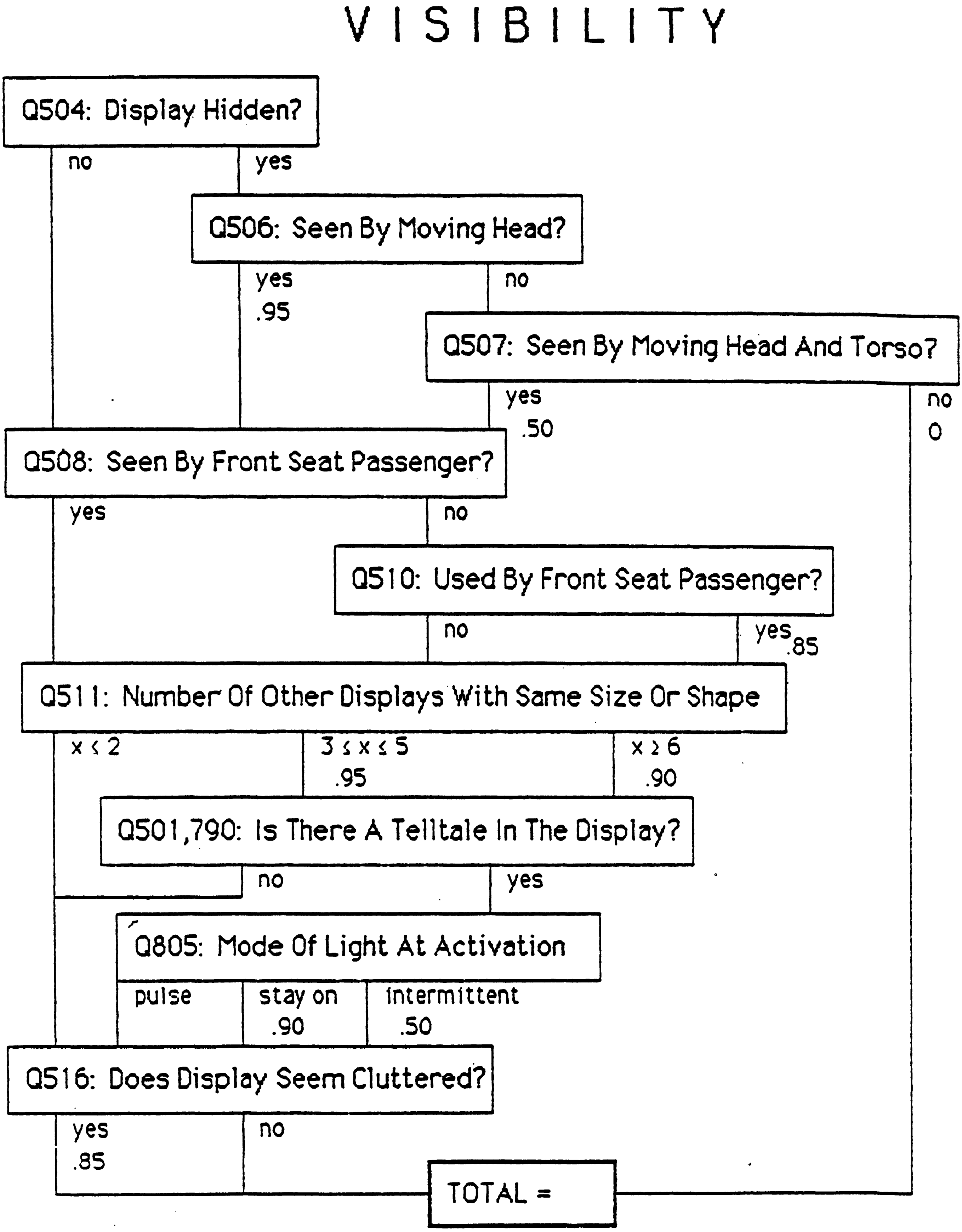


FIGURE 44, SCORING PROCESS FOR DISPLAY VISIBILITY ANALYSIS

Models Of Human Error

While the emphasis of this report is on research specific to automotive applications, failure to mention developments in a few other contexts would leave this report incomplete. The human factors profession has a long tradition of studying human errors (Fitts and Jones, 1947a, b). Most commonly this approach has been applied to predict human errors in the fabrication and delivery of nuclear weapons. To the best of the author's knowledge, this approach has not been applied to automotive design, thought it could be. The most complete overview of the subject is Meister (1971) That report describes 19 models of potential application to this same problem. (Briefer overviews are given in Meister, 1973 and Swain, 1963.) A summary of the analytic models of operability (reproduced from Meister, 1971) is shown in Table 46.

The AIR (American Institutes of Research) Data Store (Munger, Smith, and Payne, 1962) is a compilation of performance data from 164 psychological studies listing response times and error rates as a function of control and display design. The base provides considerable information about the operation of simple controls (toggle switches, rotary switches) and displays. Multiplying the probabilities for each task characteristic yields a figure for person/equipment reliability. For reference purposes, a sample table drawn from the AIR Data Store is presented in Table 47. Unfortunately, not much effort had gone into updating that data base, and in many ways it is deficient. For example, no data are provided for discrete multidirectional levers (or combined levers). Furthermore, because the information was collected for single-task performance, it is uncertain how relevant that data-base is to a timesharing activity such as driving. In addition to flaws in the supporting data, this approach (and several others) assumes that a simple multiplicative model is adequate, without interactions, and it is not known how valid that assumption is.

THERP (Technique for Human Error Rate Prediction) is an extension of the AIR Data Store. It differs primarily in permitting both continuous tracking and discrete switch-throwing behaviors and allowing for both independent and dependent operator activities.

Table 46. Summary of Analytic Models of Operability

A. Operability Prediction Models
    1. Analytic Methods
        a. American Institute for Research (AIR) data store
        b. THERP–Technique for Human Error Rate Prediction
        c. TEPPS - Technique for Establishing Personnel Performance Standards
        d. Pickrel/McDonald
        e. Berry/Wulff
        f. Throughput ratio
        g. Askren/Regulinski model
        h. DEI-Display Evaluation Index (Siegel model)
        i. Personnel Performance Metrix
        j. Critical Human Performance and Evaluative Program (CHPAE)
    2. Simulation Methods
        a. Digital Simulation Model
        b. TACDEN
        c. Boslean Predictive Technique
        d. Human Operator's Simulation (HOS)
        e. ORACLE - Operations Research and Critial Link Evaluator
        f. Personnel Subsystem Effectiveness Model

.B. Maintainability Prediction Models
    1. ERUPT - Elementary Reliability Unit Parameter Technique
    2. Personnel reliability index
    3. MIL-HDBK-472 Prediction Methods

Table 47, Sample Listing from AIR Data Store

LEVER

(Bar control which moves in a single plane; includes use of wrench or pliers to make adjustment.)

BASE TIME = 1.15

Time added	Reliability	
		1. Length
0	.9990	a. Long lever with arm movement, <u>or</u> short lever with wrist or finger movement
0	.9920	b. Short lever with arm movement
		2. Support of operating member
0	.9990	a. Present
.50	.9950	b. Absent
		3. Plane of movement
0	.9992	a. Vertical
0	.9999	b. Horizontal
		4. Control movement amplitude (Extent of movement from one extreme to the other.)
0	.9964	a. 5-10°
.20	.9970	b. 10-20°
.40	.9975	c. 30-40°
.60	.9985	d. 40-60°
		5 Control resistance
		a. Hand operation
0	.9999	(1) 2-5 lbs.
.50	.9992	(2) 10-20 lbs.
		b. Arm operation
0	.9990	(1) 2-5 lbs.
0	.9999	(2) 10-20 lbs.
.50	.9995	(3) 20-30 lbs.
		6. Control/display movement relationship (direction of movement)
0	.9999	a. Direct
1.00	.9985	b. Reverse
		7. Control/display movement ratio (Usually defined in terms of distance.)
1.50	.9957	a. 1:1
1.50	.9970	b. 1:3
1.00	.9983	c. 1:6
.50	.9975	d. 1:15
0	.9985	e. 1:30

Source: Munger, Smith and Payne (1962).

TEPPS (Technique for Establishing Personnel Performance Standards) differs from THERP in that it deals only with discrete tasks and relies entirely on expert judgments of task performance reliability. The weakness of TEPPS is that reliability between judges is low. These models do, however, provide insight into the problems of multifunction control design and evaluation; especially those models detailed previously. The models address many issues (e.g., the need for objective error estimates, the frequency, nature, and independence of multiple errors, etc.) yet to be resolved in automotive human factors literature. Currently, models such as these are used extensively by human factors specialists for the design of nuclear power plant control rooms. (See Kemeny, 1979.) Within the human factors community there is sharp disagreement between those favoring the models and those not.

Card, Moran, and Newell (1983)

While it has yet to see any automotive application, the work of Card, Moran, and Newell (1983) is particularly noteworthy. Their Model Human Processor is a summary of human performance that describes human behavior in much the same way one would characterize the behavior of a digital computer. The model consists of parameters for the decay time and capacity of several memory systems, cycle times for the processors, and rules of operation. (See Figure 45.) It was developed from data in the psychological literature and is used to design and evaluate user interfaces to computer systems. In its current form, it is most appropriate for analyzing "routine cognitive activities" performed by experts, not occasional activities such as operating secondary controls. Also, the model is intended for single task performance, not a timesharing activity (such as driving). While driver use of controls does not fit the conditions of the model ideally, the results of Model Human Processor calculations can still be quite useful.

A derivative of the Model Human Processor, the Keystroke Model, has been successfully used to analyze word processors (Roberts and Moran, 1983). The Human Processor Model should be most useful in predicting performance for highly interactive systems, such as trip computers, and less useful for predicting performance with conventional secondary controls. Similar models were used successfully during Project Mercury to design space capsule instrument panels (Lindquist and Gross, 1958; Gross, Lindquist, Peterson, and Blanchard, 1964.)

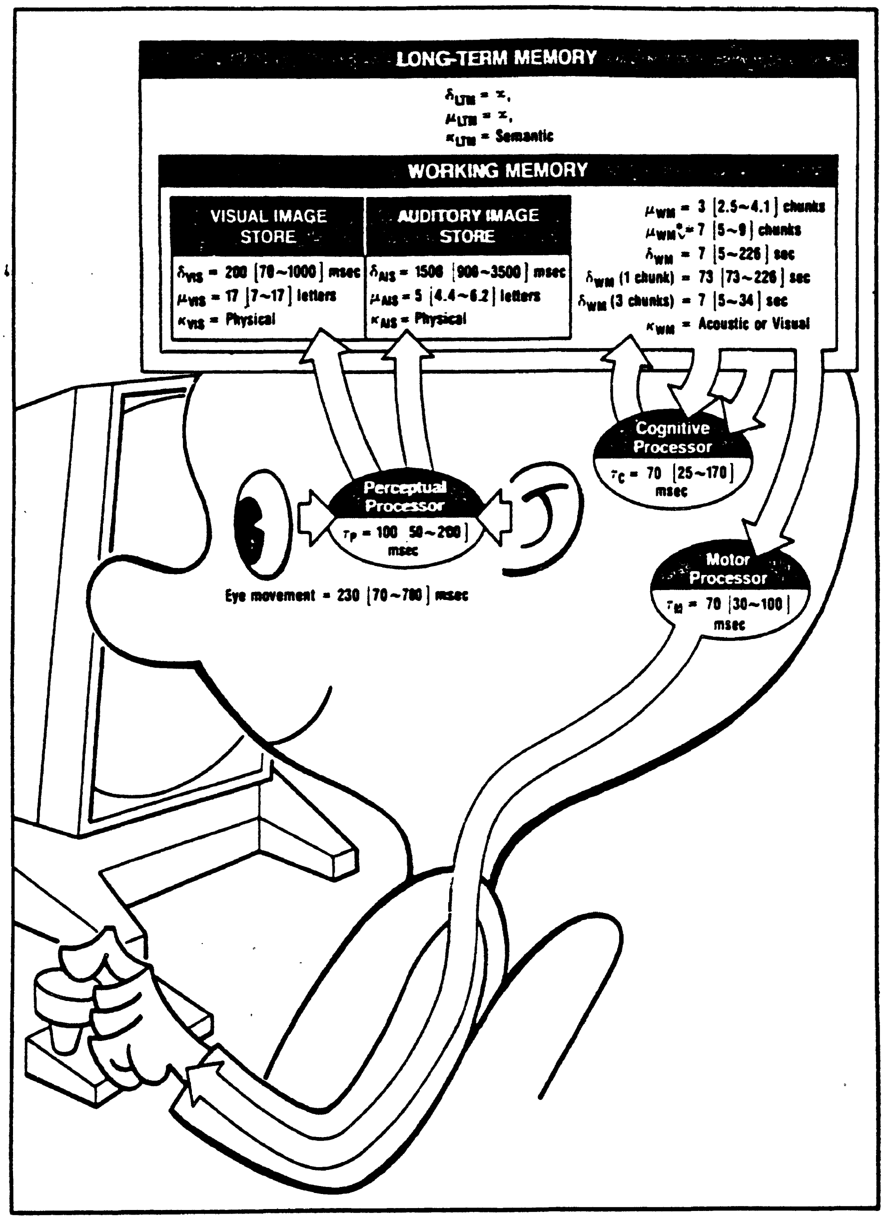


Figure 45, Model Human Processor

Rapid Prototyping

Whereas typical product development cycles are 3-5 years in the automotive industry, they are typically 1-2 years for computers. Because computer development times are so short, software was written to enable designers to quickly mockup user interfaces and obtain user reactions to them. (See Poor, 1986 for examples.) As development cycles for automobiles are reduced, software for simulating the design and operation of controls and displays will be required. At the present time, there are no automotive examples of the use of rapid prototyping methods and, other than the research at The University of Michigan (Wesselman and Green, 1986), no research even remotely related to automotive applications is being carried out.

Summary

Human Factors analyses of automobile control design vary from very general discussions of various configurations (e.g., Woodson et al., 1969) to structured evaluations (e.g., Mortimer and Post 1973; Saunby et al., 1986). The general evaluations have emphasized identifying the factors associated with a control's criticality, and using that information to make decisions about how it should be designed. Several factors have been consistently identified as important: the frequency-of-use of a control, how urgent the associated action is, the opportunities for and consequences of inadvertent operation, the time required to use a control, and the controls and displays each control is used with. There is ample information on all of those factors in the literature except frequency-of-use. The only substantive frequency data appears in Simmonds (1975b) and Anacapa Sciences (1976), and that information is incomplete.

The most common use of this information has been to recommend how a standard instrument panel should be designed. (See for example, Woodson et al., 1969; Malone et al., 1972, Black et al., 1977; Green, 1979.) Over time recommendations have changed from recommending panel-mounted controls to recommending stalk controls.

Associated with this work on design principles mentioned previously have been efforts to identify specific design recommendations for controls, especially dimensional data. Much of this work has been reported by Woodson and his colleagues and is based upon accepted human factors practice. While some of this data is old, the specific recommendations (e.g, for knob sizes) have not changed over the years and are unlikely to. These recommendations are based on human anthropometry and basic principles of behavior which take generations to change. The amount of literature on this subject is considerable and many of the critical questions about "knobs and dials" have been answered.

Complimentary to those approaches are ones that try to develop a figure-of-merit for a design, such as Mortimer and Post, but especially Saunby et al. These approaches are most useful in evaluating completed designs. They should prove to be very useful for solving practical problems. They have not yet been validated, so they must be used with some caution.

There are several human factors analysis methods that have been developed in non-automotive contexts that could be useful for designing controls. The human error modeling work done in the nuclear industry could be used to provide quantitative measures of the quality of various designs. Likewise, the Model Human Processor shows promise as a technique for evaluating highly interactive clusters, especially tripcomputer, entertainment systems, and navigation systems. Before these models are used to solve practical design problems a review of test cases is needed.

One area where the automotive industry has lagged behind the computer industry is in the development of prototyping tools (e.g., Wesselman and Green, 1987). As the pressure increases to shorten the design cycle, it will become more important to be able to rapidly simulate and test instrument panel clusters.

WHAT DO THE CURRENT DESIGN STANDARDS REQUIRE?

There are five key documents, two of which are standards, that affect the design of automobile controls and displays in the United States: ISO Standard 4040 (Location of Hand Controls, Indicators and Tell-tales) and Federal Motor Vehicle Safety Standard 101 (Controls and Displays). Also of importance are Regulation 21.01 - Directive 74/60 published by the European Economic Community, and two Society of Automotive Engineers (SAE) documents; SAE Recommended Practice J1138 (Driver Hand Controls) and SAE Information Report J1139 (Driver Hand Controls). These will be reviewed one at a time in this section.

ISO Standard 4040

The first (and current edition) of this standard was released in 1977, and makes the following recommendation:

The operational area of the following controls, when fitted to a car, shall be located to the left of the steering column:

- driving lights control (headlight switch)
- side and rear lights control
- driving light/passing light dip control (high beam)
- optical warning control (beam flasher)
- direction indicator control (turn signal)
- emergency braking control (right-hand drive only)

It also gives graphic information on operational areas of controls and display areas of indicators. (See Appendix C.) These requirements are minimal at best and are easily satisfied. The authors believe that this standard allows too much leeway in the location and design of controls. While ISO has made progress in developing standards in many areas, such progress is unlikely with regards to controls and displays. While representatives to ISO committees are supposed to be independent technical experts, the second author's experience has been that some behave as representatives of their employers. Hence, for example, if a question about control placement were to arise, their response would be to pull out product brochures and see how the change affects their products, and not to ask whether it makes sense from an ergonomics perspective. Further, to address many of the questions at hand, cross-cultural research is needed, and no government, company, or trade association is willing to support that work.

European Economic Community Regulation 21.01 - Directive 74/60

This directive regulates the interior fittings of vehicles manufactured in the EEC, and includes control arrangements as well as seats, sliding roofs, etc. The emphasis of the document is on the effects of control placement and design on crashworthiness, not ease of use. The detailed specifications in this document emphasize testing procedures to be used to assure compliance. They provide information on how far a switch can protrude from a surface, how rounded the surface must be, and other considerations to minimize injuries during impact. Readers interested in these details should peruse the directive contained in Appendix D.

In many ways this standard is quite general. It, like many EEC standards with a British tradition, is subjective, and depends upon interpretation by the individual inspectors who assure compliance. In contrast, regulations and standards in the U.S., which most readers of this report are familiar with, are described in precise, legal terms.

Federal Motor Vehicle Safety Standard 101

Virtually all cars sold in the United States must meet the requirements of Standard 101. (See Appendix E.) That standard specifies requirements for the location, identification, and illumination of controls and displays. The majority of the standard is concerned with lighting and labeling issues.

With regard to controls, the standard requires that a number of secondary controls be operable by the driver while wearing a three point restraint (horn, ignition, headlamp, turn signal, panel brightness, wiper/washer, front and rear defrost/defog, choke, cruise control, hazard, and the driver's sun visor). The standard says nothing about where they should be located nor how they should operate. Labeling requirements, such as where symbols might be used and which words are appropriate, are covered in great detail. These requirements will not be covered here as labeling is not the focus of this report.

In response to several petitions, the Federal Government recently reissued an older version of the 101 standard as Standard 100. The older version differs slightly in the lighting requirements and only applies to cars made before September 1, 1989 (Federal Register, Part M, March. 9, 1987, page 7151).

The current 101 Standard is a very weak document. It does not say anything about where controls belong (other than drivers should be able to operate them), and neither reflects the current state of knowledge or accepted human factors practice.

SAE Documents

SAE is a professional organization which consists primarily of engineers within the U.S. but also has some international membership. Within the SAE organization, the body responsible for standards concerning automobile controls is the Controls and Displays Subcommittee of the Human Factors Engineering Committee.

SAE has three types of documents they can issue to influence design, Information Reports, Recommended Practices, and Standards. All of them are described in the SAE Handbook (Society of Automotive Engineers, 1987), the "bible" of the industry. Information Reports are "compilations of engineering reference data or educational material useful to the technical community" (Handbook item 7.3.3). Recommended Practices are described as "documentations [sic] of practice, procedures and technology that are intended as guides of standard engineering practice. Their content may be of a more general nature, or they may propound data that have not yet gained broad acceptance" (Handbook item 7.3.2). Standards are referred to as "documentation of broadly accepted engineering practices or specifications for a material, product, process, procedure, or test method" (Handbook item 7.3.1). So, Information Reports contain ideas engineers should know about, Recommended Practices are procedures engineers should follow, and Standards are procedures engineers must follow. However, in this context "must" doesn't mean "required" because the standards are voluntary.

As noted previously, there are two SAE documents relevant to this report, SAE Recommended Practice J1138, Design Criteria-Driver Hand Controls Location for Passenger Cars, Multi-purpose Passenger Vehicles, and Trucks (10,000 GVW and Under), and SAE Information Report J1139, Supplemental Information-Driver Hand Controls Location for Passenger Cars, Multipurpose Passenger Vehicles, and Trucks (10,000 GVW and Under).

The Recommended Practice (in Appendix F) states that drivers should be able to reach and grasp 11 controls (steering wheel, gearshift, turn signal, ignition, horn, dimmer, wiper/washer, headlamp, defroster, hazard, and hand brake) while wearing a lap and shoulder belt. It is not clear if extension of the shoulder belt is allowed. The Practice also states that seven other controls (beam flasher, climate, radio, vent remote control, lighter, ashtray, and "accessory controls") must be in reach when only a lap belt is worn. (Accessory controls are never defined.)

The Practice also states that the horn should be on the steering wheel. In addition, the driver should be able to read the displays for the wiper/washer, headlamp, defroster, climate, radio, remote vent, lighter, ashtray, and accessory controls, all with minimal head movement. Finally, the Practice states that the turn signal, dimmer, wiper/washer, headlamp, and beam flasher controls should be to the left of the steering wheel centerline, and the gearshift, ignition, defroster, hazard, climate, radio, lighter, and ashtray should be to the right.

This Practice has few requirements and in some cases does not reflect current knowledge. The Practice was last approved in 1977, and what is most surprising is that it is only a Practice, not a Standard. The dated nature of the Practice is evident in several areas:

1. The requirement concerning reach while only wearing a lap belt makes no sense at all. Many states require that both a lap belt and a shoulder belt be worn while driving. Further, in almost all U.S. cars, they are a single system (three point system), so one must wear both or neither. Thus, according to SAE Practice, a number of controls that are commonly used while a car is moving, such as the radio and climate controls, can be located where the driver cannot reach them while belted.

2. Related to this is the failure of this document to mention that mounting controls at the maximum extent of reach is the absolute minimum acceptable standard. Drivers want the controls much closer to them than the farthest they can reach. (See Hallen, 1977.)

3. The Practice does not reflect the current state of knowledge. For example, none of the literature written since 1979 is referred to (e.g., Green, 1979; Jack, 1985), and some of the literature written 10 years ago is ignored. This should not be so, since SAE documents are supposed to be reviewed and re-approved every five years.

4. The Practice does not mention any other commonly accepted human factors design standards such as Military Standard 1472C (U.S. Department of Defense, 1981). As noted later, that document contains extensive recommendations on the size, spacing, and desired operating forces for controls. That information is never mentioned and should be.

5. In most cases, the Practice is far too loose. For example, as described later, when controls are located more than five inches from where drivers expect them to be, there is an increase in the time to reach for and operate controls. Yet the Practice only constrains controls (and then only some of them), to a particular side of the steering wheel.

6. Finally, the practice never acknowledges why human factors issues are important, namely because people prefer vehicles with controls that are easy to use, and that controls that take a long time to use distract drivers from paying attention to the road and could cause accidents.

SAE Information Report J1139 (in Appendix G) contains commentary that supports J1138. For the most part, it describes the research carried out by Anacapa (e.g., Anacapa Sciences, 1976). That research is also described in detail in this report.

While J1139 does contain a few specific suggestions (e.g., don't put the parking brake and hood release next to each other, don't make the climate control look like a radio, put the lighter near the ashtray), the report should include much more fundamental human factors data (similiar to that in Military Standard 1472C). Finally, the report identifies some of the direction of motion stereotypes for controls, but not all of them. At this time, for example, the data from Jack (1985), described earlier, should be added.

- WHAT DO THE CURRENT DESIGN STANDARDS REQUIRE? -

HOW SHOULD CONTROLS BE DESIGNED?

How Should Designers Prepare For Control Design?

The most current overview of secondary controls research is contained in this report, which is a good place to start for designers of secondary controls. Another important resource is a human factors textbook such as Sanders and McCormick (1987), which contains a broad range of information relevant to controls design. MIL-STD-1472C, considered the Bible of the human factors field, is also essential reading for designers, as it contains lengthy and exacting descriptions of standards for control arrangements, coding, dimensions, actuation forces, etc.

Finally, designers should consider attending a short course on human factors, both to learn current design practices and to meet others in the field who may become important resources. One such short course is taught at the Chrysler Center for Continuing Engineering Education at the University of Michigan.

General Design Rules And Methods

There have been many studies carried out on control design, unfortunately most of them are over 10 years old. In many cases, the research literature must be applied with some caution because the designs tested and driver expectancies on which they are based do not reflect the current practice.

However, the general design rules have not changed and to many they seem like common sense. That is true in some cases, but common sense often may not be common knowledge until it is explained. Most of these rules have been mentioned in the "Human Factors Analysis" section. What the authors have done in the section that follows is to list those rules, and support them wherever possible, with specific automotive research. In some cases in the past, this supporting information was not provided.

When applying these rules users should keep in mind what makes an instrument panel good from the human factors perspective. A good instrument panel minimizes the opportunities for accidents. This means that use of the controls does not distract the driver from paying attention to where they are going. Also, for controls used in an emergency (e.g., honking a horn to alert another driver who may not see them, turning on the wiper to clear spray from the windshield, etc.), one should be able to use them quickly. The accident literature suggests the distraction problem is more common.

A good instrument panel is also easy to use. Drivers should be able to find a control without difficulty the first time they look for it and require no instruction on how to operate it. Performance measures of interest include the time and errors associated with looking for, reaching for, and operating controls.

Rule 1 - Put controls where they are expected.

It is clear that there is a strong relationship between the time to use a control and how far it is from where drivers expect it to be. In brief, the work of Anacapa (1976) show that there is no or little decrement in performance if a control is within five inches of where a driver expects it to be and on the expected surface. The farther a control is from where it is expected the longer it takes to use it. This relationship is linear with distance as well. Anacapa Sciences (1974) also noted that time-to-locate and error rates were "...positively correlated (r=.54) with the degree to which the control locations agreed with the expectancy patterns determined in our earlier studies" (p.2). Thus, expectancies and performance do tie together.

Expectancies vary with the target population. Most of the surveys in this study examining control expectancies have used American drivers as subjects. Americans tended to expect panel-mounted controls, while Europeans were more used to stalk controls, especially the French and Italians for the headlight switch (39%) and the French and British for the horn (50%). Since expectancies strongly influence where controls should be located, this suggests that it will not be possible to design a "world car" to meet these conflicting expectations.

There appear to be some standard expectancies for control locations across the different experiments, including headlights on left panel, horn on steering wheel hub, and climate controls and radio on panel to right of driver. Other items, such as windshield wiper/washer controls, while generally expected to be to the driver's left, may be mounted either on stalks or on the panel (Anacapa Sciences, 1976).

The difficulty in applying distance and location rules is that expectancies change with time. Most of the expectancy data are over 10 years old and were collected before the use of stalk controls was common. In Appendix A are expectancy data for the secondary controls of interest. Expectancies for each of those controls are also identified in the specific design recommendations that follow.

Rule 2 - Put controls used for critical functions closer to the driver than others.

The horn should be close to the driver because it is often necessary to warn other drivers of one's presence. For example, if a driver is backing out of a stall and is about to back into another driver in the aisle, one doesn't have time to search for the horn. Likewise, if one is driving down the road and a passing vehicle splashes mud on the windshield totally obscuring one's view of the road, it is important to be able to clear the windshield quickly.

Malone et al. (1972) assigned controls subjective criticality levels based upon their effect on driver safety. Controls which were given priority ratings included wiper/washer controls, headlight control, horn control, and high/low beam control. Black et al. (1977) maintained that the defrost/defog control was also critical, and suggested that it be mounted as a one button control next to the wiper/washer controls on the instrument panel.

Rule 3 - Frequently used controls should be closer to driver than others.

One way to achieve ease-of-use is to minimize the cumulative time spent using controls. This can be achieved by locating the most frequently used controls close to the driver. Unfortunately, there is very little quantitative data on how often various secondary controls are used. The International Standards Organization (1975) data (described in the "Human Factors Analysis" section) is very incomplete. For example, no data are given for either the climate controls or the radio. Common experience suggests the radio is a high frequency-of-use module and it is for that reason that many manufacturers are considering installing remote controls for the radio on the steering wheel hub.

In determining reach recommendations, use the Hallen (1977) data to determine what comfortable reach is. The common procedure is to use the SAE maximum reach curves and put controls at the edge of the envelope (as far as drivers can reach), which is inconvenient for drivers. Hallen's data suggests they should be at least 10 centimeters and sometimes 20 centimeters closer.

Rule 4 - Put controls that are used together next to each other.

This is often referred to as the sequence-of-use principle. In general the flow should be left to right and top to bottom. While this principle is usually followed, there are many instances where the principle has been violated. For example, in one late model car, the cruise set, resume, and coast controls are on the right stalk, but the on-off switch is on the left.

Rule 5 - Select a control allowing the proper number of choices.

This rule comes from the basic human factors literature and has not been specifically examined in an automotive context. In brief, it implies that one should use rocker switches and slide switches for two-position controls, and rotary selector switches and slide switches when there are three or more choices. Pushbuttons should not be used when there are more than two choices (except possibly for radio station selection because of convention, and maybe for the climate control as well). Rotary and slides switches clearly indicate the user can select only one option at a time. That is not true for a pushbutton array. Also, for two-state controls, push-push buttons and pull-push knobs are not recommended because it is difficult to tell from the position of the switch which state has been selected.

Rule 6 - Have controls operate as expected.

The rule of thumb is that controls should move up, to the right, or forward for "on" or "increase." Data on population stereotypes are widely available in the literature, so they have not been repeated here. With regard to specific automotive applications, the Jack (1985) data for rocker switches are contained in the driver performance section. The authors understand that Jack is now collecting stereotype data for other types of controls.

Rule 7 - Keep designs consistent across product lines.

While people may not buy the same model car each time they get a new one, they do tend to stay with particular manufacturers. ("My dad always bought Chryslers.") To take advantage of previous experience, the design of controls should be consistent across product lines. They need not look identical, but controls should be located in the same place and operate in the same manner.

For example, Krumm et al. (1972) reported initial mean reaction time for an unfamiliar panel to be 4.3 seconds, compared to 1 to 2 seconds for "human-factored" panels. This demonstrates the need for consistent instrument panel design across product lines, since the time required to adapt to a new panel would be minimal. Perel (1983) supports this premise, pointing out that 34% of the passenger car drivers in an Indiana accident study had less than six months familiarity in their vehicles, and that one quarter of the total accident-involved drivers had less than 2,000 miles on their vehicles. This data strongly suggests that instrument panel unfamiliarity is a critical factor in vehicle accidents, and that that control design consistency is essential.

Rule 8 - Label all controls clearly.

Anacapa Sciences (1976) reported that drivers made three times as many errors searching for controls when the words and symbols were missing than when they were present. A common problem with controls, usually with functions that are less common, is that switches are labeled with abbreviations that are not well understood. When symbols are used, sometimes they are not understood either (Saunby, Farber, and DeMelli, 1987; Sayer and Green, 1987). This is particularly true for some of the symbols that are not in the ISO standard set or are new to the standard.

Proper labeling is difficult to do with stalk-mounted controls, and the data shows that these types of controls are used in most vehicles manufactured today. Thus, it is essential that those controls which are stalk-mounted be both easy to locate and operate.

Rule 9 - Use iterative design and test, test, test.

Just as important as what to do is how to do it. The favored method for developing user interfaces is commonly referred to as iterative design. This approach has been very successful for designing computer applications. The best known example is the Olympics Message System (Gould and Lewis, 1985; Gould, Boies, Levy, Richards, and Schoonard, 1987). It has not been used by the automotive industry. In brief it entails developing a prototype of the cluster or component in question, testing a small number of users, and relying upon performance data and comments from them to identify problems. That information is used to redesign the item in question. The cycle of testing and then redesign repeats, often several times. Tests and feedback from tests should not be an afterthought but an integral and planned step in the design process.

If those results are to be useful, some of them must be in numeric form (e.g., times and errors) so that one can make decisions about where changes are needed. Furthermore, one needs criteria with which those data can be compared (e.g., 95% of the driver are able to operate each control within 2 seconds of being asked to do so). Those criteria must be developed in advance of any testing.

In order to carry out such tests the ability to rapidly prototype clusters needs to be developed. Software tools for that purpose do not exist in the auto industry.

It is the authors' opinion that following this process is essential. The benefits derived from the process are likely to be as large as those from following all the other rules.

Rule 10 - Use empiric methods to analyze alternatives.

Many design alternatives can be evaluated on paper. Methods that show particular promise are the Model Human Processor (of Card, Moran, and Newell, 1983) and some of the error likelihood methods described in the human factors analysis section. Each requires some additional information in order for it to be applied. For the Card Model, there is a need for data that takes into account timesharing. As was noted earlier, the Card data is for single task performance but driving involves timesharing. For the error modeling to be useful, there is a need for frequency-of-use information on controls. As was noted before, current information on this is lacking.

Rule 11 - Follow the specific advice in Mil-Std-1472.

Military Standard 1472 contains a wealth of specific recommendations for sizes, spacing, required forces, and other details concerning how controls should be design. The standard is based on solid data, which because of the nature of the research on which it is based, will never be out of date. When applying these data designers should be careful to examine which are minimum requirements, and which are recommended values.

The rest of this section contains design recommendations for the following controls, listed in alphabetical order:

Cigarette Lighter
Climate Control
Cruise Control
Defrost/Defog
Hazard
Headlights
Headlight Dimmer
Horn
Ignition
Optical Horn
Radio
Wiper/Washer

Since it is possible this section will be used like a handbook, the material on each control starts on a new page.

When the authors began this compilation, it was hoped that examination of the literature would yield specific design recommendations for individual controls. Unfortunately this was often not the case, and instead summaries of the various recommendations are presented, along with some commentary from the authors. It should be noted that many of these recommendations are based on expectancy data which is nearly ten years old. With expectancy lag effects and generally slow changes in model design, this data still has some value, but there is a serious need for more current research in this area. For example, the current mix of operating automobiles includes a far greater number of imported cars from Europe and Japan, many of which make more use of stalks than American cars. It is very likely that this has changed drivers' expectancies in the area of control location, but there is no current research to prove this. Green, Ottens, Kerst, Adams, and Goldstein (1987) have recently collected new driver preference data for switch types and locations, and that work could radically alter the recommendations given here. (Because this report was written before Green et al. (1987) was completed, those recommendations have not been included here.) Furthermore, new control configurations such as pods and touch screens are not considered in much of the current literature. More research is needed in both areas before design recommendations can be made. Thus, these recommendations emphasize past research and standards, and utilize the best information available when the report was written.

Cigarette Lighter

The cigarette lighter is not directly related to driver safety, but either trying to find it or operating it can create a distraction. Furthermore, misuse might even lead to a fire hazard. Using the lighter involves removing one hand from the wheel for a time sufficient to grasp it and hold it while lighting a cigarette. Thus, minimizing this time through careful location of the control should be a design goal. It should be noted that there is no frequency-of-use data available for the cigarette lighter. While non-smokers will very rarely operate this control, smokers will operate it frequently. Furthermore, there is no current data regarding driver performance in locating and operating this control.

The SAE Recommended Practice (J1138) calls for placing the cigarette lighter to the right of the steering wheel, presumably on the instrument panel. Anacapa Sciences (1976) confirmed this in driver expectancy tests, with drivers consistently expecting the lighter to be located on the lower right instrument panel. However, there seems to be a lack of conformity among manufacturers, since Anacapa Sciences (1976) also reported in the results of their Control Location Performance Test that, of nine controls, the cigarette lighter was the third most difficult to locate. This may well be due to some manufacturers choosing to conceal the lighter inside the ashtray compartment. (See the "Photo Test" data in the driver performance section.) However, the consensus seems to be to place the lighter on the center instrument panel, preferably near the ashtray. The Man Factors suggested design standard places the cigarette lighter with the ashtray at the bottom of the console to the right of the driver. The Essex panel does likewise, with both items located at the bottom of the console directly over the transmission tunnel.

As the prevalence of smoking in the adult population declines, so too will the frequency of use of the lighter and concern for where it is located. It has been said by some that by the year 2000, smoking will be viewed in the same way as public spitting; something not to be done, and done by few. However, some devices still use the cigarette lighter as a power source inside the vehicle (e.g. radar detectors), and thus it is unlikely the automakers would phase out the cigarette lighter as a standard accessory.

The authors' recommendation is that it be located close to the center line of the car as the SAE Recommended Practice requires and away from any vents. While locating the lighter inside the ashtray makes it more difficult to find, that location makes it more difficult for it to be operated inadvertently by young children. If the lighter is located there, it is critical that the ashtray be labeled with the lighter symbol so the driver can more readily find it.

Climate Controls

This section considers the climate controls as a group but not the individual controls in the cluster. Furthermore, recommendations for Defrost/Defog are summarized under a separate heading, a practice consistent within the literature.

Climate controls are not directly tied to driver safety, but are used frequently enough and are complex enough that their design and location are important for safe driving. Minor adjustments with the climate controls should be easy to make, and control location and operation should not distract the driver.

The SAE Recommended Practice (J1138) suggests that climate controls be located to the right of the steering wheel, within easy view, and labeled with simple words. The Control Location Performance Test in Anacapa Sciences (1974) found climate controls the third-easiest to locate in slide-projection and on-the-road tests (see the "Photo Test" data), which suggests a fair degree of consistency in location among manufacturers. Further, Anacapa Sciences (1976) reports a mean time of 1.7 seconds to locate the climate controls. However, higher times were reported by Khadilkar (4.2 s.) and Malone (5.1 s.), who included both reach and operating time in their measurements, while Anacapa only included reach. This suggests that operating the climate controls is more difficult than other secondary controls. Anacapa Sciences (1976) also reported that a survey of 1,482 motorists in California indicated that climate controls were found equally well whether located on the left or right panel, but were more difficult to operate when located on the center console, where the required reach is longer.

With the many variations of airflow available to the driver (panel, bi-level, floor, fan speed, temperature, etc.), there is a tendency among manufacturers to attempt to assign discrete controls to each position, usually in push-button form. Human factors texts are unanimous in suggesting slide switches or knobs for such multiple-position discrete controls, as opposed to the aforementioned push-buttons. Unfortunately, the authors do not know of any data to support this commonly accepted recommendation.

Black et al. (1977), in a suggested future draft of FMVSS 101, recommend that climate controls should be mounted on the upper right instrument panel, providing independent control of (a) fresh or recirculating air, (b) direction of air flow, (c) rate of air flow, (d) addition of heat, and (e) addition of refrigeration. This recommendation corresponds with the results of the expectancy surveys, and is a good location for easy accessibility and operation. The Essex panel has the climate controls located on the lower center panel, and the Man

Factors recommendation is that it be placed mid-center on the instrument panel.

The authors agree that a location to the right side of the steering wheel is appropriate with specification of the exact location to be determined from the driver preference experiment being carried out in parallel with this literature review (Green, Ottens, Kerst, Adams, and Goldstein). At the moment, the authors have no specific recommendations for the design of the cluster itself, though the operation of the controls should follow population stereotypes (up and to the right for on or increase). It may be that the only way to eliminate problems with first-time operation of the climate controls will be through standardization.

Cruise Control

Cruise controls are an option being fitted to more and more new automobiles as a driver convenience (61.5% of U.S.-built cars in 1986). They directly control the speed of the vehicle, and therefore should be simple to locate and operate. Driver confusion could easily lead to a dangerous situation and thus simplicity should be maximized.

Unfortunately, there is neither frequency-of-use data nor driver performance data available for analysis, particularly examining stalk- vs. panel- vs. wheel-mounting of this control. There are no requirements concerning placement of the cruise control in SAE J1138. In terms of driver preference Kuechenmeister (1974) found drivers were evenly divided as to whether cruise controls should be considered for inclusion in a multifunction stalk (30.4% yes, 30.4% no, 39.1% no opinion).

The expectancy data are equally indecisive. Black, Woodson, and Selby (1977) found that test subjects expected the cruise control to be located on a stalk on the left side of the steering column and consist of at least an on/off button and a setting switch. However, drivers also expected the windshield washer to be a button on the end of the left-hand stalk, but a combination of these controls is impossible. Black et al. therefore recommended that the cruise control be mounted on a right-hand stalk. They assert windshield washing is a priority item more closely related to driver safety than the cruise control. This contrasts with the recommendation of Malone et al. (1972), which favored mounting the cruise control on the left stalk, in combination with the turn signal control. Readers should bear in mind these recommendations are from a time when cruise controls and stalk-mounted controls were far less common than they are today.

If a single location must be chosen, the authors would argue for mounting the cruise control on the steering wheel. Specific recommendations about control type and placement will emerge from the Green, Ottens, Kerst, Adams, and Goldstein (1987) experiment. This location was chosen over stalk controls for the following reasons. Reaching for a stalk control requires the driver to remove his or her hand from the wheel, decreasing the level of control the driver has over the vehicle. Use of the cruise controls is only at high speed. Often the need to turn the cruise function off can arise unexpectedly and when the time available is short. While one can do that by touching the brake, it is commonly done manually. Also important, however, is that operation of a stalk-mounted cruise control (either pushing an end-of-stalk set button or moving a slide switch to turn on the cruise function) can result in inadvertent operation of the turn signal or the high beams. Even more significant are problems that occur when a stalk-mounted cruise control is combined with a stalk-mounted wiper/washer. In this instance, inadvertent operation of the washer or wiper is not uncommon, which can both startle the driver and in some cases obliterate view of the road ahead.

Defrost/Defog Controls

The sudden fogging of front and rear windows in cold or damp driving causes a dangerous situation as the driver loses sight of the road. Poor location of defrost/defog controls should not delay rapid operation of this control by the driver. Emphasis should be on placing the controls within easy reach, as well as making them simple to operate. A further point, not related to controls but still relevant, is that rapid clearing of the windshield is necessary, and thus, fan and heating power should be suitable for the worst possible climate conditions. Finally, there is no data on rear-window defrost-defog controls. This is a common control, and needs to be included in further research.

The SAE Recommended Practice (J1138) is to locate the defroster to the right of the steering wheel on the instrument panel. Two expectancy surveys, Anacapa Sciences (1974) and Anacapa Sciences (1976), confirm this by finding that motorists look on the right panel for this control. Furthermore, their expectancy is very strong for this location in both domestic and foreign cars, as shown in the chapter entitled "Where Do Drivers Expect To Find Controls." Locating and operating these controls continues to be a problem, however, with high mean activation times reported by both Khadilkar (4.2 s.) and Malone (7.4 s.). The Man Factors panel has environmental controls grouped together on the lower center console, while the Essex panel places these controls immediately to the right of the steering wheel on the instrument panel. Unfortunately, there is no frequency-of-use data available for these controls. Such data would allow researchers to establish the criticality of these controls and contribute to suggestions for their placement.

In a study of accident causation, Burger et al. (1977) noted a large number of problems associated with the location of the defroster/defogger, indicating that the location of these controls may not yet be sufficiently standardized. In a significant departure from the standard, Black et al. (1977) recommended that defrost/defog controls be located in the same instrument panel location as the windshield wiper/washer and be operated by a single button.

Thus, there seems to be strong evidence for placement of this control on the right side of the panel. There is no specific automotive data on how the control should be designed, but it is clear that the control should be dedicated to this single function and not buried in some deep menu on a touch screen interface that requires multiple switch hits to access. Further, consideration should be given to linking the defrost control to the fan so that turning on the defroster automatically turns on the fan. This would reduce the time required to operate this function.

Hazard Control

The Hazard (or four-way) flasher control is used mostly when the vehicle is stationary, although its use in poor-visibility situations is common. Its use is usually prompted by a breakdown while still in or alongside the stream of traffic, and thus its operation might be carried out while the driver is under some degree of stress. Problems with finding and operating this switch are not unusual.

SAE Recommended Practice (J1138) calls for locating the hazard switch to the right of the steering wheel. The expectancy surveys in both Anacapa Sciences (1974) and Anacapa Sciences (1976) found that drivers expected to find the hazard switch to be located on the steering column, usually on the right side. Furthermore, when asked in Anacapa Sciences (1976) to express the strength of their expectations, drivers rated "Hazard Switch - right side of column," with a 6 on a scale of 1=low to 9=high. Further, Black et al. (1977) found that their subjects expected to find the hazard switch mounted on the right side of the steering wheel and operated by pulling it on.

Elsholz and Bortfeld (1978) found in a driver performance study that drivers experienced difficulties operating any one of the four hazard controls available (left-side stalk control - push left; rocker switch on right side of instrument panel - push down; touch control in same place - push left; left-side panel-mounted push button - push right). In the control location performance test in Anacapa Science (1976), the hazard switch was the second most difficult to locate, requiring a mean time of 2.4 seconds. Khadilkar reported an even higher mean time of 3.5 seconds.

In the survey of 1,482 California motorists in Anacapa (1974), the hazard switch was found most quickly and accurately when it was located in the same place in the test car as in the driver's car. In cases where the driver had no such switch in their own car, their performance was generally better with a panel-mounted switch than one mounted on the steering column.

Malone et al. (1972), in designing a new 'standard' instrument panel (the Essex panel), recommended that the hazard switch be located on the upper right instrument panel as opposed to the steering column. Finally, Kuechenmeister (1974) found that the majority of his 24 subjects would not like to see the hazard switch mounted on a multifunction stalk.

A single, clear conclusion is difficult, but it is apparent that in general, the hazard switch should be located to the right of the steering column. The question of whether to mount it on the column itself or on the instrument panel isn't a critical issue, but the authors would argue for standardizing the location to one of the two so drivers can find it easily. As far as which location is "better," the panel location is usually more visible to the driver. However, placing it on the instrument panel increases the number of controls the driver must ordinarily choose from, and thus increases response time and number of errors. If a panel location is chosen, a rocker switch should be used in line with common practice for this control. A specific recommendation for this control should emerge from the driver preference data in Green, Ottens, Kerst, Adams, and Goldstein (1987).

Headlight On/Off Control

Headlights are usually not operated in reaction to any sudden stimulus, and thus their control location is not quite as critical as some others. However, the switch should be easy to find and operate, and care should be taken in combining this control with others on a multifunction stalk, since studies have shown that this causes difficulty.

The SAE Recommended Practice is to place the headlights switch to the left of the steering wheel. Expectancy surveys from Anacapa Sciences (1974) and Anacapa Sciences (1976) confirm this recommendation. Furthermore, Anacapa Sciences (1976) reports that drivers rated the strength of their expectations at 7.25 (on a scale of 1=low to 9=high).

Black et al. (1977) found strong expectancies (3:1) or better in favor of panel- over stalk-mounting of headlight controls. Elsholz and Bortfeld (1978) found that none of the four configurations they tested (left stalk - push up/down; instrument panel stalk control, right side - pull towards the driver, or left side - push up; rocker switch on the left side of the instrument panel) were easily located by drivers. Drivers also had problems locating the parking light function when it was a stalk control (left side - push up or down) or a rocker switch (on steering wheel - push right side forward).

In a survey of difficulty of control location in Anacapa Sciences (1974), the headlight switch fell in the middle range, neither the most difficult, nor the easiest to locate. Anacapa Sciences (1976), in their survey of 1,482 California motorists, found that performance in locating the headlight switch was especially poor when the switch was on a pod or a stalk, or in an unusual location, such as under the panel. Their performance test yielded a 1.5 second activation time.

The Simmonds (1976a, b, c) studies, in estimating confusion likelihoods, found it highly likely that the headlight controls would be confused with the wiper switch and the parking lights if it were stalk-mounted. They also provided frequency-of-use data which shows that the headlight control is only activated 4% of the time that the engine is running. This is fairly low, as would be expected, since the control is used twice (on/off) in night driving, and generally never in daylight driving.

Malone et al. (1972) recorded a mean activation time of 2.3 seconds, and suggested that headlights be located in the far upper left of their Essex panel, clustered with the other parking-light controls. Black et al. (1977) recommended as part of their suggested future draft of FMVSS 101 that headlight/parking lights be activated with a knob on the left panel which is pulled or rotated on. However, there are some incidental data suggesting that a pull-on knob is not a good design. With this design one cannot easily tell what position the knob is in by looking at the knob, and other cues, such as illumination of the panel, are less than ideal indicators during daylight hours (Green, Conroy, Appelucci, and Allen, 1972). This inevitably leads to cars being parked during the morning with their headlights left on (and a dead battery that evening). It also leads to people driving at nightfall using only their parking lights, thinking they have their headlights on.

McCallum, Dick, and Casey (1982) suggest that the headlight on/off switch be located on a pod to the left of the steering wheel. They also suggested that the switches be of the "piano-key" type along the outside of the pod, allowing the driver simple fingertip operation without releasing the wheel. They also suggest that alternating textured and smooth keys on the pod would allow the driver to select the proper key without looking away from the road.

While a preference study carried out as part of Simmonds (1976a, b, c) indicated that stalk controls were favored in general for headlights, dimmers, turn signals, and wiper/washers, there is some question as to the validity of this outcome, especially since Kuechenmeister (1974) found that his drivers would not like the on/off switch for headlights/parking lights mounted on a stalk. Thus, stalk-mounting of this control seems questionable.

The authors believe this control should be mounted on the left side of the panel even though that violates the human factors principle of functional grouping. (For now, the dimmer control is assumed to be on a stalk.) Furthermore, because the control is used moderately often, it should be within easy reach (for example on a pod). Also, the authors suggest that the on/off control be automatically illuminated whenever the light level is low, and the engine is running or a door is opened. Often finding the light switch is a Catch-22 problem. If a person is driving and it gets dark, they should turn on their headlights (and panel lights). But in order to turn the lights on, one needs light to find the switch. A further advantage of automatic illumination of the on/off switch is that it serves as a gentle reminder to the driver as to when turning on the headlights is advisable. It makes sense to the authors that this be required by SAE J1138 and FMVSS 101.

Headlight Dimmer Control

The headlight dimmer control switches the headlight between low and high beams when the lights are on. This function is often confused with the optical horn, which one uses to flash between those levels. It should be easy to locate and operate in the dark. Beam switching is usually done when oncoming traffic makes the driver switch from high to low beams. The driver needs to respond quickly to avoid blinding the driver in an oncoming vehicle. Thus, the switch should not require significant effort to locate.

SAE Recommended Practice is to place the headlight dimmer switch to the left of the steering wheel. Early studies favored floor mounting of the headlight dimmer control. For example, for their "human-engineered" instrument panels both Conover et al. (1969) and Malone et al. (1972) recommended floor-mounting for the dimmer. Krumm (1974) reported that driver reaction time in activating dimmers favored floor-mounting over stalk-mounting, but in the twelve years since this study, stalk-mounted dimmers have become much more common, and it is doubtful that these results could be replicated. In Black, Woodson, and Selby (1977), drivers expected the dimmer to be located on the floor near the driver's left foot. If mounted on a stalk, however, drivers preferred the left to the right, and the preferred means of activation was pulling towards the driver. Elsholz and Bortfeld (1978) found that their subjects experienced difficulties in the operation of high-beam controls when they were on the left stalk (move left or right) or on the panel (touch control - push up).

During the mid- and late-70's, stalk-mounted controls became more common and drivers were more likely to expect them. As a consequence, data favoring stalk mounting over panel-mounting began to appear. Kuechenmeister (1974) reported that his subjects thought that the dimmer should be included on a multifunction stalk control. Anacapa Sciences (1974, 1976) found that drivers responded more rapidly overall to panel-mounted controls, as did Kuechenmeister (1975). Faust-Adams & Nagel (1975) found response times for stalk-mounted dimmer controls averaged 300 milliseconds less than those which were panel- or floor-mounted, and that the combined mean activation time was 1.56 seconds.

Besides location, an important issue at that time was how switching should occur if the headlight had three levels instead of two. (This occurred as a result of a federal government proposal.) Mortimer and Post (1973) reported that the critical difference was not whether the controls were stalk- or panel-mounted, but rather whether beam-switching occurred in a single motion. Black et al. (1977), in the suggested revision of FMVSS 101, proposed that the dimmer be operated by the left stalk moving fore and aft (Forward = High, Mid = Low).

To conclude, the authors recommend that the Headlight Dimmer be a stalk control on the left side of the steering column, the current defacto standard. However, it is likely that any lever control in that area operating in the same manner would be just as easy to use. Such designs are also acceptable. As noted above there is considerable data favoring floor-mounting of the dimmer control, but that data is now obsolete. Floor-mounting is now rare (Green, Ottens, and Adams, 1987) and not expected by very many drivers. Results from the Green, Ottens, and Adams (1987) field survey will indicate current convention for method of operation. Whatever it is, that convention should be incorporated into the SAE Recommended Practice.

Horn

The horn is almost always used in conflict situations, usually to alert drivers of potentially dangerous circumstances. A driver should be able to operate it instantly, almost without thought. The inability of one driver to warn another of impending danger will almost inevitably lead to an accident, even though one of the drivers had recognized the problem. This is not just hypothesized to be true. In a study of accident causation, Burger et al. (1977) noted there were a significant number of accidents in which the inability to find and operate the horn was a major factor. Rurther, there were more "close calls" associated with difficulties in operating the horn than any other control.

There is considerable performance data on the use of the horn. Krumm (1974) found his subjects initially experienced a significant amount of difficulty with rim-blow and stalk-mounted horns, reporting a 29 second response time for the former, and a phenomenal 9.6 seconds for the latter! Since, in this study, any time over the thirty-second time limit was recorded as thirty seconds, these results indicate that the drivers usually never found the horn. This is an extremely dangerous design, yet the rim-blow horn was standard equipment in the Oldsmobile 98. Interestingly, this design is still allowed by SAE J1138. That document states, "The audible horn control shall be located on the steering control" (Society of Automotive Engineers, 1987, p. 34.113).

Other studies present results consistent with Krumm (1974). For example, in other performance tests, activation times for the horn (on the steering wheel) were in the range of 1.2 s. (Malone et. al.) to 1.4 s. (Faust-Adams and Nagel). Elsholz and Bortfeld (1978) found in their study that European drivers had difficulty with stalk-mounted horn controls, but not with "touch controls" mounted on the steering wheel.

There is also strong driver sentiment against placing the horn on a stalk. For example, when Kuechenmeister (1974) asked if the horn should be considered for incorporation in a multifunction stalk control, only 4.4% of the drivers responding said "yes," while 52.2% said "no." (The remainder had no opinion.)

Previous design recommendations have all favored placing the horn control on the steering wheel. For example, for the Essex "human-engineered" instrument panel, Malone et al. (1972) recommended that the horn be mounted on the hub, finding a high likelihood of confusion if the horn were stalk-mounted. Black et al. (1977), in recommending changes to FMVSS 101, proposed that the horn be operated by push buttons on the steering wheel spokes.

Thus, there is considerable research support for locating the horn on the steering wheel hub or spokes, and not on a stalk. Since most drivers expect to find the horn in one of these two areas on the steering wheel, the optimum solution is to place the horn in both locations to facilitate rapid operation. Definitive recommendations for size are given in Green, Ottens, Kerst, Adams, and Goldstein (1987). Further, it is the authors' experience that the active area of the hub should be labeled and highlighted (e.g. by color, etc.) to differentiate the horn from surrounding padding. This is contrary to the standard designer's practice of attempting to blend in the horn activation control with the rest of the steering wheel. Finally, some consideration should be given to coupling the horn (or more formally, the acoustic horn), with the headlight flashing function (optical horn) as was proposed in Green (1979). Language identifying these requirements should be added to SAE J1138 and FMVSS 101.

Ignition

The ignition control is often not associated with secondary controls in vehicles, and usually is only operated once during each trip. However, when a stall occurs in heavy traffic, it becomes necessary to find and operate the ignition quickly under a great deal of stress. Thus, its location and operating characteristics do require careful consideration.

SAE Recommended Practice is to mount the ignition switch to the right of the steering wheel. Anacapa Sciences (1974, 1976) found that drivers expected the ignition switch to be located on the right side of the steering column or on the lower right instrument panel. Anacapa Sciences (1974) also found that the ignition switch was the second easiest to locate out of eight controls in a control-location performance test. Faust-Adams and Nagel (1975) reported a mean reaction time of 1.65 seconds to find the ignition switch in their two test vehicles, which confirms the general ease with which drivers locate this control. Black et al. (1977) had an interesting recommendation in their proposed revision of FMVSS 101, suggesting that the ignition/starter be a rotary-key switch on the panel.

It should be noted that a key-release switch has become standard equipment on some U.S. vehicles (e.g., Fords). This was to prevent accidental removal of the keys (i.e., by a child on the passenger side), which would cause the steering wheel anti-theft lock to activate and create an extremely dangerous situation. Car rental companies have reported rental vehicles being stolen because clients cannot find or operate the key release and elect to leave the keys in the ignition. A better solution might be designing an electronic system which would delay locking if the vehicle is in motion when the engine is shut off. A side benefit would result in a situation where the driver shuts off the engine when the car is in motion in order to solve a problem (e.g., sudden acceleration). In such a situation, the driver would not lose steering control over the vehicle.

Another suggestion put forth in McCallum, Dick, and Casey (1982) is that a keyless ignition system (being examined by them for Ford) be mounted either on a pod to the right of the steering wheel or on the instrument panel to the right of the steering wheel. Consumers preferred the right pod location.

The proposed pod-mounted ignition would consist of five numbered "piano keys" upon which the driver would enter a personal code sequence. The driver would then select his choice of "Start/Run" or "Accessory" using the same keys. One of the keys, color-coded and lighted red, would be labelled "Stop." Selecting "Stop" would leave the ignition unlocked for ten seconds should the driver wish to restart without entering the code sequence again. This would be a valuable safety feature in the event of a stall. Some safeguard would also need to be developed to prevent cutting the ignition accidentally by inadvertently touching the "Stop" key. However, because the key-switch ignition is so common, the authors expect that a nonstandard design such as a keyless system would meet with great consumer resistance.

It is unclear to the authors whether mounting the ignition on the column or panel is best. That decision should be based on the preference data being collected (Green, Ottens, Kerst, Adams, and Goldstein, 1987). It is clear, however, that a separate key release switch creates numerous problems for drivers.

Optical Horn Control

The optical horn has until recently been a fixture of European vehicles. Lately, however, American manufacturers have seen the wisdom behind having a second control available to warn other drivers of conflict situations. The optical horn's most common application is to warn drivers when a faster vehicle is approaching from the rear and wishes to pass. The warning consists of a quick flash of the high beams. This control operates regardless of whether the headlights are on or off. Its location should therefore be convenient for quick location and operation, either in daytime or nighttime driving conditions.

The SAE Recommended Practice (J1138) suggests that the optical horn be mounted to the left of the steering wheel. Both floor-mounted and stalk-mounted controls meet the requirements of J1138. Kuechenmeister (1974) found that drivers strongly favored incorporating the optical horn function into a multifunction stalk control (73.9% yes, 8.7% no, 17.4% no opinion). This outcome was a surprise since at the time beam switching was usually accomplished using a foot switch, and drivers usually favor designs with which they are most familiar.

The Simmonds (1976a, b, c) documents present calculated confusion likelihoods for various controls, and found there would be a fair degree of confusion between the optical horn and headlight on/off controls, as well as with windshield wipers if all were stalk-mounted. Since the recommendations give here are not for stalk-mounting of those two controls, such confusions are not a concern. (See the table in the Human Factors analysis section.) They also found in a frequency-of-use study that drivers activated the control an estimated 5% of the time they were driving.

Finally, Black et al. (1977) recommend that the optical horn be mounted on the left stalk, and be operated by pulling towards the driver.

Thus, all research indicates that the left stalk is the ideal location for the optical horn. Further, this is the current design stereotype (Green, Ottens, and Adams, 1987). However, any lever control, mounted in the same place as a column-mounted stalk and operating in the same manner, should be acceptable. As noted previously, combining operation of this control with that of the auditory horn might improve its effectiveness as a warning system. The method of operation of this control should be that preferred by drivers in the Green, Ottens, Kerst, Adams, and Goldstein (1987) experiment.

Radio Controls

The radio is not directly involved in vehicle operation, but almost every passenger car sold in the United States today has one, and thus it should be considered in control design and location. The radio is often operated while the car is moving, and often requires the driver's full attention while tuning in a frequency. Thus, its location and ease-of-use should be a major design consideration.

The SAE Recommended Practice (J1138) is to mount the radio to the right of the steering column. Anacapa Sciences (1974) found in surveys of 1,482 California drivers that control location performance was adversely affected when the radio was located to the left of the steering column. The same study also reported an average location time of 1.2 seconds for the radio. Black, Woodson, and Selby (1977), in a suggested future draft of FMVSS 101, recommended that the radio be located on the lower right instrument panel, and furthermore, that it have control knobs on both sides of the frequency display. This was suggested to reduce the time the driver spends looking at the radio instead of the road. Two early "human-engineered" instrument panels used similar designs for the radio. Essex placed the radio on the panel to the right of the driver, midway up the panel. Man Factors placed it in the same location, but slightly higher on the panel.

Simmonds (1976b) found that, based on his frequency data, the radio was a very high use item. Even though it is not directly related to driver safety, it is operated so often that poor design can have major safety implications by distracting drivers. (See Perel, 1976.) Furthermore, the car-audio systems available today are increasingly complex, and include tape and compact disc players, scan/search radios, and even sound equalizers. Most designs have buttons that are too small and too close together, labels that are not readable, and other features that violate basic human factors principles. In some cases, this results from attempts to meet DIN envelope standards instead of human factors standards. Finally, reaching problems are often found, and some consideration should be given to developing remote station selection controls.

Consistent with the data, the authors suggest the radio be located on the right side of the steering wheel, and because of its frequent use, close to the top of the panel to minimize how far away from the road the driver must look to see it. The authors, based on good human factors practice, would strongly argue against using a pair of push buttons (up and down) for manual tuning. (This is common on "high-tech" sound systems.) That design requires the driver to look away from the road and at the frequency display to determine the station selected. Preferred are knobs with detents. As the control is rotated, the driver can feel a change in force and estimate where the radio has been tuned.

Wiper/Washer Controls

The wiper/washer is one of the most important controls available to the driver. It needs to be operated quickly during a sudden downpour or when the windshield is suddenly obscured by unexpected splashing or spraying. Thus, it should be in a position that can be easily found, even when the driver has panicked and is unable to see where the vehicle is going. Furthermore, its operation should only require one quick movement, without moving the hands very far from the steering wheel. Simmonds (1976b) frequency-of-use data indicates that this is the second most often used control after the turn signal, and usages average about 10% of the time the vehicle is being driven.

Kuechenmeister (1974) examined driver performance in learning to use a stalk control with a wiper function on it and found it was fairly easy to operate. Drivers favored incorporating wiper/washer functions into a multifunction stalk control by a ratio of 10 to 1. In a direct comparison of a panel-mounted wiper/washer control with one on a stalk, Kuechenmeister (1975) found that panel-mounted controls, then common at the time, were responded to more rapidly. Drivers also rated the stalk-mounted wiper as easier to operate.

Expectancy studies carried out in Anacapa Sciences (1974) and Anacapa Sciences (1976) indicate that these controls are expected on either the left or right instrument panel, but with a tendency to expect them on the left. Anacapa Sciences (1976) went further and determined expectancy strengths for finding the wiper/washer on the left panel, and obtained an average value of 6.0 (on a scale of 1=low to 9=high). In terms of performance, drivers in the Anacapa studies found the wiper most quickly and accurately when located on the left panel (below and inboard of the headlight switch). Performance was poorest when the control was located on a pod or stalk.

In general, performance studies for the wiper control yielded mean response times ranging from 1.5 seconds (Anacapa Sciences) to 2.6 seconds (Khadilkar). The washer control yielded a higher average, with Malone reporting a mean response time of 4.5 seconds.

Data favoring stalk-mounting of the wiper controls was obtained in the 1970's. Faust-Adams and Nagel (1975) found the average response time to be 300 milliseconds less than panel- or floor-mounted controls. Black et al. (1977) found drivers had strong expectancies (3:1) in favor of stalk- over panel-mounting of these controls. However, there was no consensus as to how this stalk should operate, although pushing an end button was favored for washer activation. This did conflict with the favored method of cruise control activation, which was also an end button.

Elsholz and Bortfeld (1978) found that drivers had problems activating right-side stalk controls which twisted or moved towards or away from the driver, but not those which moved up or down. Furthermore, they found that neither a left-side stalk (push away = on) nor a left-panel control (up = on) were stereotypical operating modes for the washer.

Others have also found that drivers prefer stalk-mounted wiper controls. Mourant et al. (1977) found that the stalk with the "rotate forward or away" configuration to activate the wipers required the fewest looks, while that with a button required the most. The same "button" design required the most looks to control wiper speed. Overall, fingertip controls required 1/6 the number of direct looks of other controls, and rotary stalk controls were preferable to other types, such as buttons.

Design recommendations have changed somewhat over time. Both of the "human engineered" instrument panels in the literature had the windshield clearing controls on the panel, as opposed to a stalk, but while the Essex panel had the controls on the right upper instrument panel, the Man Factors panel placed them on the left side of the panel with the headlight control. Neither of these studies considered stalk-mounted controls, and had they, there might have been different recommendations. Black et al. (1977) suggested for a future draft of FMVSS 101 that the wiper consist of a rotary selector switch/knob on a fingertip reach panel pod to the left of the steering wheel.

In more current work, McCallum, Dick, and Casey (1982) recommended mounting wiper on/off and speed controls on a pod to the left of the steering wheel. The switches would be of the "piano key" type, with the on/off switch surface being smooth and the speed control surface textured. This would allow driver selection without visual aid. They suggested putting the washer switch on a separate pull tab on the underside of the pod.

It is difficult to make a conclusive recommendation based on the results of the research. Virtually any recommendation will meet the requirements of the SAE Recommended Practice (locate the wiper/washer controls to the left of the steering wheel). There are some hazards associated with mounting the wiper-washer control on a multifunction stalk, since inadvertent activation creates an immediate and potentially dangerous visual distraction. Yet, some studies reported faster response times for stalk-mounted controls than for panel-mounted ones. The ideal solution seems to be the use of other schemes to put controls within fingertip reach of the driver (e.g pod mounting), which the authors suggest, especially if "pulse" wipe is included. This enables the driver to easily activate the wipers to clear either a momentary spray or a downpour. Whatever type of control is fitted, it should be operable with a simple motion (pushing a button, "sweeping" a stalk) and not require a time-consuming grasp (as a knob would). Here again, the work of Green, Ottens, Kerst, Adams, and Goldstein (1987) should help decide which design is recommended.

- HOW SHOULD CONTROLS BE DESIGNED? -

WHAT ADDITIONAL RESEARCH IS NEEDED AND HOW SHOULD IT BE CONDUCTED?

How Should Researchers Prepare to Do Future Work?

Just as designers should read this entire report carefully, it is even more important for researchers to do so. For those involved in studying stalk controls, Green (1979) should be read. There are a number of details in that report that have not been included here. For those interested in controls in general, this report supersedes Green (1979).

In some cases, automotive human factors researchers have not kept up with developments in the computer industry, even though today's automobiles have much in common with standard computer interfaces. In part, that is because the automotive applications of human-computer interaction research may not be immediately obvious. For people interested in that research, Card, Moran, and Newell (1983) is highly recommended. It provides a useful methodology for evaluating human interaction with controls and displays.

What Methods Should Be Used?

The automotive human factors literature has tended to be quite applied. There have been only a few studies that formally evaluated test procedures prior to testing. Quite often, an approach is adopted because it "seemed to work reasonably well." Nonetheless, some of the important methodological issues have been resolved. The main issues are how to determine:

1. where and what types of controls drivers expect,
2. where and what types of controls drivers prefer,
3. how driver performance in using controls should be assessed,
4. how often various secondary controls are used,
5. what problems drivers say they have using controls,
6. the relationship between controls and accidents,
7. if data about preferences, expectancies, performance, problems, and accidents lead to similar design recommendations.

How Should Expectancies Be Determined?

In one experiment, Anacapa (1976) had drivers place controls on an instrument panel mockup. In another, drivers marked an "x" on a sketch of an instrument panel where they expected to find each control. It is believed the two approaches lead to similar conclusions. However, these data are primarily for flat surfaces (conventional instrument panels without stalks). As long as the image drivers see looks like an instrument panel, the presentation format (a sketch, computer display, or real panel) should not alter driver expectations.

To determine expectations for switch types, Black, Woodson, and Selby (1977) had people select controls mounted on a free-standing board. An alternative method would be to show sketches of them. Because sketches or even photographs may miss perspectives that are important, the authors believe that real, though not necessarily functioning, controls are needed.

How Should Preferences Be Determined?

Except for the recently completed experiment of Green, Kerst, Ottens, Goldstein, and Adams (1987), there are no comprehensive studies concerning methods for establishing preferences for control location or switch types. Other studies in the open literature (e.g., Mortimer and Post, 1973; Kuechenmeister, 1974; ISO, 1975; Mourant et al., 1977; McCallum, Dick, and Casey, 1982; Callahan, 1986a, b, c) have either examined a limited number of location-switch type combinations or have used car company employees, not the driving public. (Car company employees are likely to favor products their employers manufacture.) To collect location preferences, the authors would argue for using mockups or real vehicles, just as Green et al. (1987) did, not panel sketches. Ease of reach has a major influence on where driver prefer controls and that factor is not captured just by thinking about it (as one does with paper and pencil).

For switch type preferences, subjects should mount real switches on panel mockups, and not select switches from sketches or examples fixed on a display board. Furthermore, a brief session of simulated use while timesharing with steering should be included. The Green, Kerst, Ottens, Goldstein, and Adams (1987) experiment had drivers do just that. Typically people change their preferences for switches and switch locations for a few functions after operating those controls in a driving simulator. The authors do not believe a fully operational production or prototype panel is required, except for highly interactive systems such as tripcomputers. In those interactive systems, the system logic determines ease-of-use and there is no way one can get a sense for it without functional hardware. On the other hand, preferences for simple dedicated switches are determined primarily by the location and shape of the switch. (So, for example, if one were interested in switches for the windshield wiper, it is not necessary for operation of the switch to cause the wiper blade to sweep across the windshield.)

What Additional Research Is Needed?

The literature does not suggest who should be subjects in preference or expectancy studies. The authors believe it is better to use the driving public to establish driver preferences than juries of automobile company employees as was done in the Keuchenmeister (1974) and Ford B-I-C studies.

How Should Driver Performance Be Assessed?

There is a wealth of data on driver performance-related measures and the relationships between measures. The most popular combinations of measures include response (or use time) and errors for using controls (Malone et al., 1972; Middendorf et al., 1974; Kuechenmeister, 1974; Krumm, 1974; Faust-Adams and Nagel, 1975; Anacapa, 1976; Mourant et al., 1977; McCallum et al., 1982; Khadilkar, 1983; Heintz et al., 1985; and Snyder and Monty, 1985). Also common is the frequency or duration of direct looks (Mourant et al., 1977; Snyder and Monty, 1985) with time measures, and with errors (Anacapa, 1976).

The tradeoffs between time and errors have been consistently reported in the psychological literature (Pachella, 1974; Pew, 1969). It is accepted that when making simple decisions, people will be both fast and accurate in the easy conditions, and be slow and make errors in the difficult ones. (This version of the speed-accuracy tradeoff must be distinguished from the common version of it where, at a particular point in time, people can increase their accuracy by slowing down (and vice versa)).

Also, the time to use a control measured in the laboratory is correlated with performance on the road (Malone, Krumm, Shenk, and Kao, 1972). Thus, times measured in the laboratory are a good indication of how well a control is designed. While the time measured must be scaled to predict on-the-road performance, the values recorded nonetheless directly reflect the ease of use of a control, a parameter of great interest. Because it is such an important part of driving, the authors would argue for including a concurrent tracking task to increase the strength of the connection. (Its need has not been formally tested in an experiment, but providing that task clearly makes the experiment more appealing.)

In carrying out such studies, only a limited number of responses for each subject-control combination may be required. In Malone et al. (1972) performance times for using controls reached an asymptote after about five trials.

As noted previously, errors are also an important and useful measure. While they should be collected, the authors would argue against considering them as the primary measure of interest. Because each response contains only binary information about errors (whether or not one occurred), hundreds or thousands of responses for each condition are required to get stable estimates of error probabilities. On the other hand, each response yields a time accurate to three or four significant figures. Therefore, far fewer responses are needed (maybe an order of magnitude) to get a stable estimate of the time. The thousands of responses per condition required to get stable error estimates is often more than most sponsors can afford.

Clearly, eye fixations are informative as well. However, they are difficult to collect and analyze. Unless an automated system is available for those purposes, the authors would not recommend that eye movements be recorded.

How Should the Accident Data Be Examined?

Obtaining information about the use of controls and accidents is not easy. There are no data bases that directly code problems associated with controls. There is only one study of this in the literature and it relied upon searching police report narratives stored in computer files. There has been some informal discussion at UMTRI of developing a narrative accident data base for fatal accidents in the state of Michigan but there are no formal proposals for action.

How Should Reports of Problems Be Collected?

Mail-in surveys of licensed drivers (Anacapa, 1974; Burger et al., 1977) and interviews of rental car drivers (Anacapa, 1974, 1976) have been used to obtain reports of problems drivers have using controls. The Anacapa (1976) data suggests there is a correlation between the two methods and both seem to yield reasonable data. The selection of the method is a matter of cost.

How Well Correlated Are the Various Measures?

There is some information, but not much, on the relationships between measures. As noted previously, there is considerable evidence that the performance measures (response time, errors, eye movements, lane deviations, etc.) are correlated with each other. Also correlated are expectancy with performance (Anacapa, 1976) and reports of problems with performance (Mourant et al., 1977).

What Research Is Needed?

In addressing these questions, an important issue is how much realism is required. While production vehicles offer more realism than mockups or sketches, they also cost more. When selecting the level of realism for a study, the question is, "Does changing the level of realism change the conclusions one would reach about the relative merits of alternative designs?" (In scientific jargon, "Is the interaction of realism with other dependent measures statistically significant?")

Other perspectives are important as well. The data collected in human factors studies will be used by managers and people who work for them who may not be trained in statistics. They may not understand the scientific arguments about interactions. They must believe in the data if they will use it, and what they really want are experimental contexts that closely match actual driving. In the discussion that follows, only the minimum level of realism required to satisfy scientific concerns is called for. As a practical matter, greater realism may be needed to convince designers the data are useful.

The authors strongly believe that several studies should be conducted over the next five to ten years to address issues related to human factors and the design of automobile secondary controls. Those studies concern accidents (identifying which controls are distracting to drivers and lead to accidents, which controls tend to produce injuries when struck), how frequently various secondary controls are used, basic human performance research (developing new tools and methods for collecting data, developing a human performance model), identifying driver expectancies and preferences for controls, developing prototyping tools, and determining recommendations for switch feel and sound.

Which Secondary Controls Are Associated With Accidents?

There is considerable interest in designing controls so they don't distract drivers. Without specific accident data identifying what the problems are, it is very difficult to do. The best source for this information are the narrative descriptions of accidents in police reports. It has been said the North Carolina data base, used in the past, is not in good shape. It may therefore be necessary to create a new narrative data base for this purpose. This data base would be useful for examining other problems for which information is not coded in most structured accident data bases. For example, in the past there was a recurring interest in post-crash fires. But since the term "fire" was not coded, tabulating accidents was difficult.

Also useful could be data on the extent to which drivers are injured by controls in crashes. The UMIVOR data base (University of Michigan Transportation Research Institute, 1986) has a variable that identifies such accidents. This kind of information could be used to examine the usefulness of the EEC rules for control design.

Finally, the authors would argue for looking at case law to determine what human factors problems have been cited in product-related actions, paying particular attention to controls. No one has ever done this and this information would be useful in establishing research priorities.

What Additional Research Is Needed?

How Often Are Various Secondary Controls Used?

An important principle in designing controls is that frequently-used controls should be close to the driver. Except for the Simmonds (1976a, b, c) statistics, there are no data. Further, the Simmonds data does not contain any information on use of the radio or climate controls, both high frequency-of-use items. In addition, depending on the Simmonds data is risky since it is not clear exactly how the data were obtained.

There is considerable interest in making radios easier to use. One way to achieve that is to provide remote radio controls on the steering wheel hub. But without statistics on how often the various radio functions are used, it is difficult to decide what should be remotely mounted.

What Human Performance Research Is Needed?

There is a continuing and critical need for basic human performance research concerning how people use controls. Related to that is a need for simple experimental tools designers can use to test prototype instrument panel configurations. To carry out such research, a PC-based driving simulator is needed. The purpose of the simulator would be to generate a simple road scene and collect steering performance data. High fidelity simulators do exist, but they are so expensive (Mercedes spent 20 million dollars for one) that no American car manufacturer has one.

Also needed to support performance studies are better methods for recording the use of controls. It is very expensive to hard-wire each possible configuration of interest. While one could videotape driver actions, it is likely those data would be analyzed by hand, which is very time-consuming. More automated methods are needed.

Using these improved tools, several basic studies should be conducted. The purpose of the studies would be to develop a quantitative model that predicts the time to use controls in timesharing activities such as driving. The Model Human Processor (Card, Moran, and Newell, 1983) and the proposal of Green (1979) are examples of the form that model could take. This model should ultimately prove to be of great value to designers, allowing them to substitute paper and pencil, or computer tradeoff analyses of driving activities, for more expensive laboratory or on the road studies. Of the research proposed in this report, this project has the highest priority.

Where and What Kinds of Controls Do Drivers Expect and Prefer?

There is also a continuing need for research on expectancy and preferences for controls. Pod control configurations are being examined in a subsequent study in this series (Green, Kerst, Ottens, Goldstein, and Adams, 1987) so further examination of that configuration is not needed. However, some manufacturers have plans to produce cars with flat, conventional panels in the future. The most recent expectancy data for flat panels is from the mid-70s and it is dated. Information on both control location and types is needed.

A key issue is whether or not both preference and expectancy data are required. As Anacapa (1976) showed, the time to use a control depends upon how close it is to where drivers expect it. That argues for collecting expectancy data. On the other hand, the goal of giving customers what they want, argues for preference data. Further, at any given time, existing expectancies are being used to design future vehicles (three or four years ahead). Compensating for this are expectancy lag effects. Individual expectancies depend upon the car one is driving, not the latest model that is out. Expectancies change with each new car purchase, estimated at once every four years (Andrea, 1987). It is not clear what the relationship is between expectancies and preferences, but presumably they are correlated. For these reasons, the authors would argue for collecting preferences over expectancies, but both types of information are useful.

What Design Tools Are Needed?

A major problem in the automotive industry is that even when human factors data exists, it often is not applied. Most designers have little formal training in human factors and there are not enough human factors engineers in the industry to help them. Further, when designers do get feedback (for example, from a test) it is often months after their work is completed, too late to influence the first production run. Designers need a way to get human factors feedback while they are creating the design. This could be accomplished by including some human factors expertise in a computer program for prototyping instrument panels. While the CAD companies have done some work to include data on human reach in their software, not much has been done to include human factors expertise concerning control selection, size, spacing, and so forth. Much of the detailed human factors data needed exists; it is only a matter of incorporating it in software. As with many of the previously mentioned efforts, the authors' bias is towards implementing this software on a PC so that it is widely available to engineers.

What Should Switches Feel and Sound Like?

Within the industry there seems to be considerable interest in this issue. While it is important to customer appeal, the authors would give it lower priority than other work mentioned here.

What Will Make It Difficult to Complete the Research Agenda?

While there are many questions to be resolved concerning controls, getting those questions answered will be difficult. The purpose of what follows is to identify those difficulties, and in some cases, propose solutions. Clearly the authors believe there is a great gap between what designers and engineers need to know and is now known. Changing this situation is a major professional challenge.

Research support is hard to come by. The National Highway Traffic Safety Administration (NHTSA) of the U.S. Department of Transportation has sponsored much of the research on controls. The last project NHTSA funded was four years ago (Khadilkar, 1983). NHTSA's primary mandate is to support safety research, but many of the projects identified in this report relate to ease-of-use, not an issue of current emphasis. (There has been some discussion of supporting related research on improved evaluation methods.) There are no alternative federal sources because all problems relating to transportation are DOT's responsibility. NHTSA should be encouraged to change its program emphasis to address contemporary and future problems, in particular those related to advanced technology and competitiveness.

The Motor Vehicle Manufacturers Association (MVMA) has a long history of supporting research. But with many topics to cover, the funding doesn't go very far. The last study on controls MVMA funded was eight years ago (Green, 1979). Any project MVMA would fund would have to be championed by their Human Factors Engineering Committee.

In the past, suppliers of switches have not supported research. They tend to be small operations with little capital. With the growth in outsourcing and the trend to give suppliers more responsibility for engineering, that could change. In other areas, especially headlighting, there has been strong supplier interest in supporting human factors research, particularly by the Japanese. That could happen for controls as well.

Over the next few years the car manufacturers will be the primary source of research support. With regard to controls, the manufacturers are most likely to support studies related to ease-of-use in an applications context. In the past research has been sponsored by product development groups, not groups concerned with upgrading the corporate technical capabilities. Since this pattern will probably not change, support for basic research will be difficult to find.

An extremely significant exception to this pattern is the Chrysler Challenge Fund. That program is a corporate-level effort to support major projects. If Chrysler maintains that leadership role and supports some of the research identified here, that single program could advance the state-of-the-art in automotive control design more than any other program has since human factors research first began.

There isn't a research community. Because funding has been scarce, few people are familiar with the research on controls. Funding in the early 80's has been inadequate to support even one academic researcher full time. Of the 43 authors whose works are examined in the literature review, only 8 are authors of more than one piece of research and almost none have written more than two pieces. For a field to advance, a critical mass of scientists is needed, and that will only occur if there is long-term support and they are able to discuss what they are doing.

Presently, a free flow of information is discouraged. The current emphasis is on proprietary research, primarily marketing field studies (clinics). Many industry researchers are under orders from their management to say absolutely nothing about what they do. While there may be good reasons for keeping product-specific results proprietary (until the product is released), researchers should be able to openly discuss methodological details. Everyone would benefit from a greater sharing of information and there would be much less duplication of effort. Somehow middle and upper level management in industry needs to be made more aware of this problem.

The excessive emphasis on proprietary research creates problems for those in universities. The Chrysler Challenge Fund, which is supporting this literature review, is an important effort to counter this trend. Universities are supposed to advance the state of knowledge and educate students, and that depends upon the free flow of information. Most major universities (e.g., University of Michigan, MIT, Caltech, Harvard, etc.) limit the duration for which research they carry out can remain confidential (typically from four months to a year). (Because of the "publish or perish" syndrome, it is not in a faculty member's interest to conduct strictly proprietary studies.) Universities and industry need to find creative ways to structure projects to separate proprietary and nonproprietary aspects.

A particularly grey area is just what faculty members can discuss in class and what students working on research projects can talk about. Usually the constraints are different from those on publications. Clearly, it is in the manufacturers' best interest to let students (their future employees) know of their interests.

Why This Research Agenda Should Be Completed

Until the early 1980's, human factors research on secondary controls advocated for reasons of safety where safety was assessed by how much the use of controls distracted the driver from paying attention to the road ahead. While there is considerable evidence that can occur (e.g., Perel, 1976), the linkage is is not nearly as strong as for many other factors, for example, alcohol. Recent work has emphasized ease-of-use. **Customers view ease-of-use as an important product quality and consider it when deciding what to buy.** Providing easy to use products will certainly enhance a manufacturer's profitability.

But in order to design secondary controls that are easy to use, manufacturers need basic data to predict human performance when using controls, tools for designing control clusters, and procedures for testing alternative designs. To a large measure, that information does not exist and hence many of the design decisions are based upon guesswork, not rigorous engineering procedures. Consequently, the products that are developed sometimes aren't very good. That situation frustrates engineers, leaves marketing unhappy, and most importantly, does not give the customers what they want.

A Final Word

Now having read almost 200 pages filled with text, figures, and tables, some readers may be a bit disappointed with the lack of generally applicable design data and engineering analyses. Beyond the five-inch rule in the automotive literature, and some information in the general human factors literature on size, spacing, and related considerations for controls, there isn't an overwhelming body of useful knowledge. The authors believe this reflects the perspective of sponsors, who have tended to have short-term, product-specific goals. **There is an urgent need for the support of basic research, studies that will be useful 5, 10, and 20 years from now.**

A good example of that kind of work is a study carried out by the second author a few years ago on displays (Green, 1984). That study concerned how the design of displays for engine parameters and fuel influenced how well drivers understood the information shown. Questions concerned whether digital or analog displays should be used, how effective color coding was, how scales should be labeled, and so forth. The answers to those questions will not change with time and are applicable to electro-mechanical, LCD, CRT, or any other types of displays that might appear in the future. More of this type of research is needed.

What Additional Research Is Needed?

This review set out to answer several specific questions, which it has. But often the most significant outcome of a study is to identify new questions. This review has certainly done that. However, the ultimate success of this review will depend upon how effective the authors have been in convincing those in industry to follow the design recommendations and support its research agenda.

What Additional Research Is Needed?

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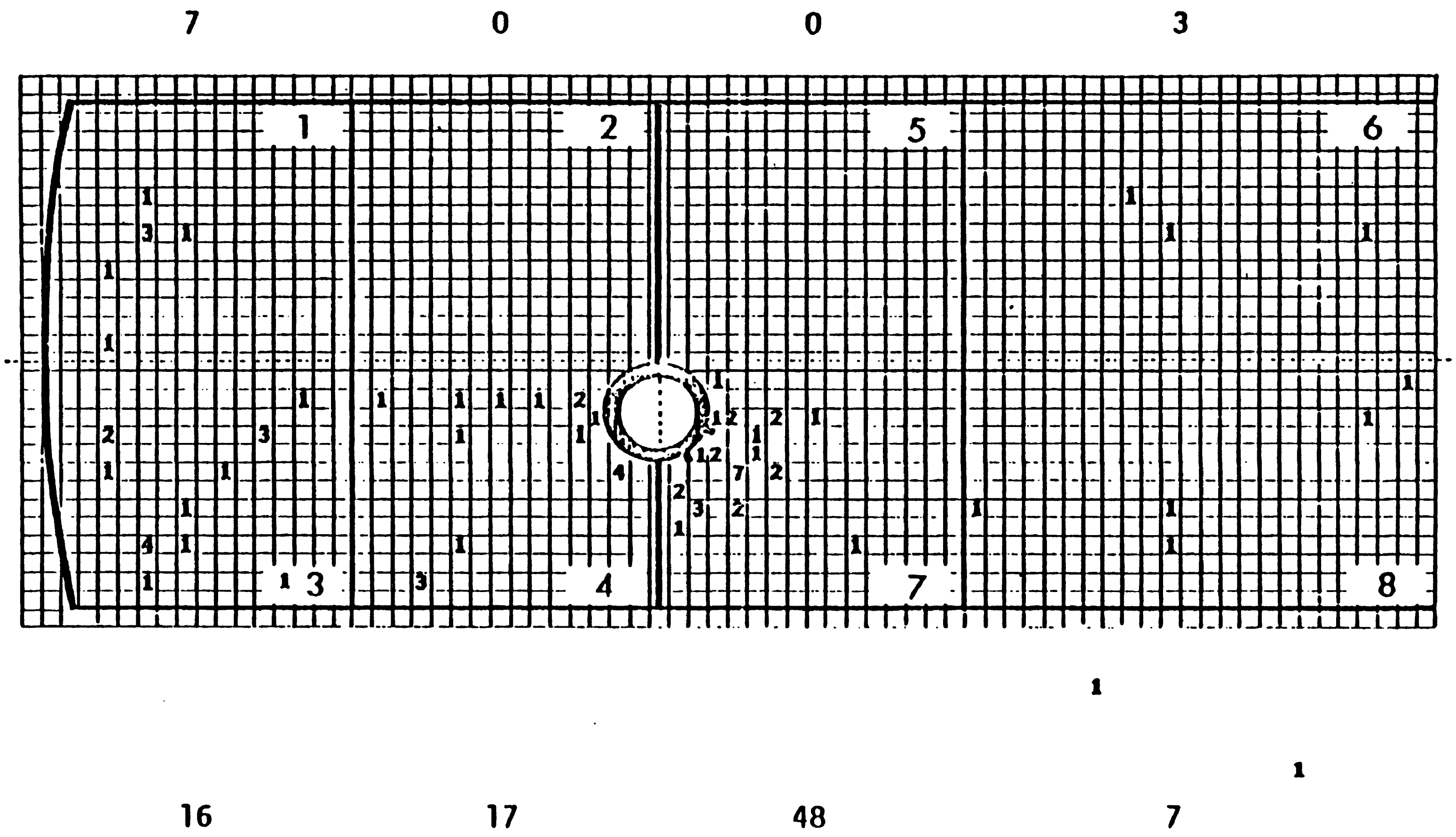
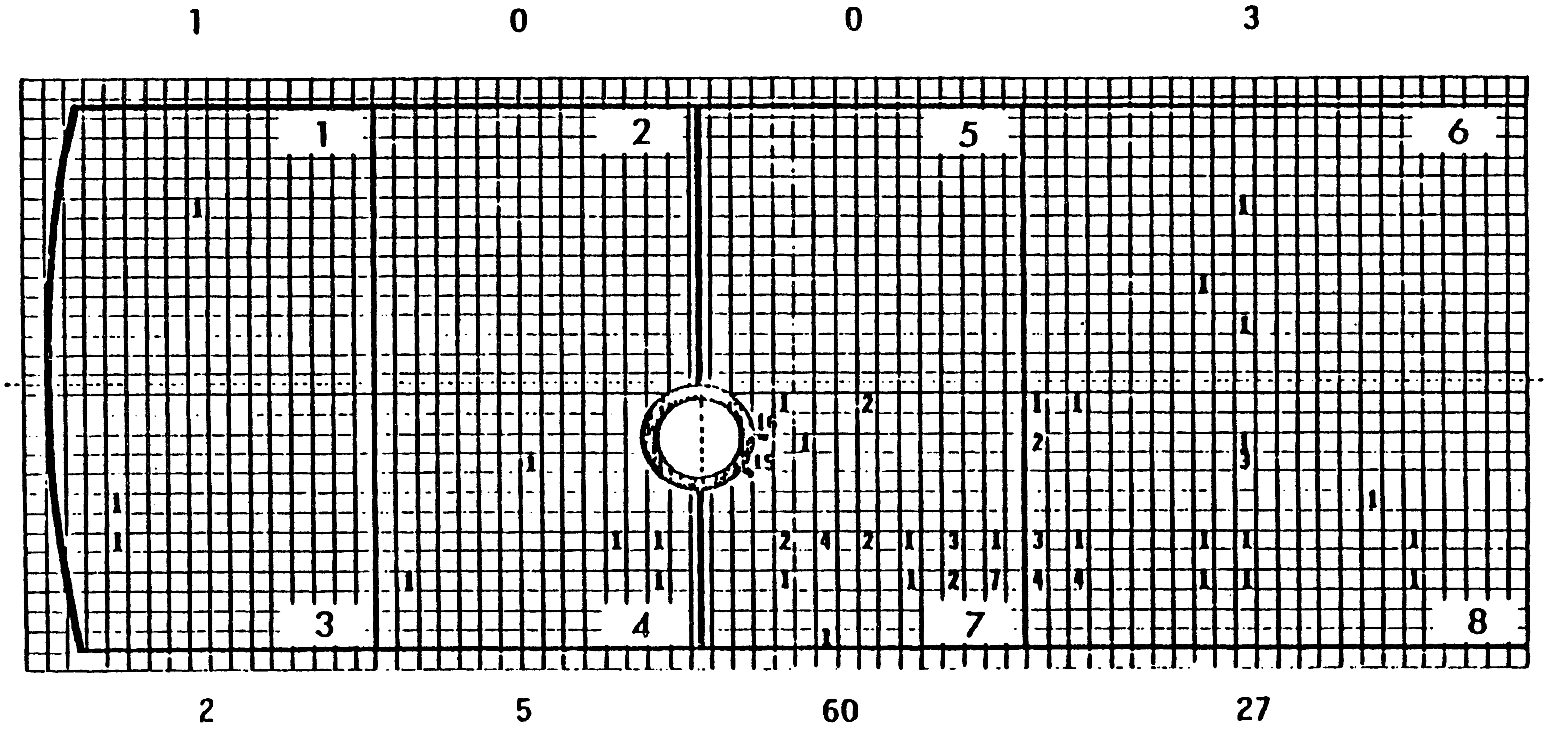
APPENDIX A - EXPECTANCY PLOTS FOR CONTROLS FROM ANACAPA 1974

FLASHER



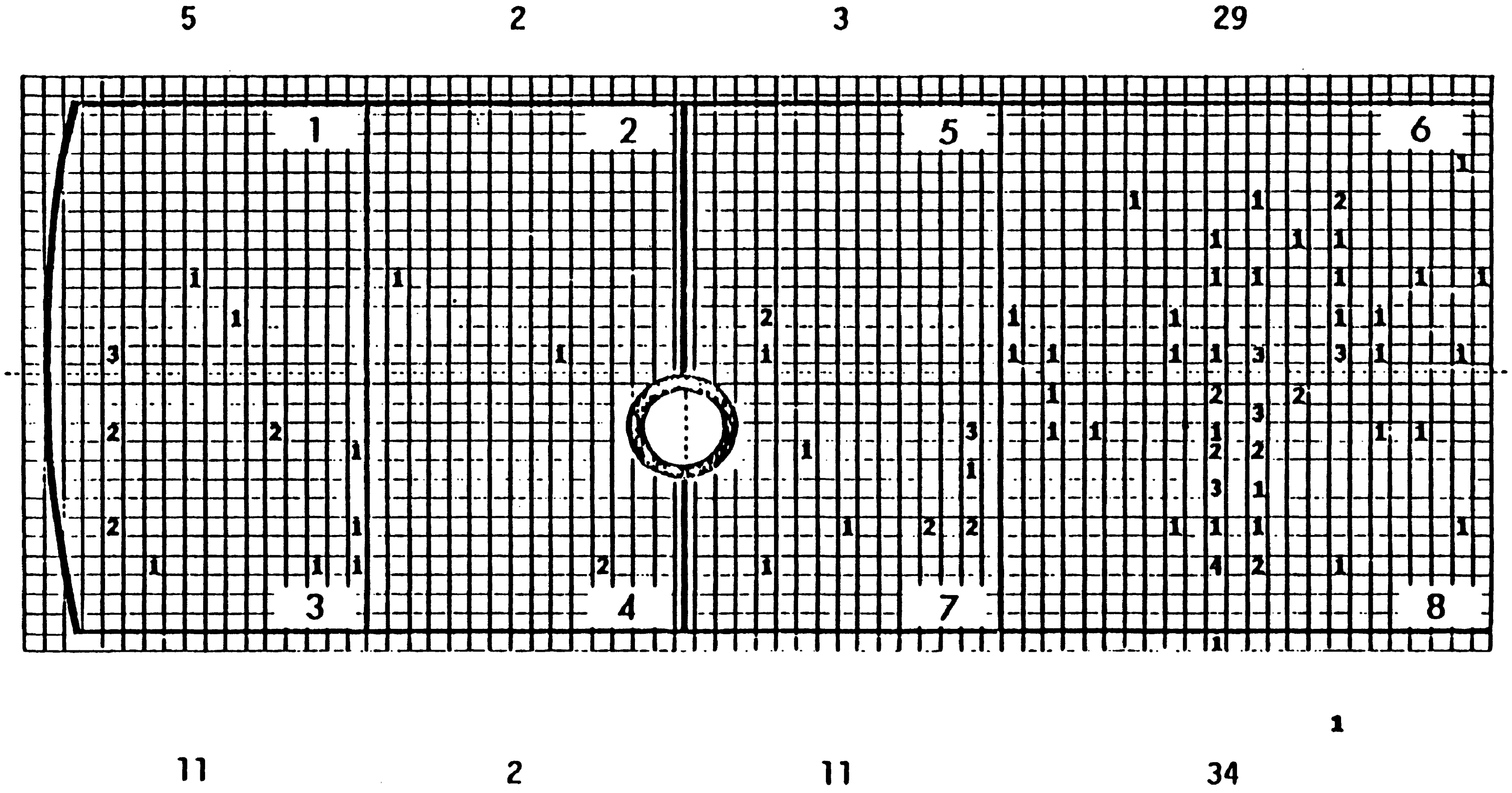
P/P EXPECTANCIES N = 98

IGNITION



P/P EXPECTANCIES N = 98

DEFROSTER



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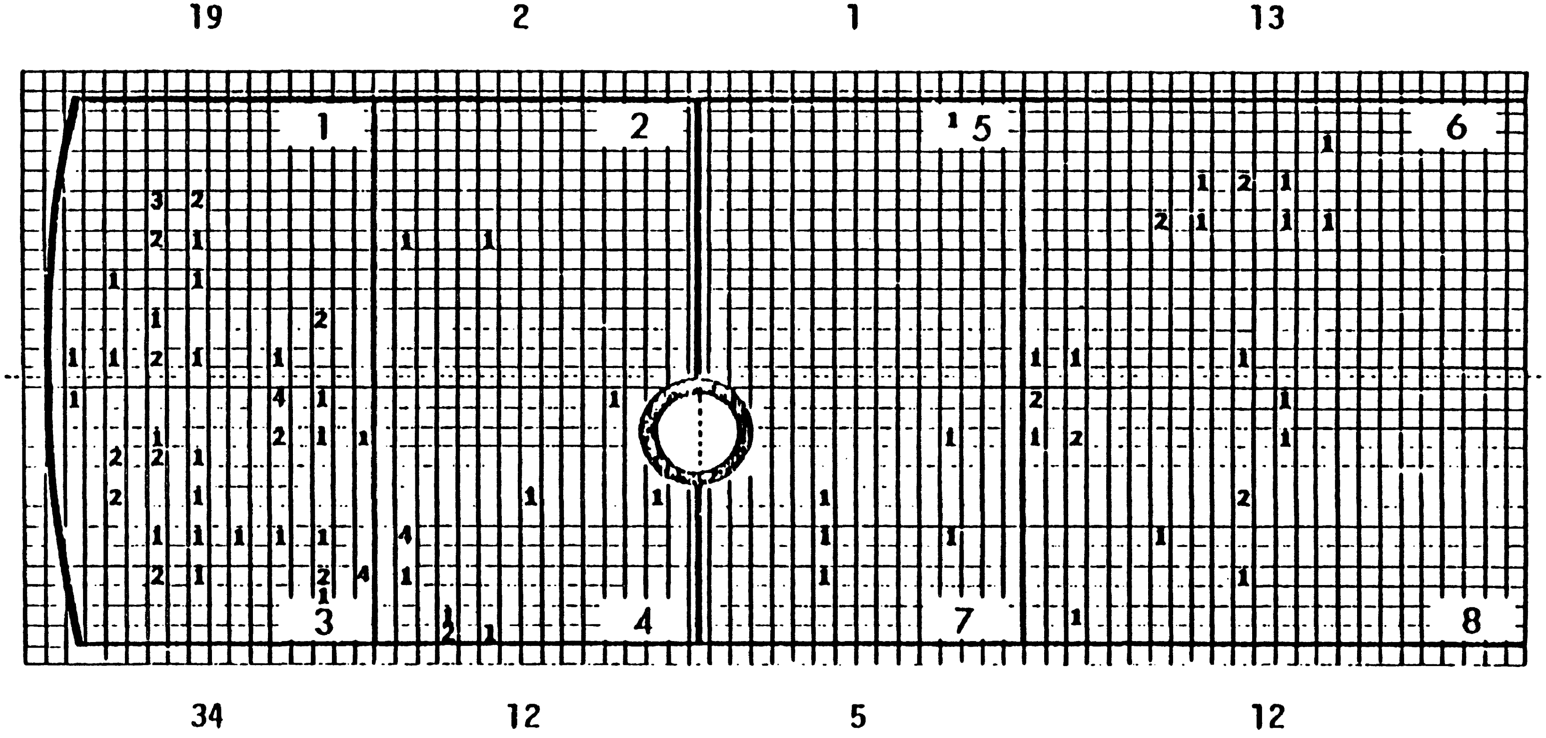
WASHER



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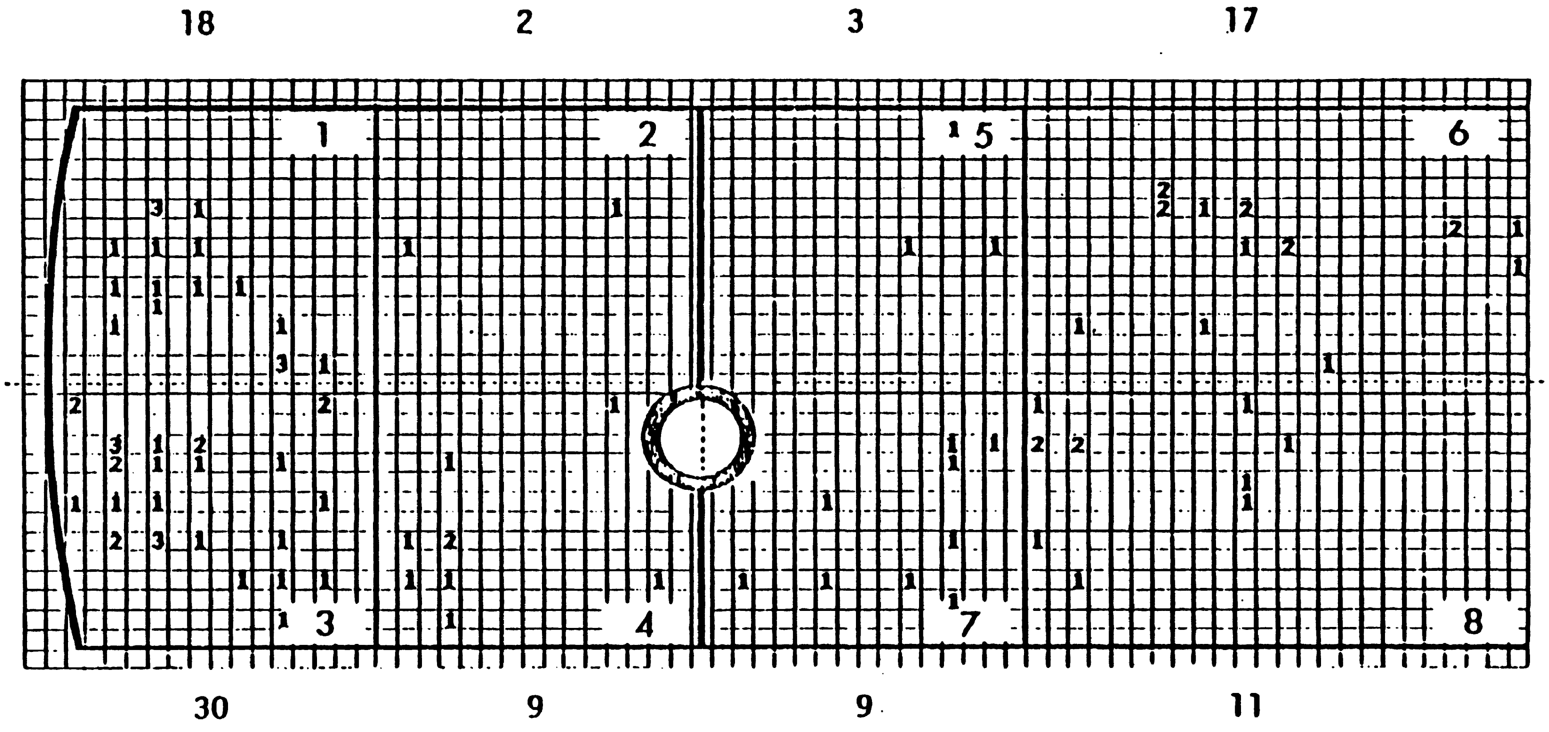
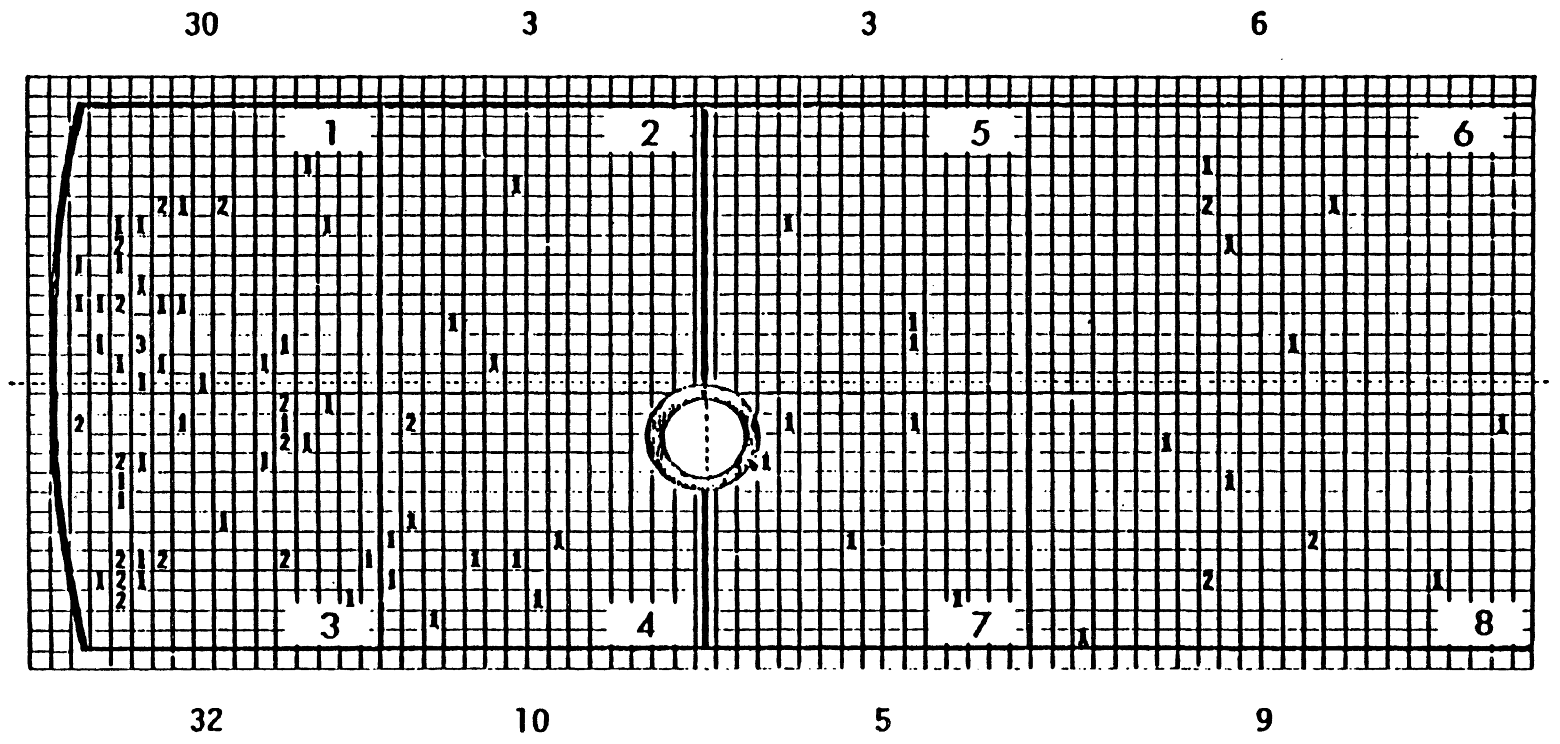
WIPER



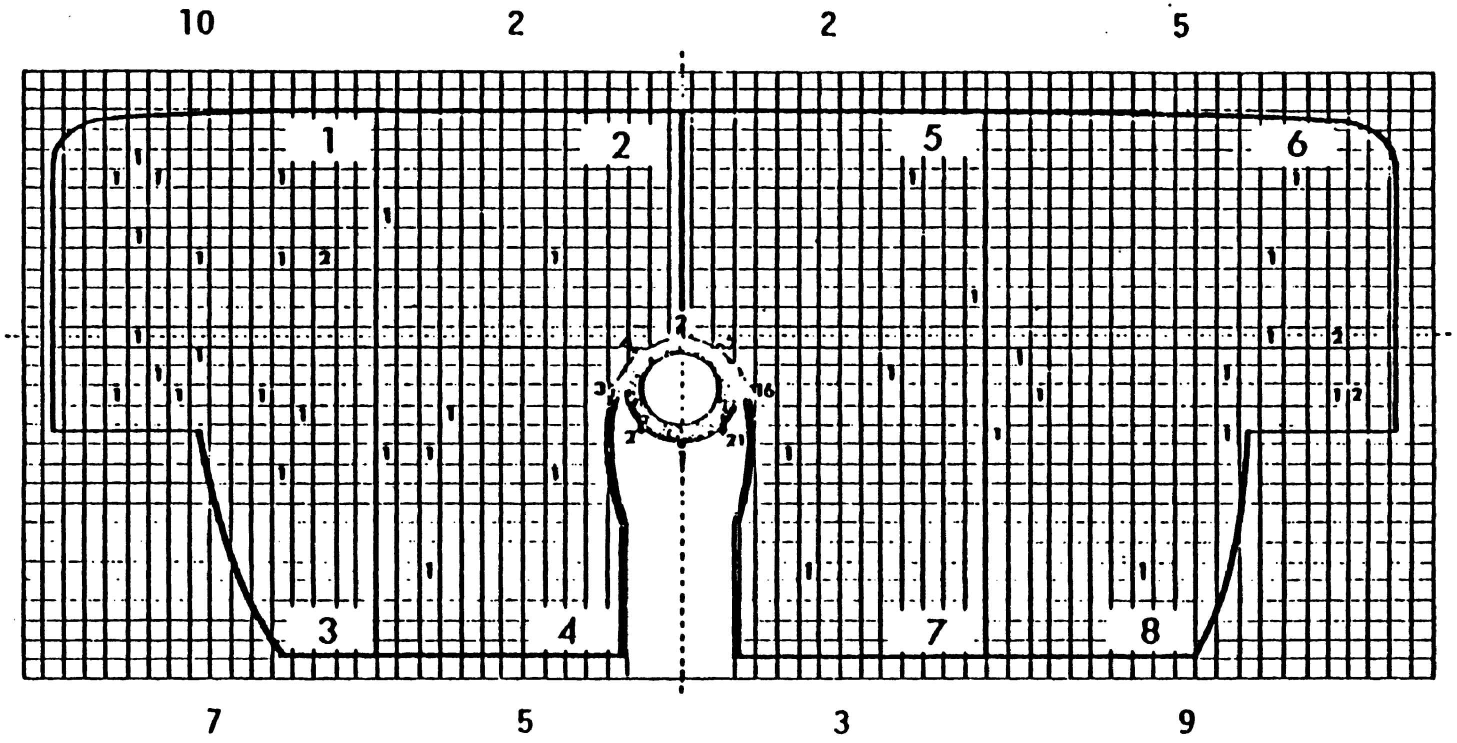
P/P EXPECTANCIES N = 99

HEADLIGHTS



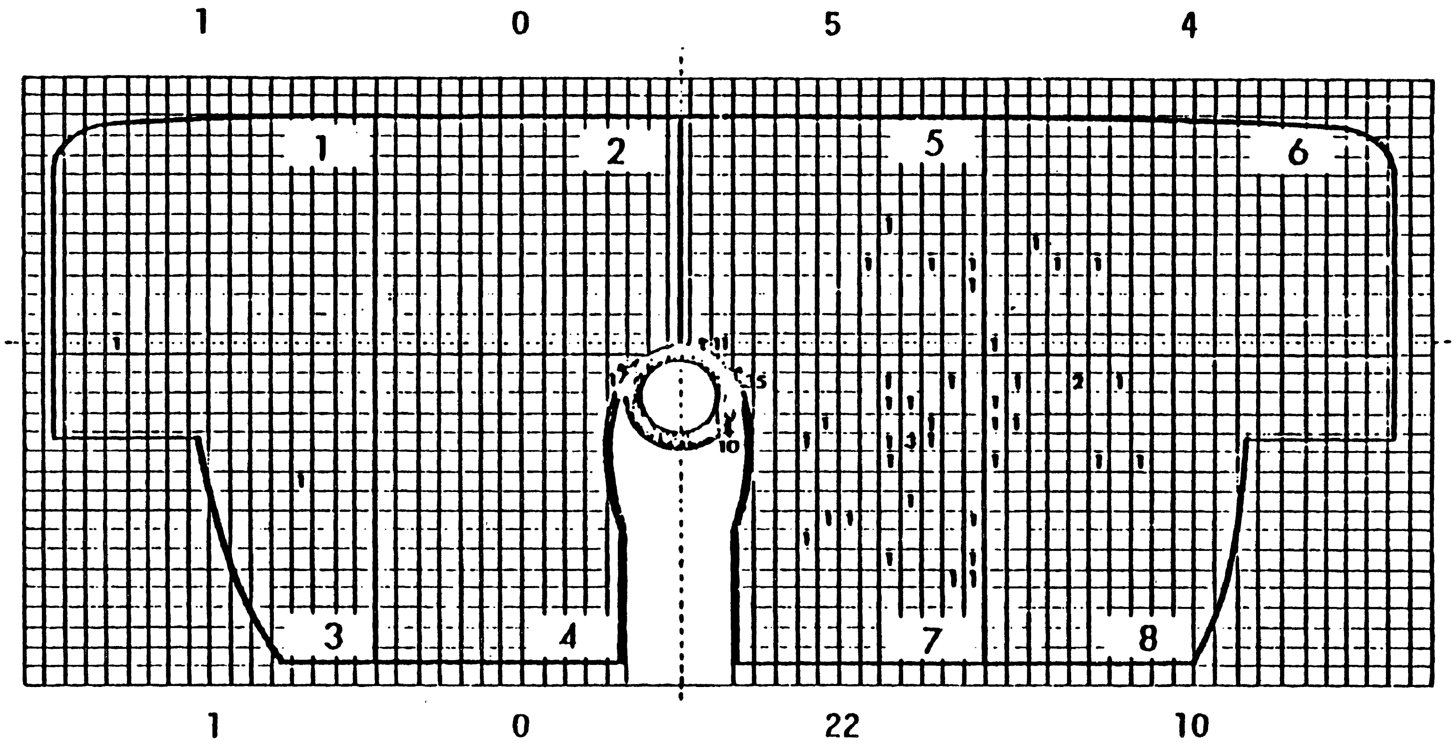
P/P EXPECTANCIES N = 98

FLASHER



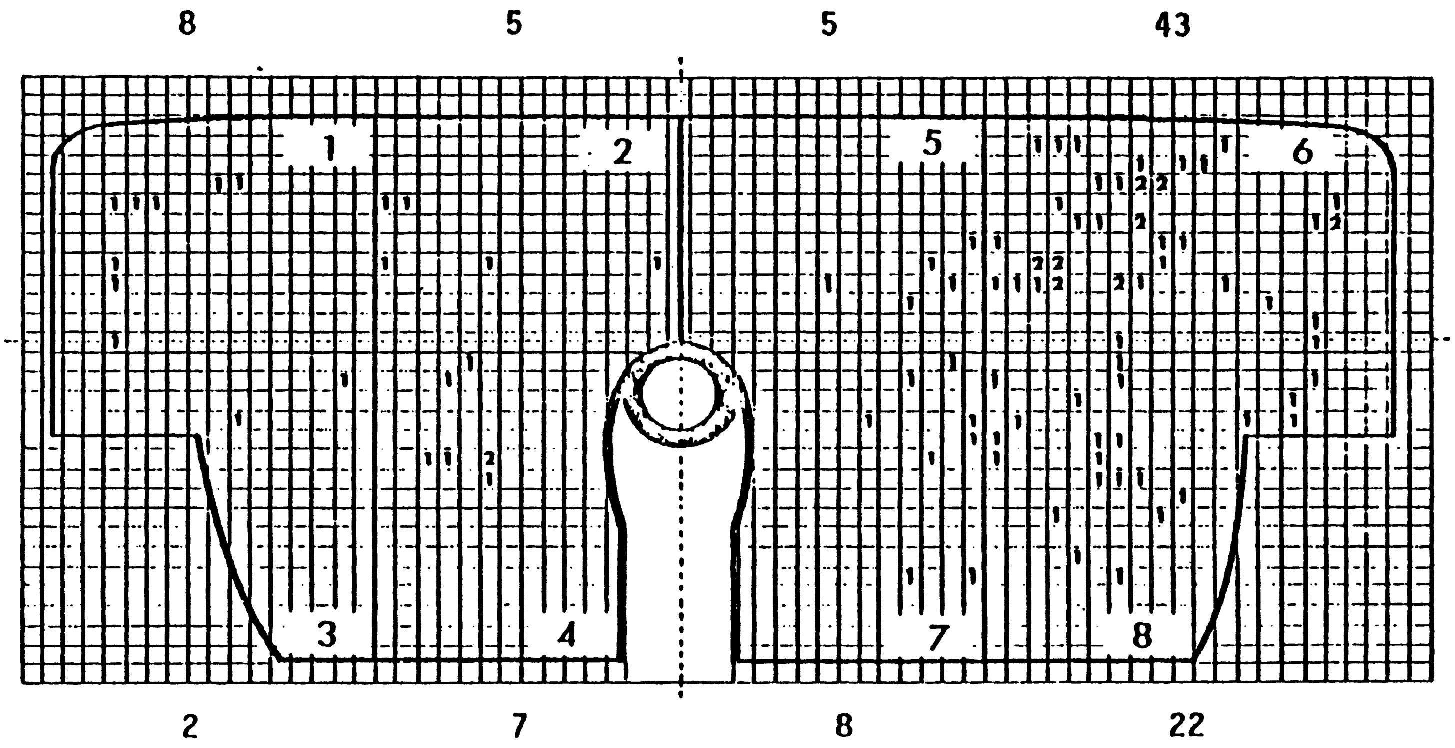
IN-CAR EXPECTANCIES N = 99

IGNITION



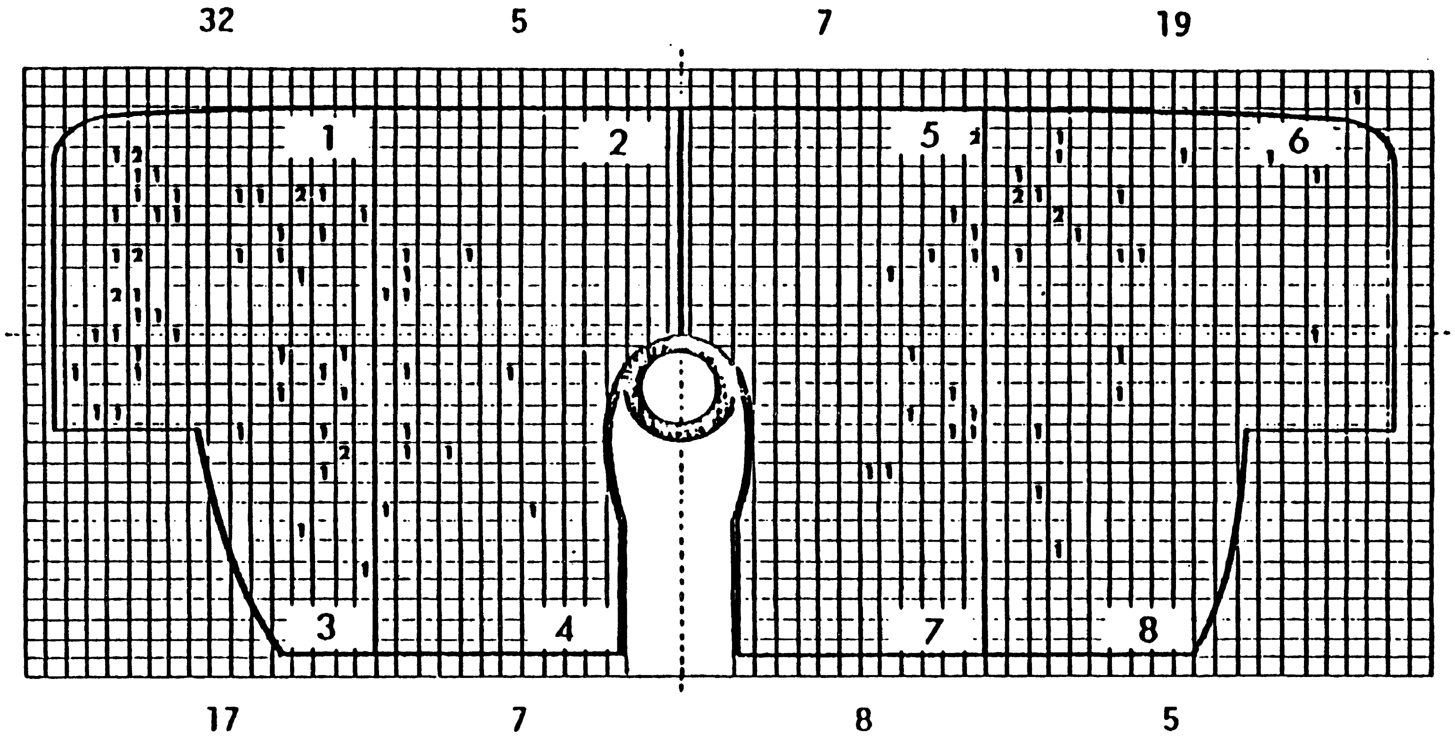
IN-CAR EXPECTANCIES N = 100

DEFROSTER



IN-CAR EXPECTANCIES N = 100

WASHER



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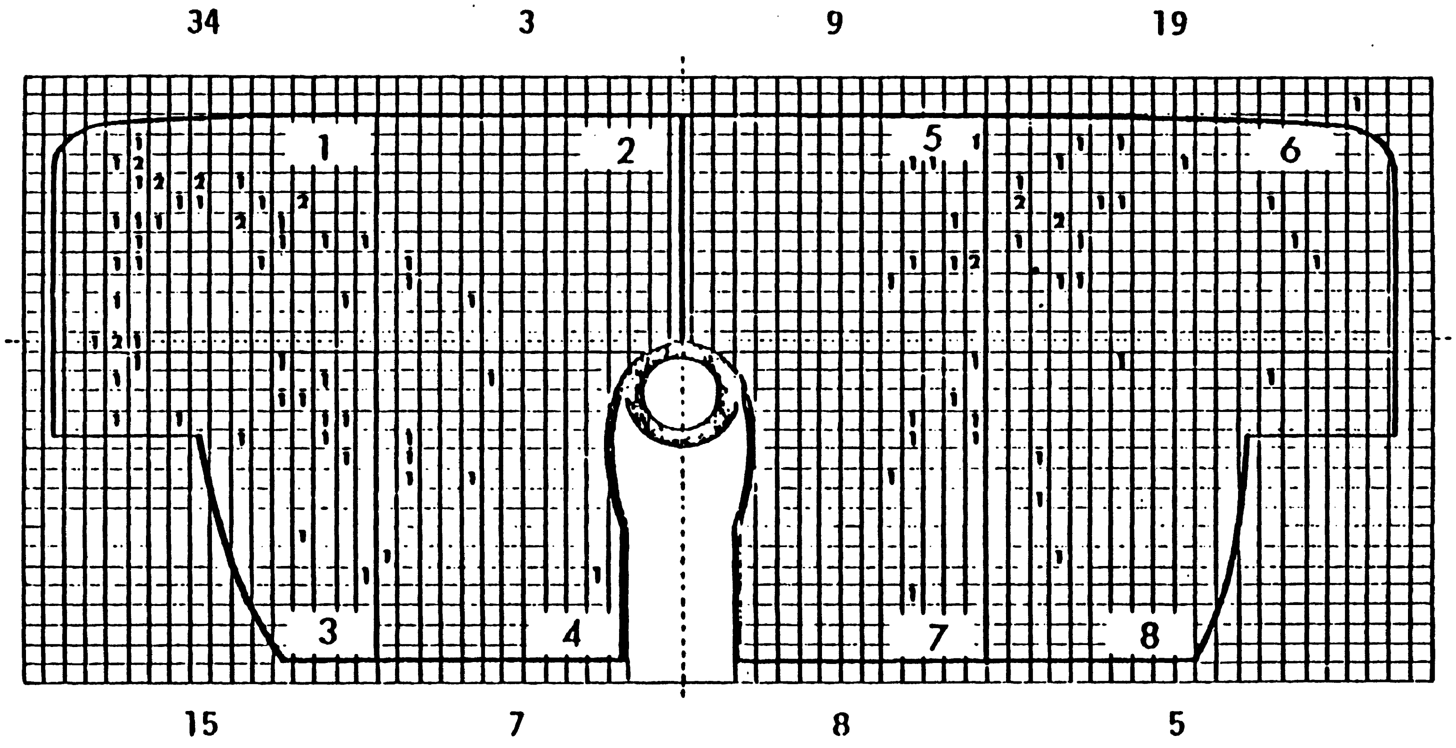
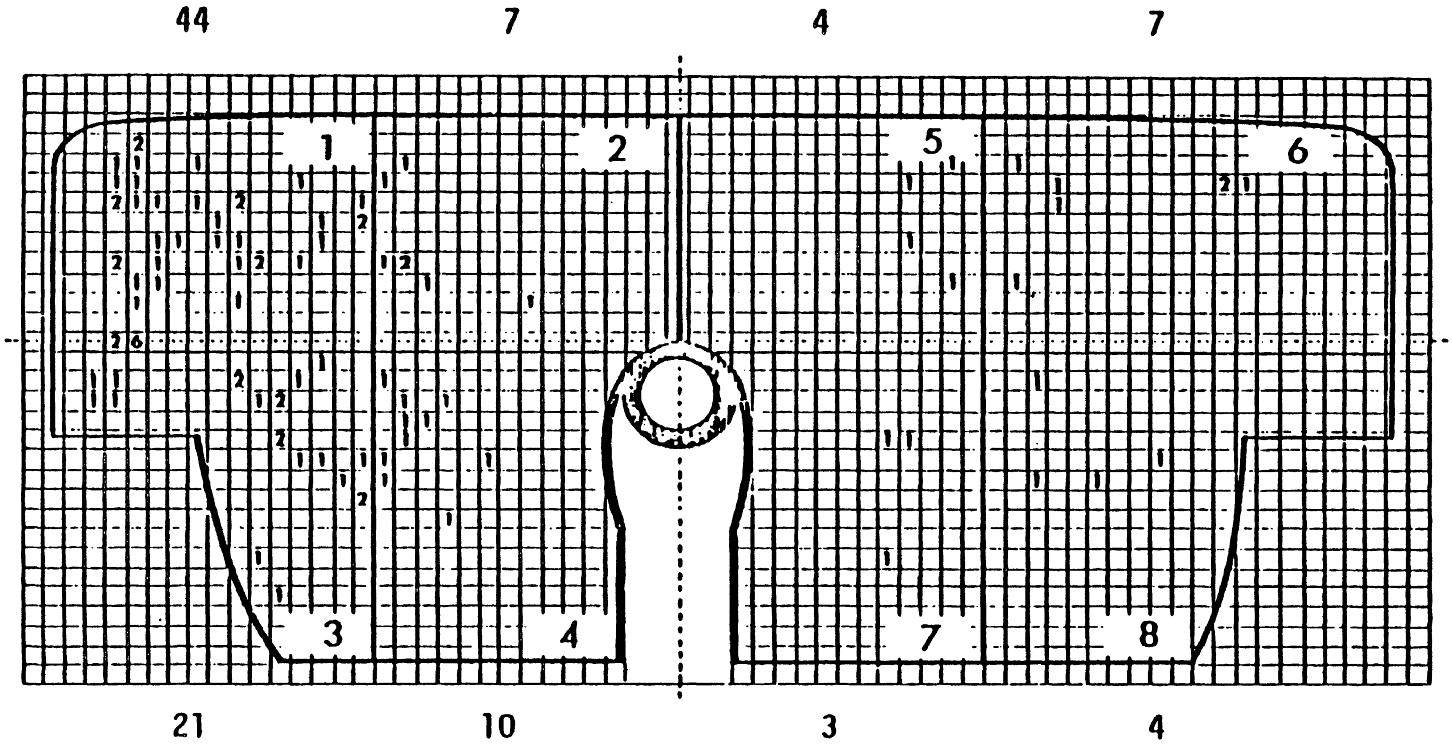


IN-CAR EXPECTANCIES N = 100

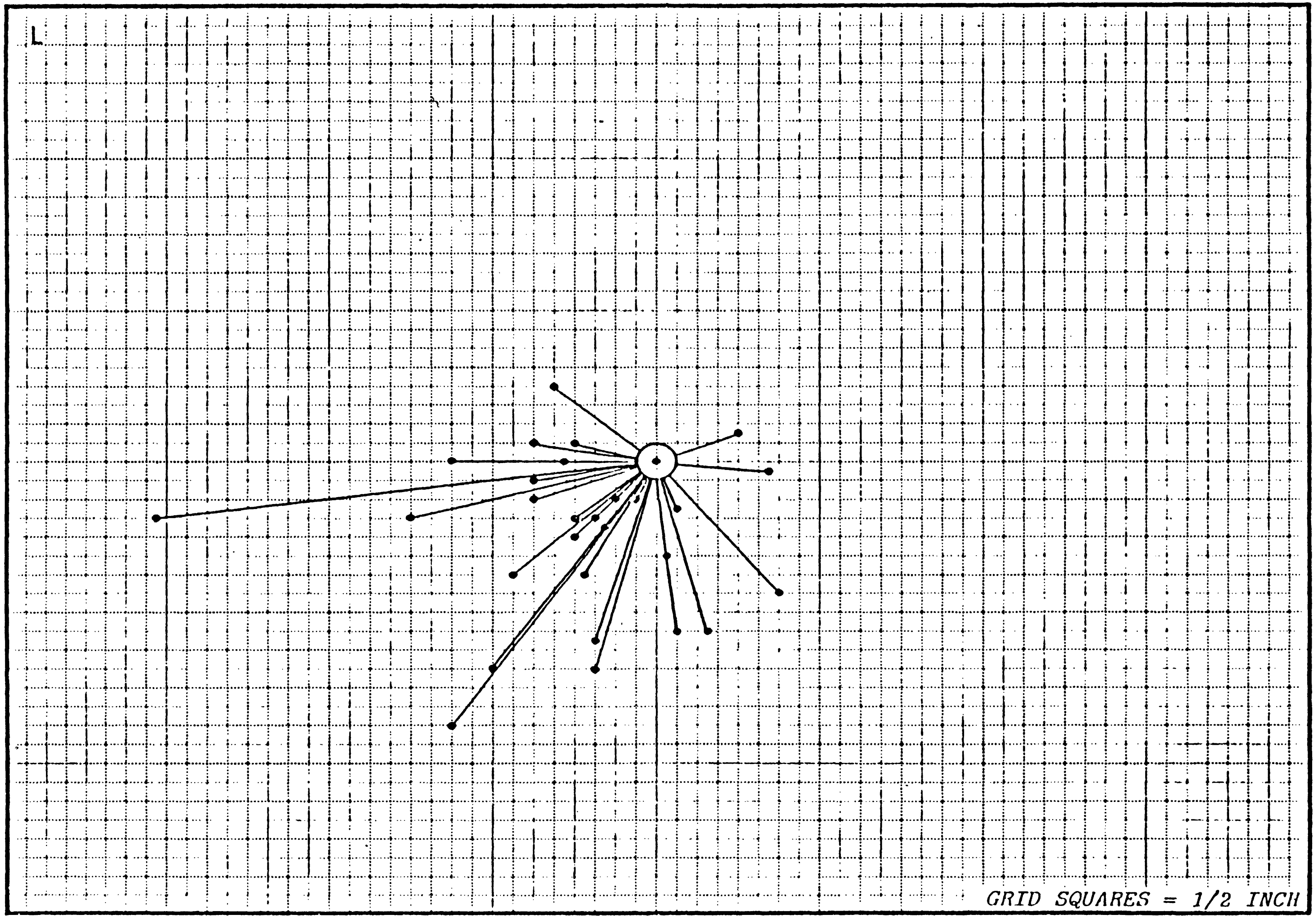
HEADLIGHT



IN-CAR EXPECTANCIES N = 100

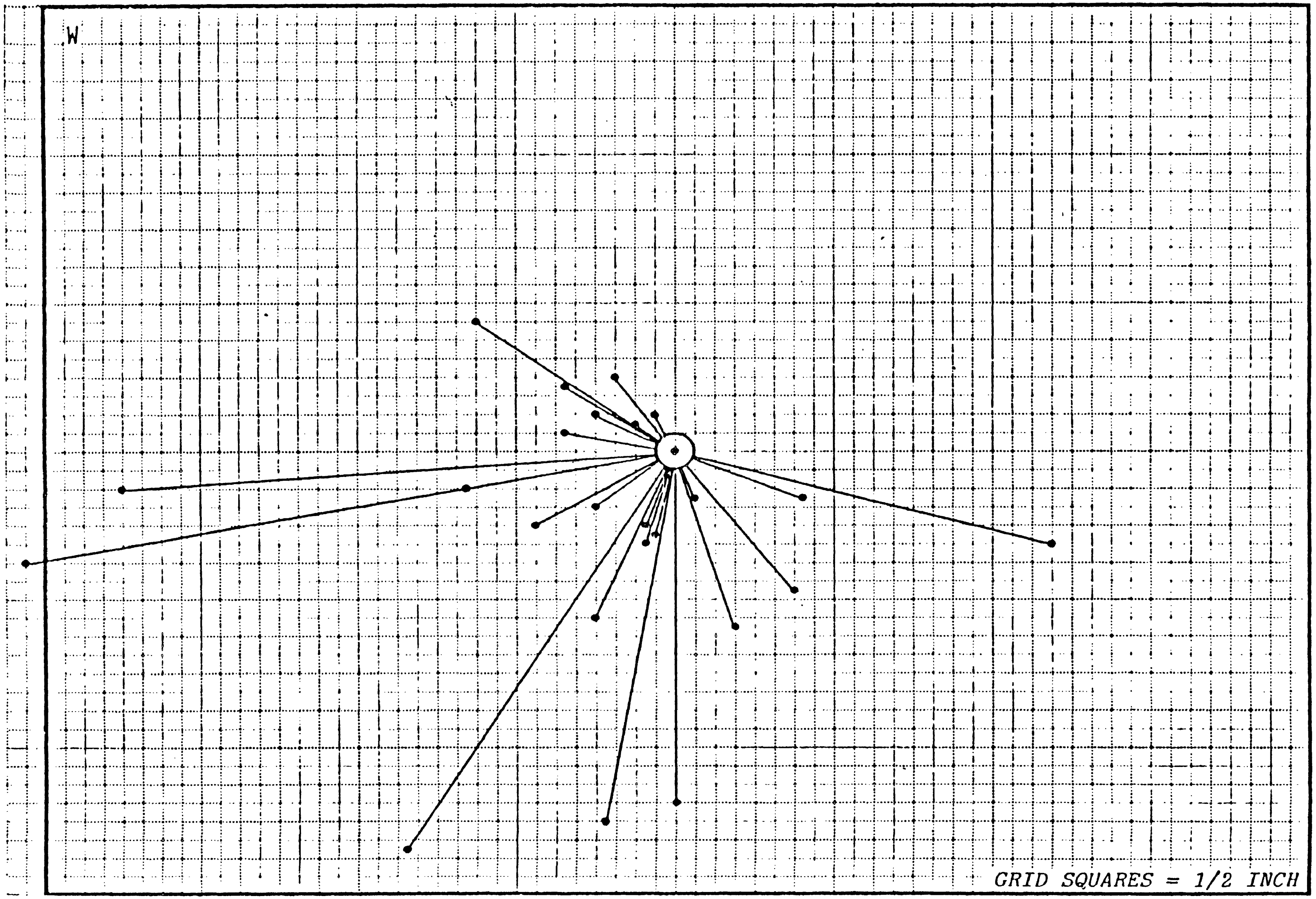
APPENDIX B - CONTROL RECALL ERRORS FROM ANACAPA 1974

HEADLIGHTS ACCURACY PLOT OF MOTORISTS' OWN-CAR RECALL



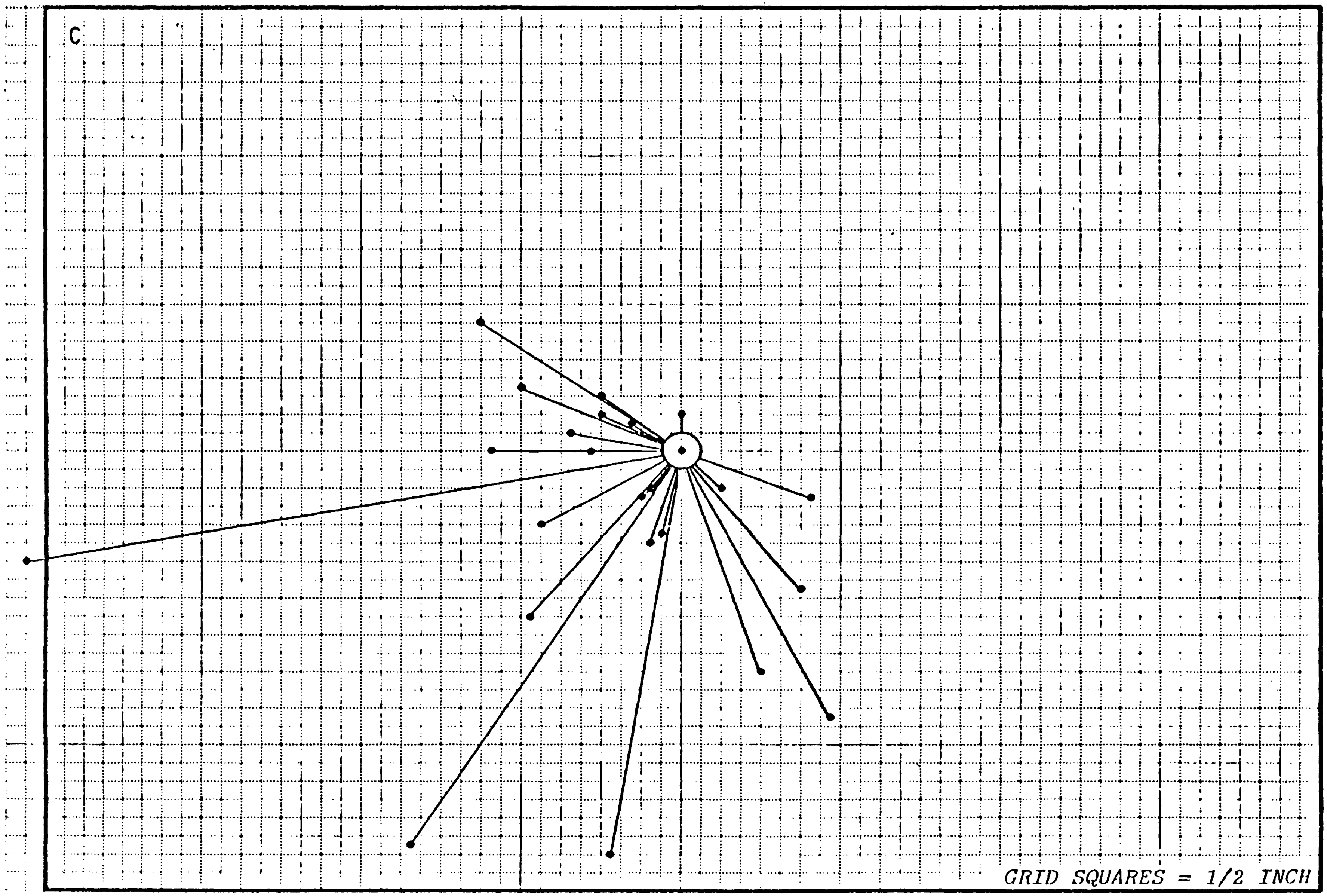
N = 28 28 Inaccurate (13" Error Maximum, 3" Error Typical)

WIPER ACCURACY PLOT OF MOTORISTS' OWN-CAR RECALL



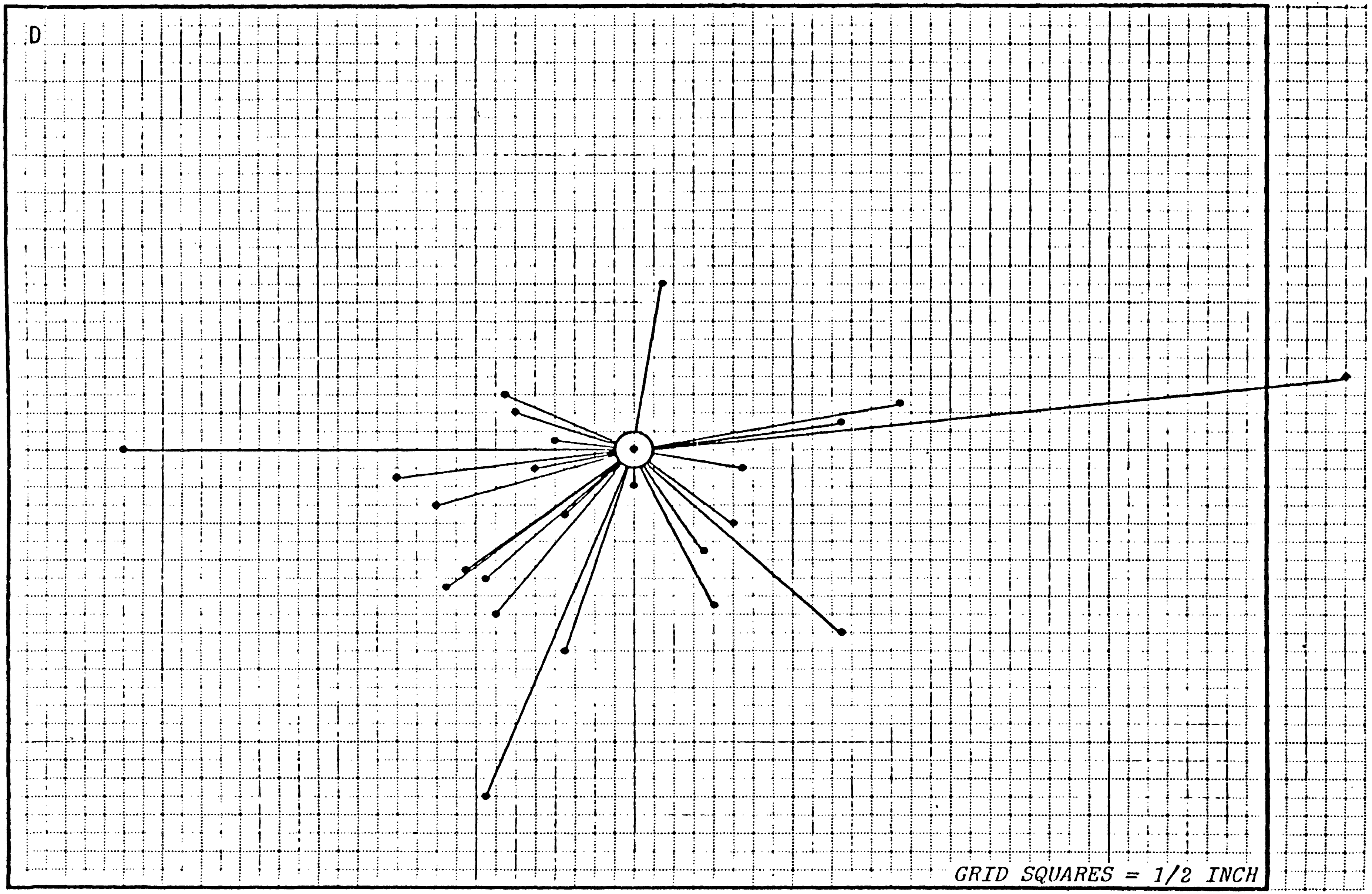
N = 28 4 Accurate 24 Inaccurate (17" Error Maximum, 2" Error Typical)

WASHER ACCURACY PLOT OF MOTORISTS' OWN-CAR RECALL



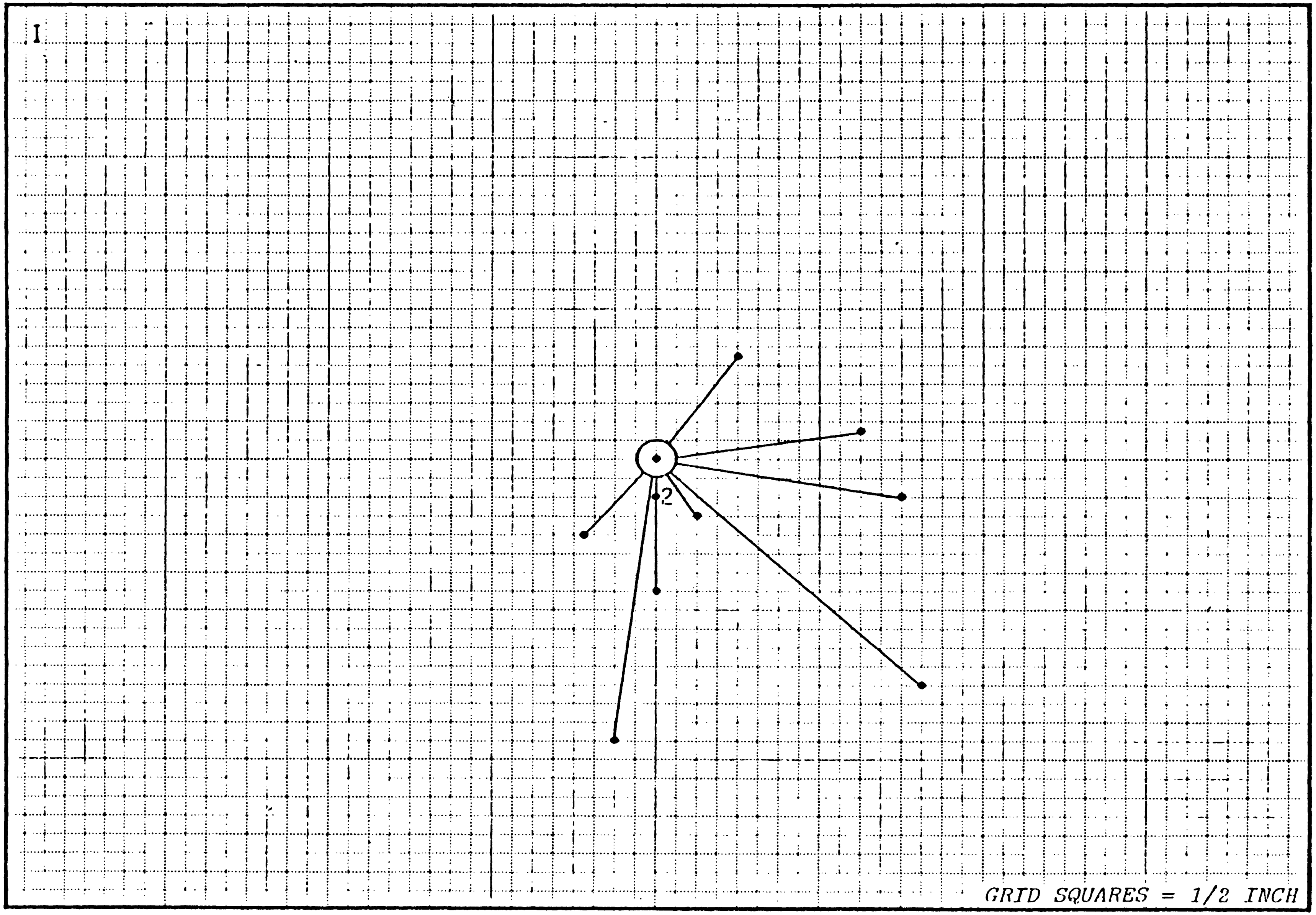
N = 28 3 Accurate 2 No Response 23 Inaccurate (17" Error Maximum, 3" Error Typical)

DEFROSTER ACCURACY PLOT OF MOTORISTS' OWN-CAR RECALL



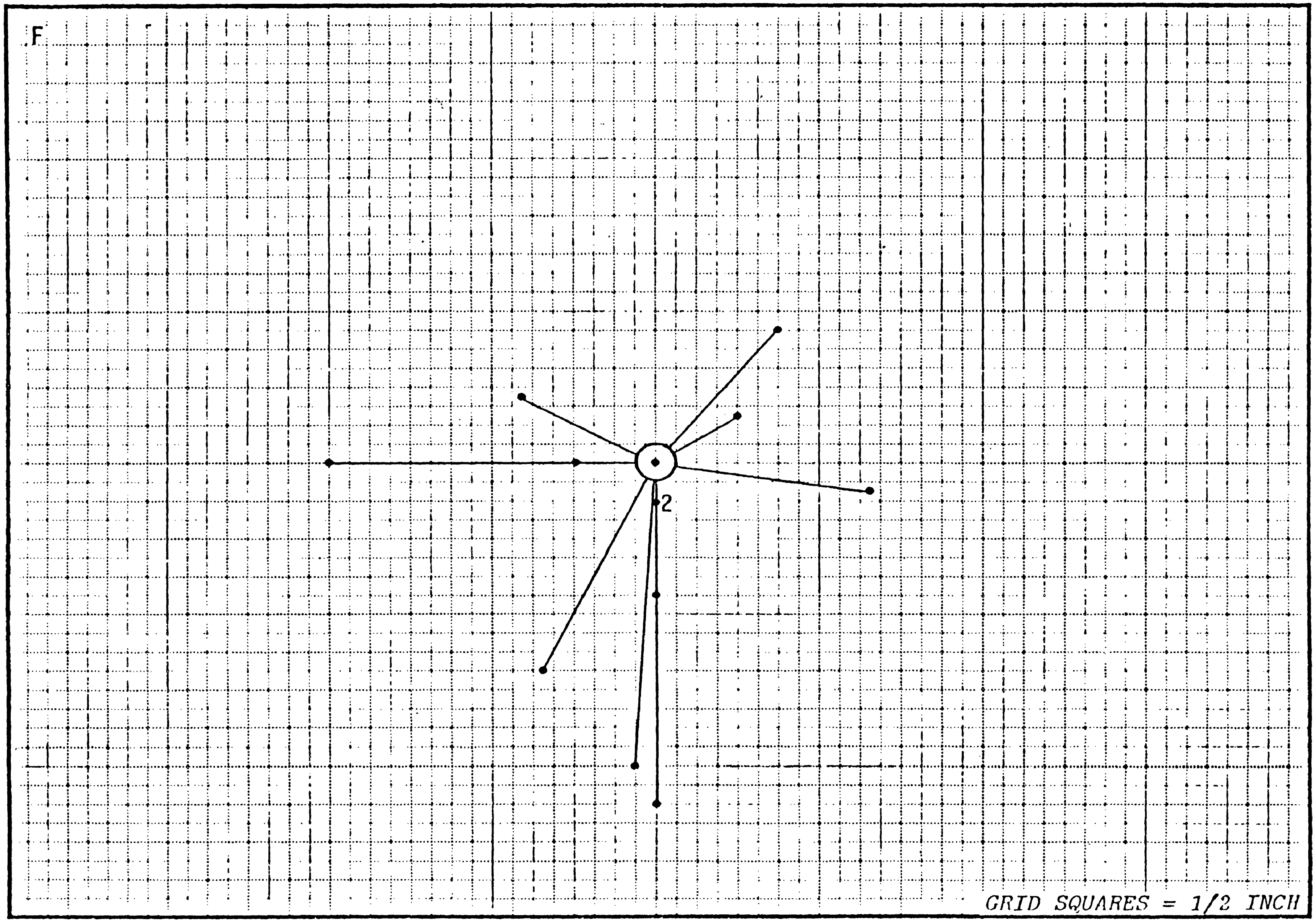
N = 28 3 Accurate 24 Inaccurate 1 No Response (18" Error Maximum, 6" Error Typical)

IGNITION ACCURACY PLOT OF MOTORISTS' OWN-CAR RECALL



N = 28 18 Accurate 10 Inaccurate (9" Error Maximum, 5" Error Typical)

FLASHER ACCURACY PLOT OF MOTORISTS' OWN-CAR RECALL



N = 28 14 Accurate 2 No Response 12 Inaccurate (9" Error Maximum, 4" Error Typical)

APPENDIX C - ISO STANDARD 4040

INTERNATIONAL STANDARD ISO 4040-1977 (E)

Road vehicles — Passenger cars — Location of hand controls, indicators and tell-tales

0 INTRODUCTION

There is a recognized potential for errors in the selection of controls essential to the safe operation of a vehicle, if these controls are not similarly located in all vehicles. Therefore, the standardization of these control locations must be considered a logical and beneficial design objective since drivers have an ever increasing opportunity to change from one vehicle to another.

1 SCOPE

This International Standard lays down the location of the controls in road vehicles, by sub-dividing the space within reach of drivers into specific zones to which certain controls essential to the safe operation of vehicles are assigned.

2 FIELD OF APPLICATION

This International Standard applies to hand-operated controls, to indicators and to tell-tales, for left- and right-hand drive passenger cars as defined in ISO 3833, sub-clause 3.1.

3 REFERENCES

ISO 3833, *Road vehicles — Types — Terms and definitions.*

ISO 3958, *Road vehicles — Passenger cars — Driver hand control reach.*

ISO ..., *Road vehicles — Determination of the H point and definition of the R point.*[1]

4 DEFINITIONS

4.1 reference plane : A vertical plane parallel to the longitudinal axis of the car, within a zone 50 mm to either side of the centre of the designated seating position for the driver at the R point.

4.2 operational area of a control : The area swept by those parts of a control which are activated by the hand while the possible modes or positions are selected in the manner intended by the designer (see figure 1).

4.3 display area of an indicator or tell-tale : The area which includes the identification of the quantity displayed and those portions required to determine its level at any point within the usable capacity of the instrumentation. It need not include, for example, bezels or the manufacturer's type number (see figure 2).

4.4 steering wheel plane : The plane passing through the upper surface of the steering wheel rim (see figure 3).

4.5 steering wheel axis : The line at right angles to the steering wheel plane, passing through the centre of rotation of the steering wheel rim.

5 REQUIREMENTS FOR LOCATION OF CONTROLS

5.1 The operational area of the following controls, when fitted to a car, shall be located to the left of the reference plane :

- driving lights control;
- side and rear lights control;
- driving light/passing light-dip control;
- optical warning control;
- direction indicator control;
- emergency braking control (right-hand drive only).

5.2 The operational area of a control for the audible warning (horn) shall be located (see figure 3) :

a) between two planes parallel to the steering wheel plane, one 10 mm above and the other 130 mm below the steering wheel plane; and

b) within a cylinder which extends 50 mm beyond the periphery of the steering wheel rim and whose axis is on the steering wheel axis.

In addition, not less than half of this control operational area shall

- either lie to the left of two planes which intersect along the steering wheel axis, and whose intersections with the steering wheel plane are at 50° and 130° to the left from the reference plane; and shall lie outside a cylinder which passes 130 mm inside the periphery of the steering wheel rim and whose axis is on the steering wheel axis;
- or lie within a cylinder of 50 mm radius whose axis is on the steering wheel axis.

Additional audible warning controls may be located elsewhere, or operational areas of controls may extend beyond the zones described above.

These assessments are to be made with the vehicle front wheels in the straight-ahead position, and the gear selector control in top gear, or drive position.

5.3 The operational area of the following control, when fitted to a car, shall be located to the right of the reference plane :

- emergency braking control (left-hand drive only).

5.4 The controls listed in 5.1, 5.2 and 5.3 shall be within the operational reach of drivers as defined by ISO 3958.

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[1] In preparation.

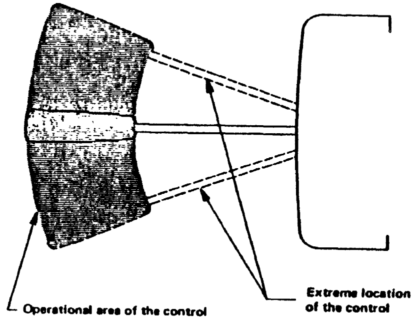


FIGURE 1 – Operational area of a control

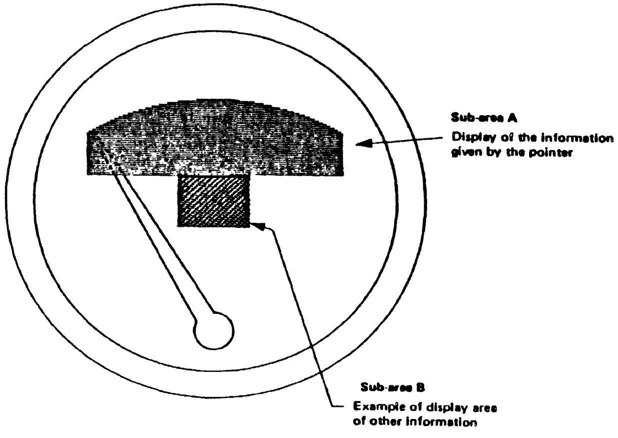


FIGURE 2 – Example of display area of indicators

Dimensions in millimetres

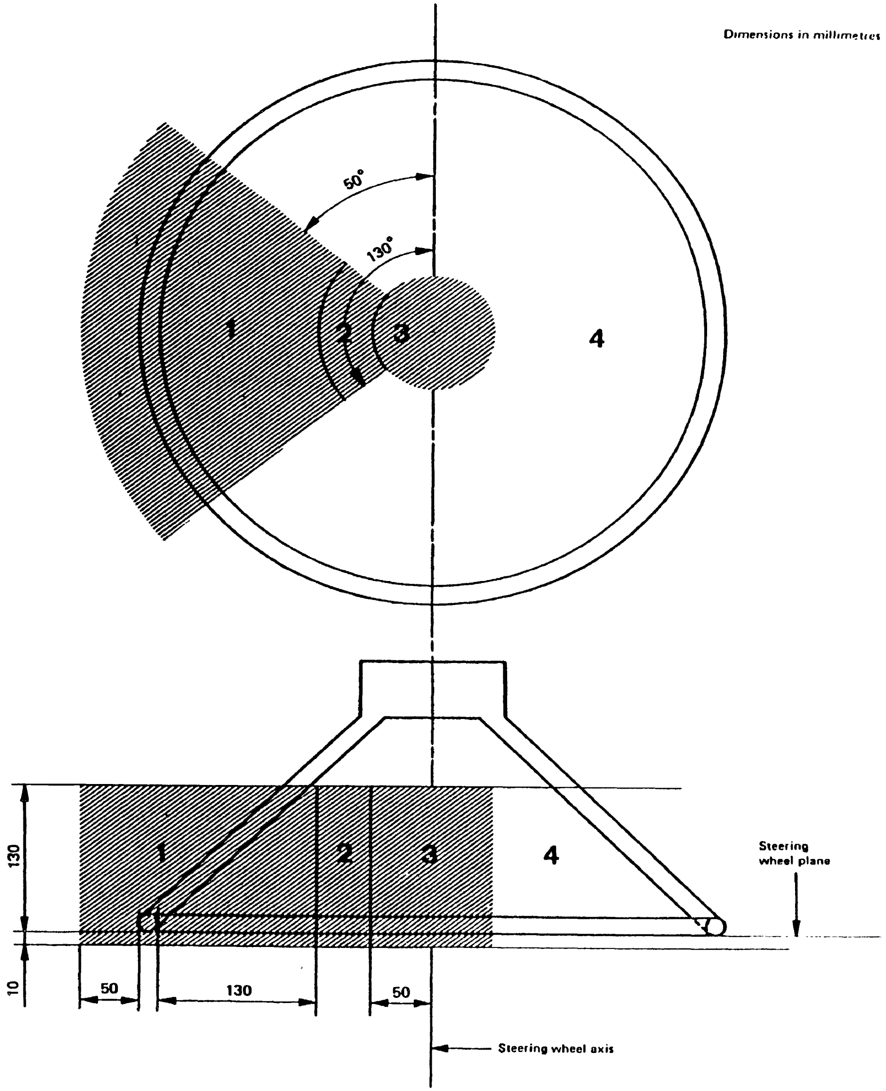


FIGURE 3 – Location of horn control

APPENDIX D - ECE REGULATION 21.01 DIRECTIVE 74/60

ECONOMIC COMMISSION FOR EUROPE
EUROPEAN ECONOMIC COMMUNITY

INTERIOR FITTINGS. ECE REGULATION 21.01 and EEC DIRECTIVE 74/60 as amended by 78/632.

PREAMBLE - ARTICLES TO THE DIRECTIVE

1. For the purposes of the Directive, 'vehicle' means any motor vehicle in category M1 (defined in Annex I of the Directive of 6 February 1970) designed for use on the road, having at least four wheels and a maximum design speed exceeding 25 km/h.

The Annexes to Directive 74/60/EEC are amended as shown in the Annex to this Directive.

2. 1. With effect from 1 January 1979 no Member State may on grounds relating to the interior fittings of motor vehicles (interior parts of the passenger compartment other than the interior rear-view mirrors, layout of the controls, the roof or opening roof, the backrest and rear part of the seats):

   - refuse in respect of a type of vehicle to grant EEC type approval, to issue the document referred to in the last indent of Article 10 (1) of Directive 70/156/EEC, or to grant national type approval; or

   - prohibit the entry into service of vehicles if the interior fittings (interior parts of the passenger compartment other than the interior rear-view mirrors, layout of the controls, the roof or opening roof, the backrest and rear part of the seats) of such type of vehicle or of such vehicles comply with the provisions of Directive 74/60/EEC, as amended by this Directive.

   2. With effect from 1 January 1979 Member States:

   - may no longer issue the document referred to in the last indent of Article 10 (1) of Directive 70/156/EEC in respect of a type of vehicle of which the interior fittings (interior parts of the passenger compartment other than the interior rear-view mirrors, layout of the controls, the roof or opening roof, the backrest and rear part of the seats) do not comply with the provisions of Directive 74/60/EEC, as amended by this Directive.

   - may refuse to grant national type approval in respect of a type of vehicle of which the interior fittings (interior parts of the passenger compartment other than the interior rear-view mirrors, layout of the controls, the roof or opening roof, the backrest and rear part of the seats) do not comply with the provisions of Directive 74/60/EEC, as amended by this Directive.

   3. With effect from 1 October 1982 Member States may prohibit the entry into service of vehicles of which the interior fittings (interior parts of the passenger compartments other than the interior rear-view mirrors, layout of the controls, the roof or opening roof, the backrest and rear part of the seats) do not comply with the provisions of Directive 74/60/EEC, as amended by this Directive.

3. The Member States shall bring into force the provisions necessary to comply with this Directive not later than 1 January 1979 and shall forthwith inform the Commission thereof.

1. SCOPE

This Regulation/Directive applies to the interior parts of the passenger compartment (other than the rear-view mirror or mirrors); the arrangement of the controls; the roof and the sliding roof, and the seatback and the rear parts of seats.

Annex I

DEFINITIONS, APPLICATIONS FOR EEC APPROVAL AND SPECIFICATIONS

2. DEFINITIONS

For the purposes of this Directive.

(2.1.)

2.2. ø 'Vehicle type' with respect to the interior fittings of the passenger compartment (other than the rear-view mirror(s): the arrangement of the controls, the roof or sliding roof, the back rest and rear part of the seats) means motor vehicles which do not differ in such essential respects as:

2.2.1. the lines of constituent materials of the bodywork of the passenger compartment,

2.2.2. the arrangement of the controls,

2.3. ø 'reference zone' means the head impact zone as defined in Annex II except:

2.3.1. ø the area bounded by the forward horizontal projection of a circle circumscribing the outer limits of the steering control, increased by a peripheral band 127 mm in width; this area is bounded below the horizontal plane tangential to the lower edge of the steering control when the latter is in the position for driving straight ahead,

2.3.2. the part of the surface of the instrument panel comprised between the edge of the area specified in point 2.3.1. above and the nearest inner side-wall of the vehicle; this surface is bounded below by the horizontal plane tangential to the lower edge of the steering control; and

2.3.3. the windscreen side pillars,

2.4. ø 'level of the instrument panel' shall mean the line defined by the points of contact of vertical tangents to the instrument panel,

2.5. ø 'roof' shall mean the upper part of the vehicle extending from the upper edge of the windscreen to the upper edge of the rear window, bounded at the sides by the upper framework of the side-walls,

2.6. 'belt line' shall mean the line formed by the transparent lower contour of the side windows of the vehicle;

(ø) See also Appendix to Annexes 1. II, III, IV and VI, on page 6.

2.7. ø 'convertible vehicle' shall mean a vehicle where in certain configurations there is no rigid part of the vehicle body above the belt line with exception of the front roof supports and/or the roll-over bars and/or the seat-belt anchorage points;

2.8. 'vehicle with opening roof' shall mean a vehicle of which only the roof or a part of it can be folded back or be open, or may slide, leaving the existing structural elements of the vehicle above the belt line;

2.9. 'folding (tip-up) seat' shall mean an auxiliary seat intended for occasional use and which is normally folded out of the way;

3. APPLICATION FOR EEC TYPE APPROVAL

3.1. The application for type approval of a vehicle shall be submitted by the vehicle manufacturer or by his representative.

3.2. It shall be accompanied by the undermentioned documents in triplicate and by the following particulars:

- a detailed description of the vehicle type with regard to the items mentioned in point 2.2. above;
- a photograph or an exploded view of the passenger compartment; and
- the numbers and/or symbols identifying the vehicle type must be specified.

3.3. The following must be submitted to the technical service responsible for conducting the tests:

3.3.1. at the manufacturer's discretion, either a vehicle representative of the vehicle type to be approved or the part(s) of the vehicle regarded as essential for the checks and tests prescribed by this Directive; and

3.3.2. at the request of the aforesaid technical service, certain components and certain samples of the materials used.

(4)

5. SPECIFICATIONS

5.1. Forward interior parts of the passenger compartment above the level of the instrument panel in front of the front seat H points, excluding the side doors

5.1.1. ø The reference zone defined in point 2.3. above must not contain any dangerous roughness or sharp edges likely to increase the risk of serious injury to the occupants. Those parts referred to in points 5.1.2. to 5.1.6 hereafter shall be deemed satisfactory if they comply with the requirements thereof.

5.1.2. ø Vehicle parts within the reference zone with the exception of those, which are not part of the instrument panel and which are placed at less than 10 cm from glazed surfaces shall be energy-dissipating as prescribed in Annex III. Those parts within the reference zone which satisfy both of the following conditions shall also be excluded from consideration:

- if, during a test in accordance with the requirements of Annex III, the pendulum makes contact with parts outside the reference zone; and

- if the parts to be tested are placed less than 10 cm away from the parts contacted outside the reference zone, this distance being measured on the surface of the reference zone;

any metal support fittings shall have no protruding edges.

5.1.3. (0) The lower edge of the instrument panel, unless it meets the requirements of point 5.1.2. above, shall be rounded to a radius of curvature of not less than 19 mm.

5.1.4. (0) Switches, pull-knobs, etc., made of rigid material, which, measured in accordance with the method described in Annex V from 3.2 mm to 9.5 mm from the panel, shall have a cross-sectional area of not less than 2 cm^2, measured 2.5 mm from the point projecting furthest, and shall have rounded edges with a radius of curvature of not less than 2.5 mm.

5.1.5. (0) If these components project by more than 9.5 mm from the surface of the instrument panel, they shall be so designed and constructed as to be able, under the effect of a longitudinal horizontal force of 37.8 daN delivered by a flat ended ram of not more than 50 mm diameter either to retract into the surface of the panel until they do not project by more than 9.5 mm or to become detached; in the latter case no dangerous projections of more than 9.5 mm shall remain; a cross-section not more than 6.5 mm from the point of maximum projection shall be not less than 6.50 cm^2 in area.

5.1.6. (0) In the case of a projection consisting of a component made of non-rigid material of less than 50 shore A hardness mounted on a rigid support, the requirements of points 5.1.4. and 5.1.5. shall apply only to the rigid support.

5.2. Forward interior parts of the passenger compartment below the level of the instrument panel and in front of the front seat H points, excluding the side doors and the pedals

5.2.1. (0) Except for the pedals and their fixtures and those components that cannot be contacted by the device described in Annex VI and used in accordance with the procedure described therein, components covered by point 5.2. shall comply with the requirements of points 5.1.4. to 5.1.6. above.

5.2.2. (ø) The hand-brake control, if mounted on or under the instrument panel, shall be so placed that, when it is released, there is no possibility of occupants of the vehicle contacting it in the event of a frontal impact. If this condition is not met, the surface area of the control shall satisfy the requirements of point 5.3.2.3. below.

5.2.3. (ø) Shelves and other similar items shall be so designed and constructed that their supports in no case have protruding edges and they meet one or other of the following conditions:

5.2.3.1. (ø) the part facing into the vehicle shall present a surface not less than 25 mm high with edges rounded to a radius of curvature of not less than 3.2 mm. This surface shall be covered with an energy-dissipating material as defined in Annex III, and shall be tested in accordance therewith, the impact being applied in a horizontal longitudinal direction.

5.2.3.2. (ø) Shelves and other similar items shall, under the effect of a forward-acting horizontal longitudinal force of 37.8 daN exerted by a cylinder of 110 mm diameter with its axis vertical, become detached, break up, be substantially distorted or retract without producing dangerous features on the rim of the shelf. The force must be directed at the strongest part of the shelves or other similar items.

5.2.4. If the items in question contain a part made of material softer than 50 shore A hardness when fitted to a rigid support, the above requirements, except for the requirements covered by Annex III relating to energy absorption shall apply.

5.3. (ø) Other interior fittings in the passenger compartments in front of the transverse plane passing through the torso reference line of the manikin placed on the rearmost seats.

5.3.1. Scope

The requirements of 5.3.2. below shall apply to control handles, levers and knobs and to any other protruding objects not referred to in points 5.1. and 5.2. above (see also under 5.3.2.2.).

5.3.2. (ø) Requirements

If the items referred to in point 5.3.1. are so placed that occupants of the vehicle can contact them, they shall meet the requirements of points 5.3.2.1. to 5.3.4. If they can be contacted by a 165 mm diameter-sphere and are above the lowest H point (see Annex IV) of the front seats and forward of the transverse plane of the torso reference line of the manikin on the rearmost seat, and outside the zones defined in points 2.3.1. and 2.3.2., these requirements shall be considered to have been fulfilled if:

5.3.2.1. (ø) Their surface shall terminate in rounded edges, the radii of curvature being not less than 3.2 mm.

5.3.2.2. (ø) Control levers and knobs shall be so designed and constructed that, under the effect of a forward-acting longitudinal horizontal force of 37.8 daN either the projection in its most unfavourable position shall be reduced to not more than 25 mm from the surface of the panel or the said fittings shall become detached or bent; in the two latter cases no dangerous projections shall remain.

Window winders may, however, project 35 mm from the surface of the panel.

5.3.2.3. (ø) The hand brake control when in the released position and the gear lever when in any forward gear position, except when placed in the zones defined in points 2.3.1. and 2.3.2. and zones below the horizontal plane passing through the H point of the front seats, shall have a surface area of at least 6.5 cm^2 measured at a cross-section normal to the longitudinal horizontal direction up to a distance of 6.5 mm from the furthest projecting part, the radius of curvature being not less than 3.2 mm.

5.3.3. The requirements of point 5.3.2.3. shall not apply to floor-mounted hand brake control; for such controls if the height of any part in the released position is above a horizontal plane passing through the lowest H point of the front seats (see Annex IV) the control shall have a cross sectional area of at least 6.5 cm^2, measured in a horizontal plane, not more than 6.5. mm from the furthest projecting part (measured in the vertical direction). The radius of curvature must not be less than 3.2 mm.

5.3.4. (ø) Other items of equipment in the vehicle not covered by the preceding points such as seat slide rails, equipment for regulating the horizontal or vertical part of the seat, devices for retracting safety belts, etc. shall not be subject to any of these provisions if they are situated below a horizontal plane passing through the H point of each seat, even though the occupant is likely to come into contact with such items.

5.3.4.1. (ø) Components mounted on the roof but which are not part of the roof structure, such as grab handles, lights and sun visors, etc., shall have a radius of curvature of not less than 3.2 mm and, in addition, the width of the projecting parts shall not be less than the amount of their downward projection; alternatively, these components shall pass the energy-dissipating test in accordance with the requirements of Annex III.

5.3.5. If the items in question include a part made of material softer than 50 shore A hardness mounted on a rigid support, the above requirements shall apply only to the rigid support.

5.4. (ø) Roof

5.4.1. Scope

5.4.1.1. The requirements of point 5.4.2. below shall apply to the inner face of the roof.

5.4.1.2. However, they shall not apply to such parts of the roof as cannot be contacted by a sphere 165 mm in diameter.

5.4.2. Requirements

5.4.2.1. (ø) That part of the inner face of the roof which is situated above or forward of the occupants shall exhibit no dangerous roughness or sharp edges, directed rearwards or downwards. The width of the projecting parts shall not be less than the amount of their downward projection and the edges shall have a radius of curvature of not less than 5 mm. In particular, the rigid roof sticks or ribs, with the exception of the header rail of the glazed surfaces and door frames, shall not project downwards more than 19 mm.

5.4.2.2. If the roof sticks or ribs do not meet the requirements of point 5.4.2.1., they must pass the energy-dissipation test in accordance with the requirements of Annex III.

5.4.2.3. The metal wires which stretch the lining of the roof and the frames of the sun visors must have a maximum diameter of 5 mm or be able to absorb the energy, as prescribed in Annex III. Non-rigid attachment elements of the frames of the sun visors shall meet the requirements of point 5.3.4.1.

5.5. (ø) Vehicles with an opening roof.

5.5.1. Requirements

5.5.1.1. The following requirements and those of point 5.4. above shall apply to vehicles with an opening roof when the roof is in the closed position.

5.5.1.2. (ø) In addition, the opening and operating devices shall:

5.5.1.2.1. be so designed and constructed as to exclude as far as possible accidental operation;

5.5.1.2.2. Their surfaces shall terminate in rounded edges, the radii of curvature being not less than 5 mm.

5.5.1.2.3. (ø) be accommodated, when in the position of rest, in areas which cannot be contacted by a sphere 165 mm in diameter. If this condition cannot be met, the opening and operating devices shall, in the position of rest, either remain retracted or be so designed and constructed that, under the effect of a force of 37.8 daN applied in the direction of impact defined in Annex III as the tangent to the trajectory of the headform, either the projection as described in Annex V shall be reduced to not more than 25 mm beyond the surface on which the devices are mounted or the devices shall become detached; in the latter case no dangerous projections shall remain.

5.6. (ø) Convertible vehicles

5.6.1. (ø) In the case of convertible vehicles, only the underside of the top of the roll-bar and the top of the windscreen frame in all its normal utilization positions shall comply with the requirements of point 5.4. The system of folding rods or links used to support a non-rigid roof shall, where they are situated above or forward of the occupants, exhibit no dangerous roughness or sharp edges, directed rearwards or downwards.

5.6.2. Vehicles with a sliding roof shall be subject to the requirements of point 5.5., applicable to vehicles with a sliding roof.

5.7. Rear parts of seats anchored to the vehicle.

5.7.1. Requirements

5.7.1.1. (ø) The surface of the rear parts of seats shall exhibit no dangerous roughness or sharp edges likely to increase the risk or severity of injury to the occupants.

5.7.1.2. (ø) Except as provided in points 5.7.1.2.1., 5.7.1.2.2., and 5.7.1.2.3., that part of the back of the front seat which is in the head-impact zone, defined in Annex II, shall be energy-dissipating, as prescribed in Annex III. For determining the head-impact zone, the front seats shall, if they are adjustable, be in the rearmost driving position with their backs inclined as near as possible to 25° unless indicated otherwise by the manufacturer.

5.7.1.2.1. In the case of separate front seats, the rear passengers' head-impact zone shall extend for 10 cm on either side of the seat centre-line, in the top part of the rear of the seat-back.

5.7.1.2.1. In the case of seats fitted with head-restraints each test shall be carried out with the head-restraint in the lowest position and at a point situated on the vertical line passing through the centre of the head-restraint.

5.7.1.2.1. In the case of a seat which is designed to be fitted in several types of vehicle, the impact zone shall be determined by the vehicle whose rearmost driving position is, of each of the types considered, the least favourable; the resultant impact zone will be deemed adequate for the other types.

5.7.1.2.2. In the case of front bench seats, the impact zone shall extend between the longitudinal vertical planes 10 cm outboard of the centre line of each designated outboard seating position. The centre line of each outboard seating position of a bench seat shall be specified by the manufacturer.

5.7.1.2.3. (0) In the head impact zone outside the limits prescribed in points 5.7.1.2.1. to 5.7.1.2.2. inclusive, the seat frame structure shall be padded to avoid direct contact of the head with it: and, in these zones, shall have a radius of curvature of at least 5 mm. These parts may alternatively satisfy the energy-dissipating requirements specified in Annex III.

5.7.2. These requirements shall not apply to the rearmost seats, to seats facing sideways or rearwards, to back-to-back seats or to folding (tip-up) seats. If the impact zones of the seats, head-restraints and their supports contain parts covered with material sofer than 50 A shore hardness, the above requirements, with the exception of those relating to energy dissipation described in Annex III, shall apply only to the rigid parts.

5.8. <u>Other non specified fittings.</u>

5.8.1. The requirements of paragraph 5 shall apply to such fittings not mentioned in previous paragraphs which, within the meaning of the various requirements in points 5.1. to 5.7. and according to their location in the vehicle, are capable of being contacted by the occupants. If such parts are made of a material softer than 50 shore A hardness and mounted on (a) rigid support(s), the requirements in question shall apply only to the rigid support(s).

ANNEX II

DETERMINATION OF THE HEAD-IMPACT ZONE

1. The head-impact zone shall comprise all the non-glazed surfaces of the interior of a vehicle which are capable of entering into static contact with a spherical head of 165 mm in diameter which is an integral part of a measuring apparatus whose dimensions from the pivotal point of the hip to the top of the head is continuously adjustable between 736 mm and 840 mm.

2. The aforesaid zone must be determined by the following procedure or its graphic equivalent:

2.1. The pivotal point of the measuring apparatus shall be placed as follows for each seating position for which the manufacturer has made provision:

2.1.1. in the case of sliding seats

2.1.1.1. at the H point (see Annex IV) and

2.1.1.2. (0) at a point situated horizontally 127 mm forward of the H point and at a height either resulting from the variation in the height of the H point caused by a forward shift of 127 mm or of 19 mm.

2.1.2. in the case of non-sliding seats, at the H point of the seat under consideration.

2.2. (0) All points of contact situated forward of the H point shall be determined for each dimension from the pivotal point to the top of the head capable of being measured by the measuring apparatus within the interior dimensions of the vehicle.

In the case where the headform, with the arm set at minimum length, overlaps the front seat, from the rear H point, no contact point is established for this particular operation.

2.3. With the measuring apparatus vertical, possible points of contact shall be determined by pivoting it forwards and downwards through all arcs of vertical planes as far as 90° on either side of the longitudinal vertical plane of the vehicle which passes through the H point.

3. (ø) A 'point of contact' shall be a point at which the head of the apparatus contacts a part of the interior vehicle. The maximum downward movement shall be limited to a position where the head is tangential to a horizontal plane situated 25.4 mm above the H point.

ANNEX III

PROCEDURE FOR TESTING APPARATUS AND TEST PROCEDURE

1. SETTING UP, TEST APPARATUS AND PROCEDURE

1.1. Setting up

1.1.1. The energy-dissipating material shall be mounted and tested on the structural supporting member on which it is to be installed on the vehicle. The test shall preferably be carried out, where possible, directly on the body. The structural member, or the body, shall be firmly attached to the test bench so that it does not move under impact.

1.1.2. However, at the manufacturer's request, the item may be mounted on a fitting simulating its installation on the vehicle, on condition that the 'component/fitting' assembly has the same geometrical arrangement and a degree of rigidity not lower and on energy-dissipating capacity not higher than those of the rear 'component/structural supporting members' assembly.

1.2. Test apparatus

1.2.1. This apparatus shall consist of a pendulum whose pivot is supported by ballbearings and whose reduced mass (*) at its centre of percussion is 6.8 kg. The lower extremity of the pendulum shall consist of a rigid headford 165 mm diameter whose centre is identical with the centre of percussion of the pendulum.

(*) Note:- The relationship of the reduced mass 'm ' of the pendulum to the total mass 'm' of the pendulum at a distance 'a' between the centre of percussion and the axis of rotation and at a distance 'l' between the centre of gravity and the axis of rotation is given by the formula:

$$m_r = m\frac{l}{a}$$

1.2.2. The headform shall be fitted with 2 decelerometers and a speed measuring device, all capable of measuring values in the direction of impact.

1.3. Recording instruments

The recording instruments used shall be such that measurements can be made with the following degrees of accuracy:

1.3.1. Acceleration:

- accuracy = ± 5% of the rear value

- frequency response = up to 1 000 Hz
- cross axis sensitivity = 5% of the lowest point on the scale

1.3.2. **Speed:**

- accuracy = ± 2.5% of the rear value
- sensitivity = 0.5 km/h

1.3.3. deleted

1.3.4. **Time recording:**

- the instrumentation shall enable the action to be recorded throughout its duration and readings to be made to within one thousandth of a second
- the beginning of the impact at the moment of first contact between the headform and the test component shall be noted on the recordings used for analysing the test.

1.4. (ø) Test procedure

1.4.1. At every point of impact on the surface to be tested, the direction of impact shall be the tangent to the trajectory of the headform of the measuring apparatus described in Annex II.

For the testing of the parts as referred to in points 5.3.4.1. and 5.4.2.2. of Annex I, proceed by lengthening the arm of the measuring apparatus until contact is made with the part to be considered, up to a limit of 1 000 mm between the pivot point and top of the head of the apparatus. However, any roof sticks and ribs referred to in points 5.4.2.2. which cannot be contacted remain subject to the requirements of point 5.4.2.1. of Annex I with the exception of that relating to the height of projection.

1.4.2. Where the angle between the direction of impact and the perpendicular to the surface at the point of impact is 5° or less, the test shall be carried out in such a way that the tangent to the trajectory of the centre of percussion of the pendulum coincides with the direction defined in point 1.4.1. The headform shall strike the test component at a speed of 24.1 km/h; this speed shall be achieved either by the mere energy of propulsion or by using an additional propelling device.

1.4.3. Where the angle between the direction of impact and the perpendicular to the surface at the point of impact is more than 5°, the test may be carried out in such a way that the tangent to the trajectory of the centre of percussion of the pendulum coincides with the perpendicular to the point of impact. The test speed shall then be reduced to the value of the normal component of the speed prescribed in point 1.4.2.

2. RESULTS

In tests carried out according to the above procedures, the deceleration of the headform shall not exceed 80 g continuously for more than 3 milliseconds. The deceleration rate taken shall be the average of the readings of the two decelerometers.

3. EQUIVALENT PROCEDURES

3.1. Equivalent test procedures shall be permitted, on condition that the results required in paragraph 2 above can be obtained.

3.2. Responsibility for demonstrating the equivalence of a method other than that described in paragraph 1 shall rest with the person using such a method.

ANNEX IV

PROCEDURE FOR DETERMINING THE H POINT AND THE ACTUAL SEAT-BACK ANGLE AND FOR VERIFYING THE RELATIVE POSITIONS OF THE R AND H POINTS AND THE RELATIONSHIP BETWEEN THE DESIGN SEAT-BACK ANGLE AND THE ACTUAL SEAT-BACK ANGLE

1. DEFINITIONS

1.1. H point

The 'H point', which indicates the position of a seated occupant in the passenger compartment, is the intersection, in a longitudinal vertical plane, of the theoretical axis of rotation between the thighs and torso of a human body represented by the manikin described in point 3.

1.2. R point or seating reference point

The 'R point' or 'seating reference point' is the reference point specified by the vehicle manufacturer which:

1.2.1. has coordinates determined in relation to the vehicle structure;

1.2.2. corresponds to the theoretical position of the point of torso/thighs rotation (H point) for the lowest and most rearward normal driving position or position of use given by the vehicle manufacturer for each seating position specified by him.

1.3. Seat-back angle

'Seat-back angle' means the inclination of the seat-back in relation to the vertical.

1.4. Actual seat-back angle

'Actual seat-back angle' means the angle formed by the vertical through the H point with the torso reference line of the human body representated by the manikin described in point 3.

1.5. Design seat-back angle

'Design seat-back angle' means the angle prescribed by the vehicle manufacturer which:

1.5.1. determines the seat-back angle for the lowest and most rearward normal driving position or position of use given by the vehicle manufacturer for each seating position specified by him;

1.5.2. is formed at the R point by the vertical and the torso reference line; and

1.5.3. corresponds theoretically to the actual seat-back angle.

2. DETERMINATION OF H POINTS AND ACTUAL SEAT-BACK ANGLES

2.1. An H point and an actual seat-back angle shall be determined for each seating position specified by the vehicle manufacturer. If the seating positions in the same row can be regarded as similar (bench seat, identical seats, etc.) only one H point and one actual seat-back angle shall be determined for each row of seats, the manikin described in point 3 being seated in a place regarded as representative for the tow. This place shall be:

2.1.1. in the case of the front row, the driver's seat;

2.1.2. in the case of the rear row or rows, an outer seat;

2.2. When an H point and an actual seat-back are being determined, the seat considered shall be placed in the lowest and most rearward normal driving position or position of use given for it by the vehicle manufacturer. The seat-back shall, if its inclination is adjustable, be locked as specified by the manufacturer, or in the absence of any such specification, in a position corresponding to an actual seat-back angle of as near as possible to 25°.

3. DESCRIPTION OF THE MANIKIN

3.1. A three-dimensional manikin of a mass and contour corresponding to those of an adult male of average height shall be used. Such a manikin is depicted in Figures 1 and 2 of the Appendix to this Annex.

3.2. The manikin shall comprise:

3.2.1. two components, one simulating the back and the other the seat of the body, pivoting on an axis representing the axis of rotation between the torso and the thigh. The intersection of this axis with the vertical medium longitudinal plane of the seating position determines the H point;

3.2.2. two components simulating the legs and pivotally attached to the component simulating the seat; and

3.2.3. two components simulating the feet and connected to the legs by pivotal joints simulating ankles.

3.2.4. In addition, the component simulating the seat of the body shall be provided with a level enabling its transverse orientation to be verified.

3.3. Body-segment weights shall be attached at appropriate points corresponding to the relevant centres of gravity, so as to bring the total mass of the manikin up to 75 kg ± 1%. Details of the mass of the various weights are given in the table in Figure 2 of the Appendix to this Annex.

3.4. The torso reference line of the manikin is represented by a straight line passing through the joint between the thigh and the torso and the theoretical joint between the thorax (see Figure 1 of the Appendix to this Annex).

4. (0) SETTING UP THE MANIKIN

The three-dimensional manikin shall be set up in the following manner:

4.1. the vehicle shall be placed on a horizontal plane and the seats adjusted as prescribed in point 2.2.;

4.2. the seat to be tested shall be covered with a piece of cloth to facilitate the correct setting-up of the manikin;

4.3. the manikin shall be placed on the seat concerned, its pivotal axis being perpendicular to the median longitudinal plane of the vehicle.

4.4. the feet of the manikin shall be placed as follows;

4.4.1. in the front seats, in such a way that the level verifying the transverse orientation of the seat of the manikin is brought to the horizontal;

4.4.2. in the rear seats, as far as possible in such a way as to be in contact with the front seats. If the feet then rest on parts of the floor which are at different levels, the foot which first comes into contact with the front seat shall service as a reference point and the other foot shall be so arranged that the level enabling the transverse orientation of the seat of the manikin to be verified is brought to the horizontal;

4.4.3. if the H point is being determined at a centre seat, the feet shall be placed one on each side of the tunnel;

4.5. the weights shall be placed on the legs, the level verifying the transverse orientation of the seat of the manikin shall be brought to the horizontal, and the thigh weights shall be placed on the component representing the seat of the manikin;

4.6. the manikin shall be moved away from the seat-back by means of the knee-pivot bar and the back of the manikin shall be pivoted forwards. The manikin shall be repositioned on the seat of the vehicle by being slid backwards on its seat until resistance is encountered, the back of the manikin then being replaced against the seat-back;

4.7. a horizontal load of 10 ± 1 daN shall be applied to the manikin twice. The direction and point of application of the load are shown by a black arrow in Figure 2 of the Appendix;

4.8. the seat weights shall be installed on the right and left sides, and the torso weights shall then be placed in position. The transverse level of the manikin shall be kept horizontal;

4.9. the transverse level of the manikin being kept horizontal, the back of the manikin shall be pivoted forwards until the torso weights are above the H point, so as to eliminate any friction with the seat-back;

4.10. the back of the manikin shall be gently moved rearwards so as to complete the setting-up operation. The transverse level of the manikin shall be horizontal. If it is not, the procedure described above shall be repeated.

5. RESULTS

5.1. When the manikin has been set up as described in point 4, the H point and the actual seat-back angle of the vehicle seat considered are constituted by the H point and the angle of inclination of the manikin's torso reference line.

5.2. The coordinates of the H point in relation to three mutually perpendicular planes, and the actual seat-back angle, shall be measured for comparison with the data supplied by the vehicle manufacturer.

6. VERIFYING THE RELATIVE POSITIONS OF THE R AND H POINTS AND THE RELATIONSHIP BETWEEN THE DESIGN SEAT-BACK ANGLE AND THE ACTUAL SEAT-BACK ANGLE

6.1. The results of the measurements carried out in accordance with point 5.2. for the H point and the actual seat-back angle shall be compared with the coordinates of the R point and the design seat-back angle as given by the vehicle manufacturer.

6.2. The relative positions of the R point and the H point and the relationship between the design seat-back angle and the actual seat-back angle shall be considered to be satisfactory for the seating position in question if the H point, as defined by its coordinates, lies within a longitudinal rectangle whose horizontal and vertical sides are 30 and 20 mm long respectively and whose diagonals intersect at the R point, and if the actual seat back angle is within 3° of the design seat-back angle.

6.2.1. If these conditions are met, the R point and the design seat-back angle shall be used for the test and, if necessary, the manikin shall be so adjusted that the H point coincides with the R point and the actual seat-back angle coincides with the design seat-back angle.

6.3. If the H point or the actual seat-back does not satisfy the requirements of point 6.2., the H point or the actual seat-back angle shall be determined twice more (three times in all). If the results of two of these three operations satisfy the requirements, the result of the test shall be considered to be satisfactory.

6.4. If at least two of the three test results do not satisfy the requirements of point 6.2., the result of these shall be considered to be not satisfactory.

6.5. If the situation described in point 6.4. arises, or if verification is not possible becasue the vehicle manufacturer has failed to supply information regarding the position of the R point or regarding the design seat-back angle, the average of the results of the three tests may be used and be regarded as applicable in all cases where the R point or the design seat-back angle is referred to in this Directive.

6.6. For verifying the relative positions of the R point and the H point and the relationship between the design seat-back angle and the actual seat-back angle in a series-produced vehicle, the rectangle referred to in point 6.2. shall be replaced by a square of 50 mm side and the actual seat-back angle shall not differ by more than 5° from the design seat-back angle.

Appendix

COMPONENTS OF THREE-DIMENSIONAL MANIKIN

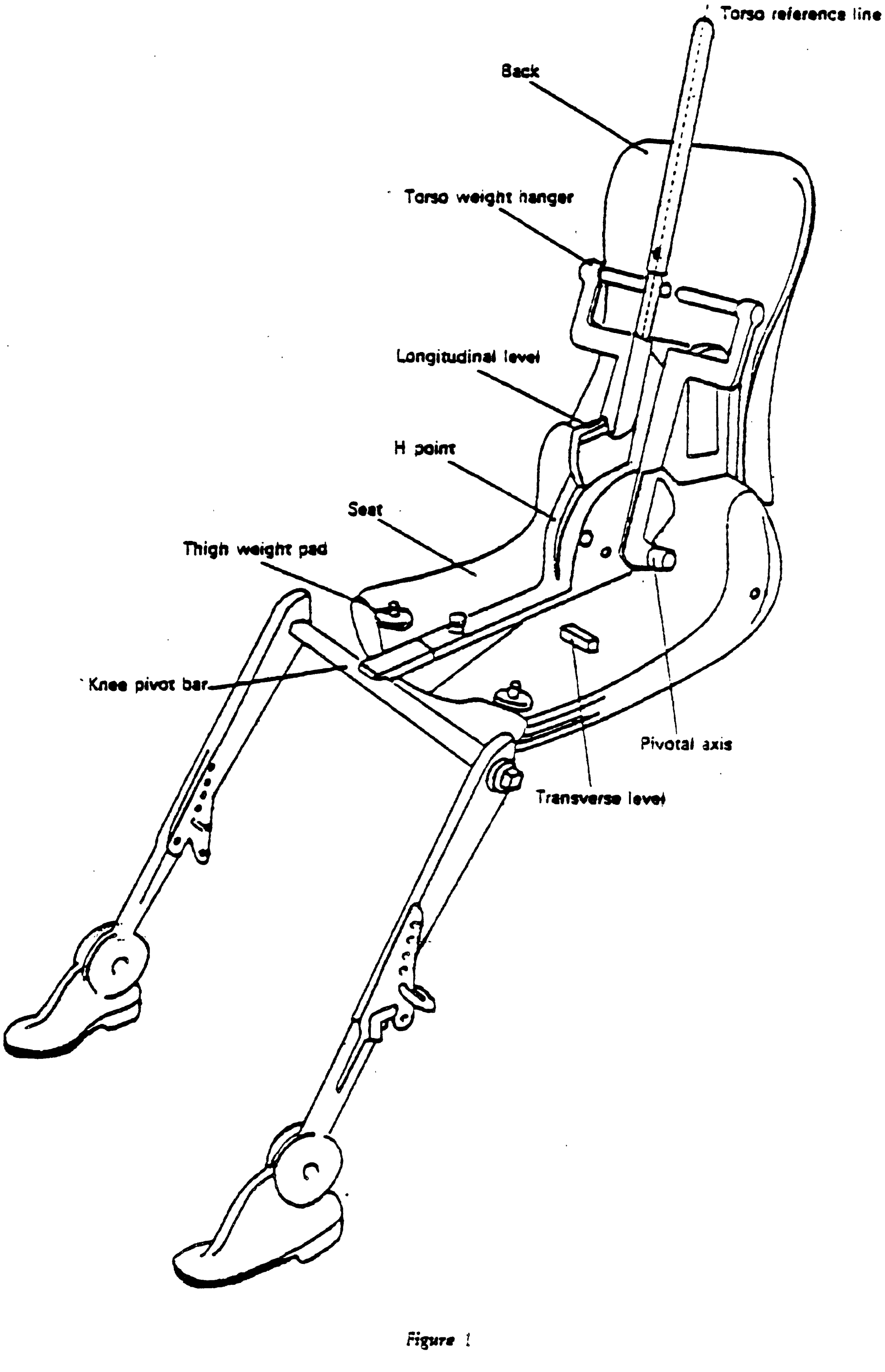


Figure 1

DIMENSIONS AND MASS OF MANIKIN

Mass of manikin	*kg*
Components simulating back and seat of body	16
Mass of torso weights	31
Mass of seat weights	8
Mass of thigh weights	7
Mass of leg weights	13
Total:	75

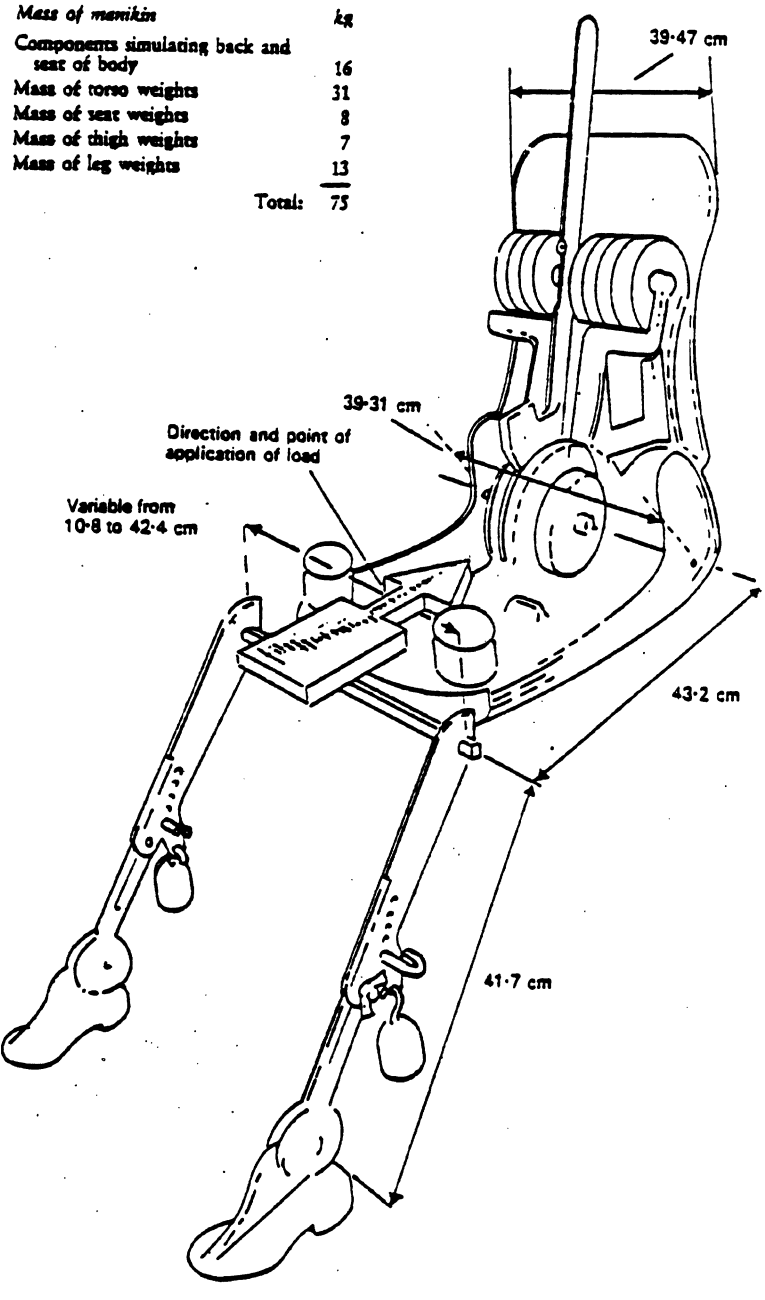


Figure 2

ANNEX V

METHOD OF MEASURING PROJECTIONS

1. To determine the amount by which an item projects in relation to the panel on which it is mounted, a 165 mm sphere shall be moved along and be kept in contact with the component under consideration, starting from the initial position of contact with the component under consideration. The projection's value is the largest of all possible variations 'y', the variation measured from the centre of the sphere perpendicular to the panel.

If the panel and components, etc., are covered with materials softer than 50 Shore A hardness, the procedure for the measuring of projections described above shall apply only after the removal of such materials.

2. The projection of switches, pull-knobs, etc., situated in the reference area shall be measured by using the test apparatus and procedure described below:

2.1. Apparatus

2.1.1. The measuring apparatus for projections shall consist of a hemispherical headform 165 mm in diameter, in which there is a sliding ram of 50 mm diameter.

2.1.2. Relative positions of the flat end of the ram and the edge of the headform shall be shown on a graduated scale, on which a mobile index shall register the maximum measurement achieved when the apparatus is moved away from the item tested. A minimum distance of 30 mm shall be measurable; the measuring scale shall be graduated in half-millimeters to make possible an indication of the extent of the projections in question.

2.1.3. Gauging procedure:

2.1.3.1. The apparatus shall be placed on a flat surface so that its axis is perpendicular to that surface. When the flat end of the ram contacts the surface, the scale shall be set at zero.

2.1.3.2. A 10 mm strut shall be inserted between the flat end of the ram and the retaining surface; a check shall be made to ensure that the mobile index records this measurement.

2.1.4. The apparatus for measuring projections is illustrated in figure 1.

2.2. Test procedure

2.2.1. A cavity shall be formed in the headform by pulling back the ram and the mobile index shall be placed against the ram.

2.2.2. The apparatus shall be applied to the projection to be measured so that the headform contacts the maximum surrounding surface area, with a force not exceeding 2 daN.

2.2.3. The ram shall be pushed forward until it makes contact with the projection to be measured and the amount of the projection shall be observed on the scale.

2.2.4. The headform shall be adjusted to obtain maximum projection. The amount of the projection shall be recorded.

2.2.5. If two or more controls are situated sufficiently close for the ram or the headform to contact them simultaneously, they shall be treated as follows:

2.2.5.1. Multiple controls, all of which can be contained in the headform cavity, shall be regarded as forming a single projection.

2.2.5.2. If other controls prevent normal testing by contacting the headform, they shall be removed and the test shall be conducted without them. They may subsequently be re-installed and tested in their turn with other controls that have been removed to facilitate the procedure.

Appendix

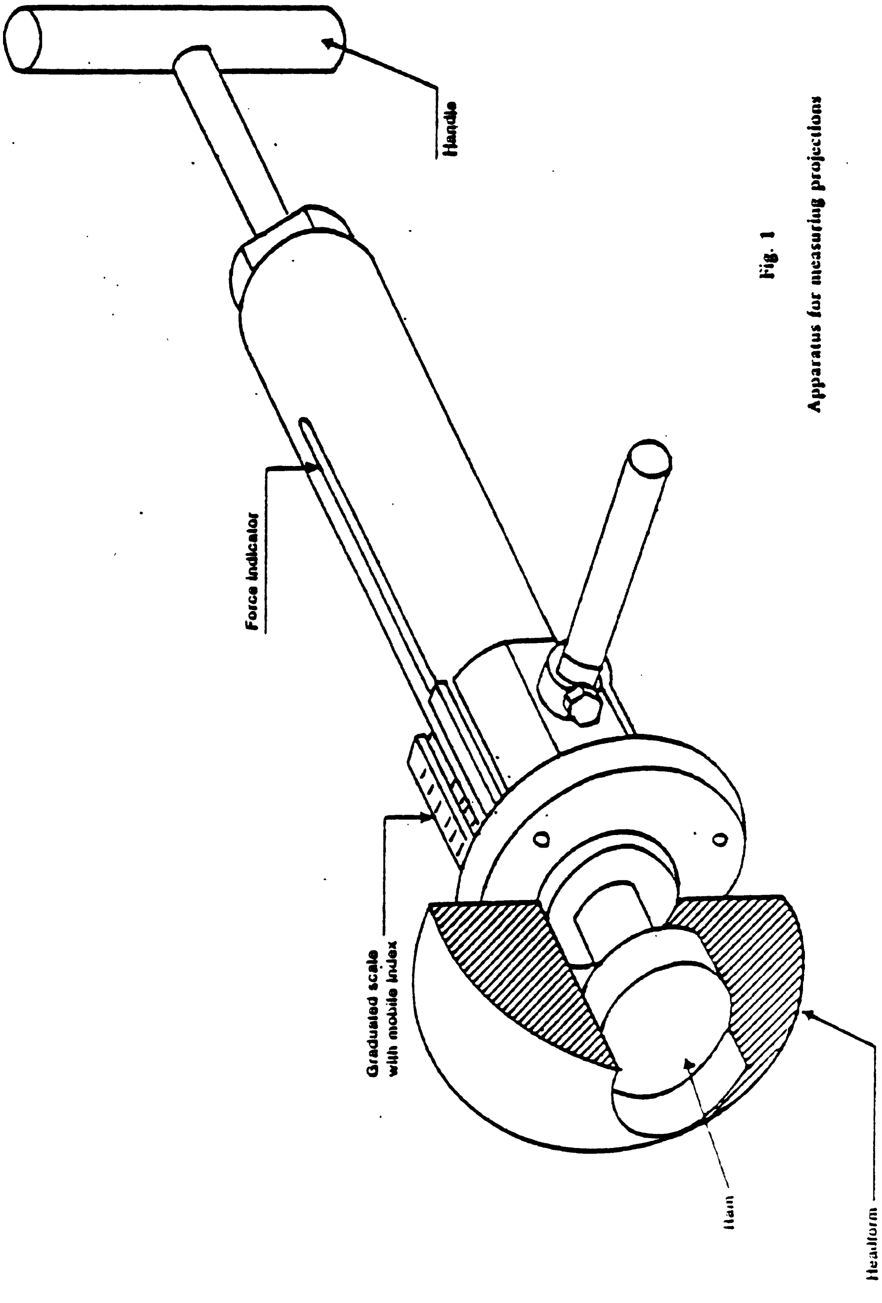


Fig. 1

Apparatus for measuring projections

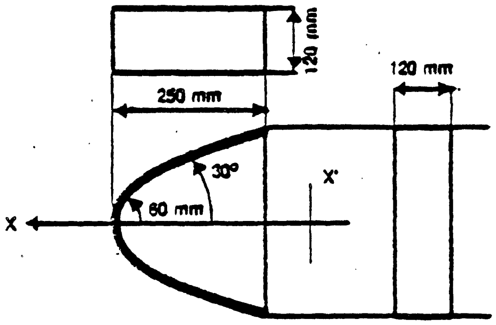
ANNEX VI

APPARATUS AND PROCEDURE FOR APPLICATION OF ITEM 5.2.1. OF ANNEX I

Those parts (switches, pull-knobs etc.) which can be contacted by using the apparatus and procedure described below shall be considered as being likely to be contacted by the knees of an occupant; (0)

1 Apparatus

Diagram of apparatus



2. Procedure

The apparatus may be placed in any position below the level of the instrumenta panel so that:

- the plane XX' remains parallel to the median longitudinal plane of the vehicle
- the axis X can be rotated above and below the horizontal through angles up to 30°

3. In carrying out the above test, all materials of less than 50 shore A hardness shall be removed.

APPENDIX TO ANNEXES I, II, III, IV AND VI

DEFINITIONS, APPLICATIONS FOR EEC TYPE-APPROVAL AND SPECIFICATIONS

To point 2.2:

The reference zone is outlined without rear view mirror. The energy-dissipation is accomplished without the rear view mirror. The pendulum shall not impact the mirror mounting.

To points 2.3. and 2.3.1:

The exemption defined by these points behind the steering wheel is also valid for the head impact area of the front passenger(s).

In the case of adjustable steering wheels the zone finally exempted is reduced to the common area of the exempted zones for each of the driving positions which the steering wheel may assume.

In the case where it is possible to choose between various steering wheels the exempted zone is determined by the use of the least favourable steering wheel having the smallest diameter.

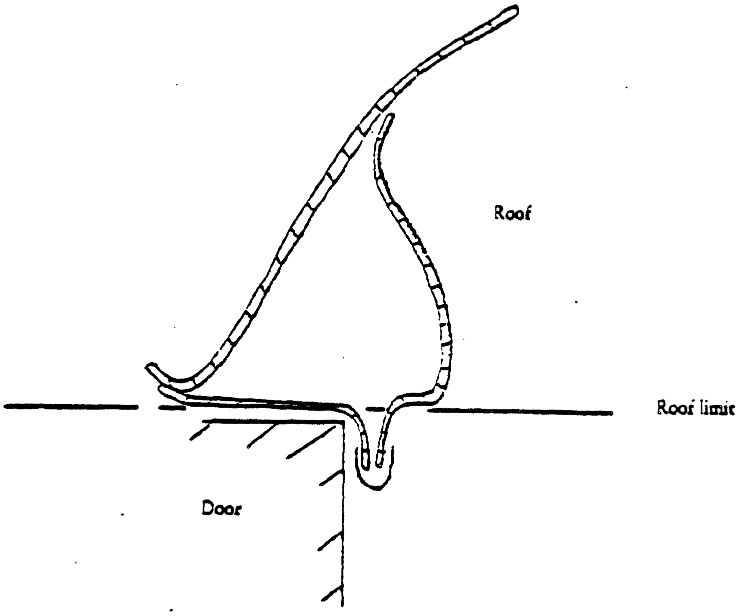
To point 2.4:

The level of the instrument panel extends over the entire width of the passenger compartment and is defined by the rearmost points of contact of a vertical line with the surface of the instrument panel when the line is moved across the width of the vehicle. Where two or more points of contact occur simultaneously then the lower point of contact shall be used to establish the level of the instrument panel. In the case of consoles, if it is not possible to determine the level of the instrument panel by reference to the points of contact of a vertical line then the level of the instrument panel shall be where a horizontal line 25.4 mm above the H point of the front seats intersects the console.

To point 2.5:

At the vehicle sides the roof shall commence at the upper edge of the door aperture. In the normal case of the lateral roof limits will be represented by the contours formed by the bottom edge (lateral view) of the remaining body when the door has been opened. In the case of windows the lateral limitation of the roof will be the continuous transparent line (penetration point of the lateral window panes). At the posts the lateral roof limitation will pass through the connecting line between the transparent lines. The definition of point 2.5 is also valid for any opening for the roof, in the closed position, of a vehicle as defined in point 2.7 or 2.8.

For measuring purposes downward facing flanges shall be ignored. These will be considered as forming part of the vehicle sidewall.



To point 2.7:

A non-removable rear window is understood to be a rigid structural element.

Cars with non-removable rear windows of rigid material are considered to be cars with opening roofs as defined under point 2.8.

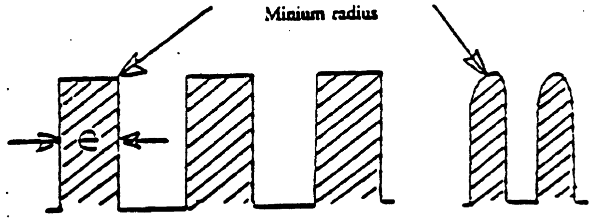
To point 5.1.1:

A sharp edge is an edge of a rigid material having a radius of curvature of less than 2.5 mm except in the case of projections of less than 3.2 mm, measured from the panel. In this case the minimum radius of curvature shall not apply provided the height of the projection is not more than half its width and its edges are blunted.

Grills are considered to comply with the regulations if they meet the minimum requirements of the following table:

(in mm)

Gap between elements	Flat elements		Rounded elements (min. radius)
	e/min	radius min.	
0 to 10	1.5	0.25	0.50
10 to 15	2.0	0.33	0.75
15 to 20	3.0	0.50	1.25



To point 5.1.2:

During the test it is determined whether parts within the impact zone used for reinforcement may be displaced or protrude so as to increase the hazards to passengers or the severity of injuries.

To point 5.1.3:

These two concepts (level and lower edge of the instrument panel) may be distinct. However, this paragraph is included in point 5.1. (... above the level of the instrument panel ...) and, therefore, is applicable only where these two concepts are combined. In the case where the two concepts are not combined, i.e. where the bottom edge of the instrument panel is located below the level of the instrument panel, it will be considered under point 5.3.2.1. by reference to point 5.8.

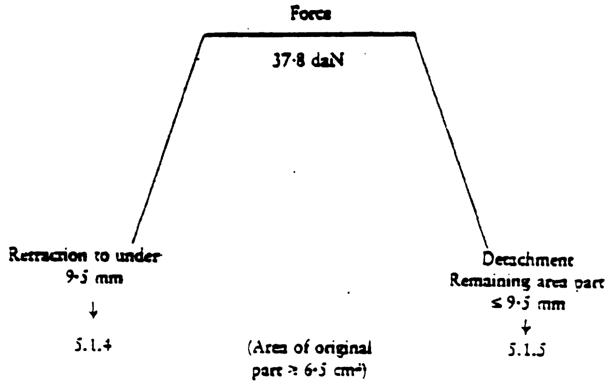
To point 5.1.4:

If a pull handle or knob has a width dimension equal to or more than 50 mm and is located in a zone such that if it were less than 50 mm in width the maximum projection would be determined using the headform measuring apparatus with point 2 of Annex V, the maximum projection shall be determined in accordance with point 1 of Annex V, i.e. by using a 165 mm diameter sphere and determining the maximum variation in height of the 'y' axis.

The cross-sectional area shall be measured in a plane parallel to the surface on which the component is mounted.

To point 5.1.5:

Points 5.1.4. and 5.1.5 complement each other; the first sentence of point 5.1.5. (i.e. a force of 37.8 daN for retraction or detachment) is applied and then point 5.1.4. in case of retraction up to a protrusion between 3.2 and 9.5 mm or, in the case of detachment, the two last sentences of point 5.1.5. (the cross-section area is measured before the force is applied). However, if, under practical circumstances point 5.1.4. must be applied (retraction to under 9.5 mm and over 3.2 mm), it could be more convenient, at the manufacturer's discretion, to verify the specifications of point 5.1.4. before applying the force of 37.8 daN specified in point 5.1.5.



To point 5.1.6:

Since in the presence of soft materials, the requirements apply only to the rigid support, the projection is measured for the rigid support only.

The Shore hardness measurement is made on samples of the test subject itself. Where, due to the condition of the material it is impossible to carry out a hardness measurement by the Shore A procedure, comparable measurements shall be used for evaluation.

To point 5.2.1:

Foot pedals, their arms and immediate pivotal mechanisms but not the surrounding support metal shall be excluded from consideration.

To point 5.2.2.:

The criterion to determine whether the parking brake control can be contacted is the use of:

- the simulated head specified in Annex II, if the control is located above or on the level of the instrument panel (to be tested in accordance with point 5.1. and within the impact zone);
- the knee specified in Annex VI if the control element is located below the level of the instrument panel (in this case the control level is tested in accordance with point 5.3.2.3)

To point 5.2.3:

The technical specifications listed in point 5.2.3. apply also to shelves and those parts of consoles below the level of the instrument panel located between the front seats, provided that these are located in front of the H point. If a cavity is closed it will be treated as a glove compartment and not be subject to these specifications.

To point 5.2.3.1:

The dimensions specified refer to the surface before the addition of material of less than 50 Shore A hardness (see point 5.2.4). Energy-dissipating tests shall be conducted in the spirit of Annex III.

To point 5.2.3.2:

If a shelf becomes detached or breaks up, no dangerous features must result; this applies not only to the rim but also to other edges facing into the passenger compartment as a result of the applied force.

The strongest part of the shelf shall be considered to be adjacent to a fixture. Also, 'substantially distorted' shall mean that, under the effect of the applied force, the deflection of the shelf, measured from the initial point of contact with the test cylinder, must be a fold or a deformation visible to the naked eye. Elastic deformation shall be admissible.

The length of the test cylinder shall be at least 50 mm.

To point 5.3:

'Other parts' shall include such parts as windows catches, seat belt upper anchorages and other parts located in the foot space and at the door side, unless these parts have been treated previously or are exempted in the text.

To point 5.3.2:

That space between the forward bulkhead and the instrument panel which is located higher than the bottom edge of the instrument panel is not subject to the specifications of point 5.3.

To point 5.3.2.1:

The 3.2 mm radius applies to all contactable components covered by point 5.3. when considered in all positions of use.

As exceptions glove compartments shall be consideed only in the closed position, seat belts will normally be considered only in the fastened position but any part which has a fixed stowage position shall also comply with the 3.2 mm radius requirement in that stowed position.

To point 5.3.2.2:

The reference surface is found by application of the device described in point 2 of Annex V with a force of 2 daN. Where this is not possible the method described in point 1 of Annex V shall be used with a force of 2 daN.

The evaluation of dangerous projections is subject to the discretion of the authority responsible for the tests.

The force of 37.8 daN is applied even if the original projection is less than 35 or 25 mm, as applicable. The projection is measured under the applied load.

The horizontal, longitudinal force of 37.8 daN is normally applied by means of a flat-ended ram of not more than 50 mm diameter, but where this is not possible an equivalent method may be used; for instance, by removing obstacles.

To point 5.3.2.3:

The furthest projecting part in the case of a gear lever is that part of the grip or knob first contacted by a vertical transverse plane moved in a longitudinal, horizontal direction. If any part of a gear lever or handbrake lies above the H point level that lever will have to be considered as if the whole of it were above the H point level.

To point 5.3.4:

Where the horizontal plane(s) passing through the H point of the lowest front and rear seats do not coincide, then a vertical plane perpendicular to the vehicle's longitudinal axis shall be determined, passing through the front seat H point. The exempted zone will then be considered separately for both the front and rear passenger compartments, relative to their respective H point and up to the vertical plane defined above.

To point 5.3.4.1:

Movable sun visors shall be considered in all positions of use. The frames of sun visors shall not be regarded as rigid supports (see point 5.3.5.).

To point 5.4:

When the roof is tested to measure those protrusions and parts which can be contacted by a ball having a diameter of 165 mm, the roof lining must be removed. When evaluating the specified radii the proportions and properties attributable to the materials of the roof lining shall be taken into consideration. The roof testing area shall extend in front of and above the transverse plane limited by the torso reference line of the manikin placed on rearmost seat.

To point 5.4.2.1 (see point 5.1.1 for definition of 'sharp edges'):

The downward projection shall be measured normal to the roof in accordance with point 1 of Annex V.

The width of the projecting part shall be measured at right angles to the line of the projection. In particular the rigid roof sticks or ribs shall not project away from the inner surface of the roof more than 19 mm.

To point 5.5:

Any roof ribs on opening roofs must meet point 5.4 if they are contactable by a 165 mm diameter sphere;

To points 5.5.1.2., 5.5.1.2.1. and 5.5.1.2.2.:

The opening and operating devices when in a position of rest and with the roof closed must meet all of the specified conditions.

To point 5.5.1.2.3:

The force of 37.8 daN is applied even if the original projection is 25 mm or less. The projection is measured under the applied load.

The force of 37.8 daN applied in the direction of impact defined in Annex III as the tangent to the trajectory of the headform is normally applied by means of a flat-ended ram or not more than 50 mm diameter, but where this is not possible an equivalent method may be used; for instance, by removing obstacles.

The 'position of rest' means the position of the operating device when it is in the locked position.

To point 5.6:

The rod system of convertible tops does not represent a roll-over bar.

To point 5.6.1:

The top part of the windscreen frame starts above the transparent contour of the windscreen.

To point 5.7.1.1:

See point 5.7.1.1:

See point 5.1.1. for definition of 'sharp edge'.

To point 5.7.1.2:

In defining the head impact zone of the back of the front seats any structure necessary to support the seat back shall be considered as a component of this seat back.

To point 5.7.1.2.3:

The padding of the seat frame structure shall also avoid dangerous roughness and sharp edges likely to increase the risk of serious injuries to the occupants.

TO ANNEX II

DETERMINATION OF THE HEAD-IMPACT ZONE

To point 2.1.1.2:

The choice between the two procedures for determining height is to be left to the manufacturer.

To point 2.2:

When determining points of contact, the length of the arm of the measuring apparatus is not changed during a particular operation. Each operation starts from the vertical position.

To point 3:

The 25.4 mm dimension means the measurement from a horizontal plane passing through the H point to the horizontal tangent to the lower profile of the headform.

TO ANNEX III

PROCEDURE FOR TESTING ENERGY-DISSIPATING MATERIALS

To point 1.4:

For breakage of any component during the energy-dissipation test, see the note on point 5.1.2. in Annex I.

TO ANNEX IV

PROCEDURE FOR DETERMINING THE H POINT AND THE ACTUAL SEAT-BACK ANGLE AND FOR VERIFYING THE RELATIVE POSITIONS OF THE R AND H POINTS AND THE RELATIONSHIP BETWEEN THE DESIGN SEAT-BACK ANGLE AND THE ACTUAL SEAT-BACK ANGLE

To point 4:

For determining the H point of any seat, other seats may be removed if necessary.

TO ANNEX VI

APPARATUS AND PROCEDURE FOR APPLICATION OF POINT 5.2.1. OF ANNEX I

First sentence:

Foot-operated controls are treated as foot pedals.

APPENDIX E - FEDERAL MOTOR VEHICLE SAFETY STANDARD 101 - CONTROLS AND DISPLAYS

except as such standard or amendment may otherwise specifically provide with respect to firefighting vehicles.

[36 FR 13927, July 28, 1971]

§ 571.9 Separability.

If any standard established in this part or its application to any person or circumstance is held invalid, the remainder of the part and the application of that standard to other persons or circumstances is not affected thereby.

[33 FR 19705, Dec. 25, 1968. Redesignated at 35 FR 5118, Mar. 26, 1970]

Subpart B—Federal Motor Vehicle Safety Standards

SOURCE: 36 FR 22902, Dec. 2, 1971, unless otherwise noted.

§ 571.101 Standard No. 101; Controls and displays.

S1. *Scope.* This standard specifies requirements for the location, identification, and illumination of motor vehicle controls and displays.

S2. *Purpose.* The purpose of this standard is to ensure the accessibility and visibility of motor vehicle controls and displays and to facilitate their selection under daylight and nighttime conditions, in order to reduce the safety hazards caused by the diversion of the driver's attention from the driving task, and by mistakes in selecting controls.

S3. *Application.* This standard applies to passenger cars, multipurpose passenger vehicles, trucks, and buses.

S4. *Definitions.*

"Telltale" means a display that indicates, by means of a light-emitting signal, the actuation of a device, a correct or defective functioning or condition, or a failure to function.

"Gauge" means a display that is listed in S5.1 or in Table 2 and is not a telltale.

"Informational readout display" means a display using light-emitting diodes, liquid crystals, or other electro illuminating devices where one or more than one type of information or message may be displayed.

S5. *Requirements.* (a) Except as provided in paragraph (b) of this section, each passenger car, multipurpose passenger vehicle, truck and bus manufactured with any control listed in S5.1 or in column 1 of Table 1, and each passenger car, multipurpose passenger vehicle and truck or bus less than 10,000 pounds GVWR with any display listed in S5.1 or in column 1 of Table 2, shall meet the requirements of this standard for the location, identification, and illumination of such control or display.

(b) For vehicles manufactured before September 1, 1987, a manufacturer may, at its option—

(1) Meet the requirements in this standard to use identifying words or abbreviation or identifying symbol for a control by using those specified in Table 1(a) instead of Table 1. If none are specified in Table 1(a), none need be used for the control.

(2) Meet the requirements in this standard to use identifying words or abbreviation or identifying symbol for a display by using those specified in Table 2(a) instead of Table 2. If none are specified in Table 2(a), none need be used for the display.

S5.1 *Location.* Under the conditions of S6, each of the following controls that is furnished shall be operable by the driver and each of the following displays that is furnished shall be visible to the driver. Under conditions of S6, telltales and informational readout displays are considered visible when activated.

HAND-OPERATED CONTROLS

(a) Steering wheel.
(b) Horn.
(c) Ignition.
(d) Headlamp.
(e) Taillamp.
(f) Turn signal.
(g) Illumination intensity.
(h) Windshield wiper.
(i) Windshield washer.
(j) Manual transmission shift lever, except transfer case.
(k) Windshield defrosting and defogging system.
(l) Rear window defrosting and defogging system.
(m) Manual choke.
(n) Driver's sun visor.
(o) Automatic vehicle speed system.
(p) Highbeam.

except as such standard or amendment may otherwise specifically provide with respect to firefighting vehicles.

[36 FR 13927, July 28, 1971]

§ 571.9 Separability.

If any standard established in this part or its application to any person or circumstance is held invalid, the remainder of the part and the application of that standard to other persons or circumstances is not affected thereby.

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"Telltale" means a display that indicates, by means of a light-emitting signal, the actuation of a device, a correct or defective functioning or condition, or a failure to function.

"Gauge" means a display that is listed in S5.1 or in Table 2 and is not a telltale.

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(b) For vehicles manufactured before September 1, 1987, a manufacturer may, at its option—

(1) Meet the requirements in this standard to use identifying words or abbreviation or identifying symbol for a control by using those specified in Table 1(a) instead of Table 1. If none are specified in Table 1(a), none need be used for the control.

(2) Meet the requirements in this standard to use identifying words or abbreviation or identifying symbol for a display by using those specified in Table 2(a) instead of Table 2. If none are specified in Table 2(a), none need be used for the display.

S5.1 *Location.* Under the conditions of S6, each of the following controls that is furnished shall be operable by the driver and each of the following displays that is furnished shall be visible to the driver. Under conditions of S6, telltales and informational readout displays are considered visible when activated.

HAND-OPERATED CONTROLS

(a) Steering wheel.
(b) Horn.
(c) Ignition.
(d) Headlamp.
(e) Taillamp.
(f) Turn signal.
(g) Illumination intensity.
(h) Windshield wiper.
(i) Windshield washer.
(j) Manual transmission shift lever, except transfer case.
(k) Windshield defrosting and defogging system.
(l) Rear window defrosting and defogging system.
(m) Manual choke.
(n) Driver's sun visor.
(o) Automatic vehicle speed system.
(p) Highbeam.

(q) Hazard warning signal.
(r) Clearance lamps.
(s) Hand throttle.
(t) Identification lamps.

FOOT-OPERATED CONTROLS

(a) Service brake.
(b) Accelerator.
(c) Clutch.
(d) Highbeam.
(e) Windshield washer.
(f) Windshield wiper.

DISPLAYS

(a) Speedometer.
(b) Turn signal.
(c) Gear position.
(d) Brake failure warning.
(e) Fuel.
(f) Engine coolant temperature.
(g) Oil.
(h) Highbeam.
(i) Electrical charge.

S5.2 *Identification.*

S5.2.1 Vehicle controls shall be identified as follows:

(a) Except as specified in S5.2.1(b), any hand-operated control listed in column 1 of Table 1 that has a symbol designated in column 3 shall be identified by that symbol. Any such control for which no symbol is shown in Table 1 shall be identified by the word or abbreviation shown in column 2, if such word or abbreviation is shown. Words or symbols in addition to the required symbol, word or abbreviation may be used at the manufacturer's discretion for the purpose of clarity. Any such control for which column 2 of Table 1 and/or column 3 of Table 1 specifies "Mfr. Option" shall be identified by the manufacturer's choice of a symbol, word or abbreviation, as indicated by that specification in column 2 and/or column 3. The identification shall be placed on or adjacent to the control. The identification shall, under the conditions of S6, be visible to the driver and, except as provided in S5.2.1.1 and S5.2.1.2, appear to the driver perceptually upright.

(b) S5.2.1(a) does not apply to a turn signal control which is operated in a plane essentially parallel to the face plane of the steering wheel in its normal driving position and which is located on the left side of the steering column so that it is the control on that side of the column nearest to the steering wheel face plane.

S5.2.1.1 The identification of the following need not appear to the driver perceptually upright:

(a) A master lighting switch or headlamp and tail lamp control that adjusts control and display illumination by means of rotation, or any other rotating control that does not have an off position.

(b) A horn control.

S5.2.1.2 The identification of a rotating control other than one described by S5.2.1.1 shall appear to the driver perceptually upright when the control is in the off position.

S5.2.2 Identification shall be provided for each function of any automatic vehicle speed system control and any heating and air conditioning system control, and for the extreme positions of any such control that regulates a function over a quantitative range. If this identification is not specified in Table 1 or 2, it shall be in word or symbol form unless color coding is used. If color coding is used to identify the extreme positions of a temperature control, the hot extreme shall be identified by the color red and the cold extreme by the color blue.

Example 1. A slide lever controls the temperature of the air in the vehicle heating system over a continuous range, from no heat to maximum heat. Since the control regulates a single function over a quantitative range, only the extreme positions require identification.

Example 2. A switch has three positions, for heat, defrost, and air conditioning. Since each position regulates a different function, each position must be identified.

S5.2.3 Except for informational readout displays, any display located within the passenger compartment and listed in column 1 of Table 2 that has a symbol designated in column 4, shall be identified by that symbol. Such display may, in addition be identified by the word or abbreviation shown in column 3. Any such display for which no symbol is provided in Table 2 shall be identified by the word or abbreviation shown in column 3. Informational readout displays may be identified by the symbol designated in column 4 of Table 2 or by the word or abbreviation shown in column 3. Additional words or symbols may be used at the manufacturer's discretion for the purpose of clarity. The identification required or permitted by this section shall be placed on or adjacent to the display that it identifies. The identification of any display shall, under the conditions of S6, be visible to the driver and appear to the driver perceptually upright.

S5.3 *Illumination.*

S5.3.1 Except for foot-operated controls or hand-operated controls mounted upon the floor, floor console, or steering column, or in the windshield header area, the identification required by S5.2.1 or S5.2.2 of any control listed in column 1 of Table 1 and accompanied by the word "yes" in the corresponding space in column 4 shall be capable of being illuminated whenever the headlights are activated. However, control identification for a heating and air-conditioning system need not be illuminated if the system does not direct air directly upon windshield. If a gauge is listed in column 1 of Table 2 and accompanied by the word "yes" in column 5, then the gauge and its identification required by S5.2.3 shall be illuminated whenever the ignition switch and/or the headlamps are activated. Controls, gauges, and their identifications need not be illuminated when the headlamps are being flashed. A telltale shall not emit light except when identifying the malfunction or vehicle condition for whose indication it is designed or during a bulb check upon vehicle starting.

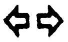
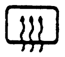
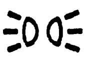
S5.3.2 Except for informational readout displays, each discrete and distinct telltale shall be of the color shown in column 2 of Table 2. The identification of each telltale shall be in a color that contrasts with the lens, if a telltale with a lens is used. Any telltale used in conjunction with a gauge need not be identified. The color of informational readout displays will be at the option of the manufacturer.

S5.3.3 Light intensities for controls, gauges, and their identification shall be continuously variable from: (a) A position at which either there is no light emitted or the light is barely discernible to a driver who has adapted to dark ambient roadway conditions to (b) a position providing illumination sufficient for the driver to identify the control or display readily under conditions of reduced visibility. Light intensities for informational readout systems shall have at least two values, a higher one for day, and a lower one for nighttime conditions. The intensity of any illumination that is provided in the passenger compartment when and only when the headlights are activated shall also be variable in a manner that complies with this paragraph. The light intensity of each telltale shall not be variable and shall be such that, when activated, that telltale and its identification are visible to the driver under all daytime and nighttime conditions.

S6. *Conditions.* The driver is restrained by the crash protection equipment installed in accordance with the requirements of § 571.208 of this part (Standard No. 208), adjusted in accordance with the manufacturer's instructions.

Table 1

Identification and Illumination of Controls

Column 1	Column 2	Column 3	Column 4
Hand Operated Controls	Identifying Words or Abbreviation	Identifying Symbol	Illumination
Master Lighting Switch	——	 [5]	——
Headlamps and Tail lamps	(Mfr. Option)[2]	(Mfr. Option)[2]	——
Horn	——	 [4]	——
Turn Signal	——	 [3] [5]	——
Hazard Warning Signal	——	 [5]	Yes
Windshield Wiping System	——		Yes
Windshield Washing System	——		Yes
Windshield Washing and Wiping Combined	——		Yes
Heating and or Air Conditioning Fan	——	 or 	Yes
Windshield Defrosting and Defogging System	——		Yes
Rear Window Defrosting and Defogging System	——		Yes
Identification, Side Marker and or Clearance Lamps	——	 [2] [5]	Yes
Manual Choke	Choke	——	——
Engine Start	Engine Start[1]	——	——
Engine Stop	Engine Stop[1]	——	Yes
Hand Throttle	Throttle	——	——
Automatic Vehicle Speed	(Mfr. Option)	——	Yes
Heating and Air Conditioning System	(Mfr. Option)	(Mfr. Option)	Yes

[1] Use when engine control is separate from the key locking system.

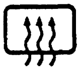
[2] Separate identification not required if controlled by master lighting switch.

[3] The pair of arrows is a single symbol. When the controls for left and right turn operate independently, however, the two arrows may be considered separate symbols and be spaced accordingly.

[4] Identification not required for vehicles with a GVWR greater than 10,000 lbs., or for narrow ring-type controls.

[5] Framed areas may be filled.

TABLE 1 (a)
Identification and Illumination of Controls

Column 1 Hand Operated Controls	Column 2 Identifying Words or Abbreviation	Col. 3 Identifying Symbol	Col. 4 Illumination
Headlamps and Tail Lamps	Lights	 [2,4]	—
Turn Signal	—		—
Hazard Warning Signal	Hazard	 [4]	Yes
Clearance Lamps System	Clearance Lamps or Cl Lps	 [3,4]	Yes
Windshield Wiping System	Wiper or Wipe		Yes
Windshield Washing System	Washer or Wash		Yes
Windshield Washing and Wiping Combined	Wash-Wipe		Yes
Heating and/or Air Conditioning Fan	Fan		Yes
Windshield Defrosting and Defogging System	Defrost, Defog or Def		Yes
Rear Window Defrosting and Defogging System	Rear Defrost, Rear Defog or Rear Def		Yes
Engine Start	Engine Start[1]	—	—
Engine Stop	Engine Stop[1]	—	Yes
Manual Choke	Choke	—	—
Hand Throttle	Throttle	—	—
Automatic Vehicle Speed	(Mfr. Option)	—	Yes
Identification Lamps	Identification Lamps or Id Lps	—	Yes
Heating and Air Conditioning System	(Mfr. Option)	—	Yes

1. Use when engine control is separate from the key locking system.

2. Use also when clearance, identification, parking and/or side marker lamps are controlled with the headlamp switch.

3. Use also when clearance lamps, identification lamps and or side marker are controlled with one switch other than the headlamp switch.

4. Framed areas may be filled.

Table 2

Identification and Illumination of Displays

Column 1	Column 2	Column 3	Column 4	Column 5
Display	Telltale Color	Identifying Words or Abbreviation	Identifying Symbol	Illumination
Turn Signal Telltale	Green	Also see FMVSS 108	 [1] [6]	—
Hazard Warning Telltale	Red[4]	Also see FMVSS 108	 [2] [6]	—
Seat Belt Telltale	Red[4]	Fasten Belts or Fasten Seat Belts. Also see FMVSS 208.	 or 	—
Fuel Level Telltale	Yellow	Fuel	 or 	—
Gauge	—			Yes
Oil Pressure Telltale	Red[4]	Oil		—
Gauge	—			Yes
Coolant Temperature Telltale	Red[4]	Temp		—
Gauge	—			Yes
Electrical Charge Telltale	Red[4]	Volts, Charge or Amp		—
Gauge	—			Yes
Highbeam Telltale	Blue or Green[4]	Also see FMVSS 108	 [6]	—
Malfunction in Anti-Lock or	Yellow	Antilock or Anti-lock Also see FMVSS 105	—	—
Brake System	Red[4]	Brake. Also see FMVSS 105	—	—
Brake Air Pressure Position Telltale	Red[4]	Brake Air. Also see FMVSS 121	—	—
Speedometer	—	MPH[5]		Yes
Odometer	—	—[3]	—	—
Automatic Gear Position	—	Also see FMVSS 102	—	Yes

---

[1] The pair of arrows is a single symbol. When the indicator for left and right turn operate independently, however, the two arrows will be considered separate symbols and may be spaced accordingly.

[2] Not required when arrows of turn signal tell-tales that otherwise operate independently flash simultaneously as hazard warning tell-tale.

[3] If the odometer indicates kilometers, then "KILOMETERS" or "km" shall appear, otherwise, no identification is required.

[4] Red can be red-orange. Blue can be blue-green.

[5] If the speedometer is graduated in miles per hour and in kilometers per hour, the identifying words or abbreviations shall be "MPH and km/h" in any combination of upper or lower case letters.

[6] Framed areas may be filled.

TABLE 2 (a)
Identification and Illumination of Internal Displays

Column 1	Col. 2	Column 3	Column 4	Column 5
Display	Telltale Color	Identifying Words or Abbreviation	Identifying Symbol	Illuminate
Turn Signal Tell-Tale	Green	Also see FMVSS 108	⇦ ⇨ [1] [5]	—
Hazard Warning Tell-Tale	Red[4]	Also see FMVSS 108	 [2]	—
Seat Belt Tell-Tale	Red[4]	**Fasten Belts or Fasten Seat Belts. Also see FMVSS 208.**		—
Fuel Level Tell-Tale	Yellow	Fuel		—
Gauge	—	Fuel		Yes
Oil Pressure Tell-Tale	Red[4]	Oil		—
Gauge	—	Oil		Yes
Coolant Temperature Tell-Tale	Red[4]	Temp		—
Gauge	—	Temp		Yes
Electrical Charge Tell-Tale	Red[4]	Volts, Charge or Amp		—
Gauge	—	Volts, Charge or Amp		Yes
Speedometer	—	MPH[6]	—	Yes
Odometer	—	—	—	—
Automatic Gear Position	—	Also see FMVSS 102	—	Yes
High Beam Tell-Tale	Blue[4] or Green	Also see FMVSS 108		—
Brake Air Pressure Position Tell-Tale	Red[4]	Brake Air Also See FMVSS 121	—	—
Malfunction in Anti-Lock or	Yellow	Anti-Lock Also see FMVSS 105-75	—	—
Brake System	Red[4]	Brake Also see FMVSS 105-75	—	—

1. The pair of arrows is a single symbol. When the indicator for left and right turn operate independently, however, the two arrows will be considered separate symbols and may be spaced accordingly.
2. Not required when arrows of turn signal tell-tales that otherwise operate independently flash simultaneously as hazard warning tell-tale.
3. If the odometer indicates kilometers, then "KILOMETERS" or "km" shall appear, otherwise, no identification is required.
4. Red can be red-orange. Blue can be blue-green.
5. Framed arrows may be filled.
6. If the speedometer is graduated in miles per hour and in kilometers per hour, the identifying words or abbreviations shall be "MPH and km/h" in any combination of upper or lower case letters.

[43 FR 27542, June 26, 1978, as amended at 44 FR 55583, Sept. 27, 1979; 45 FR 71804, Oct. 30, 1980; 47 FR 2998, Jan. 21, 1982; 49 FR 30196, July 27, 1984; 50 FR 23431, June 4, 1985]

APPENDIX F - SAE RECOMMENDED PRACTICE J1138

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DESIGN CRITERIA—DRIVER HAND CONTROLS LOCATION FOR PASSENGER CARS, MULTI-PURPOSE PASSENGER VEHICLES, AND TRUCKS (10 000 GVW AND UNDER)—SAE J1138

SAE Recommended Practice

Report of Human Factors Engineering Committee approved September 1977.

1. Scope—The purpose of this SAE Recommended Practice is to describe design criteria pertaining to the location and labeling of hand controls necessary to or frequently used during the operation of passenger cars, MPV, and trucks 10 000 GVW and under. The results of SAE human factors research have strongly influenced these recommendations, specifically in the areas of driver reach, control-locating performance, and control location expectancies. Deviations from this recommended practice should be made only after careful study of the various SAE publications on these subjects, as referenced here and in SAE J1139 (September, 1977), Supplemental Information—Driver Hand Controls Location for Passenger Cars, MPV's and Trucks (10 000 GVW and Under).

2. Introduction—The location of essential controls should be based, insofar as possible, on performance rather than design considerations and must be governed by human engineering practice as it pertains to hand reach, visibility, identification, and operating mode. These considerations may be mutually exclusive, in certain vehicles, because of conflicting design requirements. In these cases, the recommended practice should be followed starting with the highest priority considerations until all available control location space has been used.

Any restriction in the location of controls and displays must respect the need to accommodate not only safety requirements and serviceability, but also the spatial requirements necessary to package the components behind the

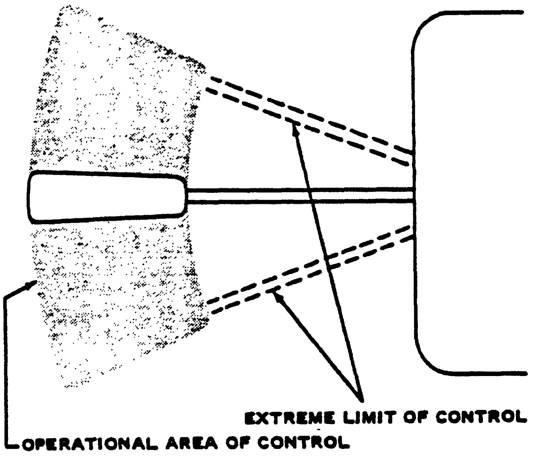

FIG. 1—OPERATIONAL AREA OF CONTROL

control and display surface. These restrictions in control locations are not intended to preclude the adoption of new control innovations or inventions that may be superior to known technology and which could result in safer, more efficient operation of the vehicle. It should be recognized that different classes of vehicles such as trucks may require different control locations because of their distinct environment.

3. *Term Definitions*

3.1 Driver Hand Control Reference Plane—A vertical longitudinal plane through the steering wheel center Y coordinate.

3.2 Driver Hand Control Operational Area—The area or region swept by those parts of a control which are activated or contacted by the hand while the control is in all the possible modes or positions. (See Fig. 1.)

3.3 Driver Hand Control Display Area—The area which includes the identification of the control and those portions required to determine its position at any point within its range. It need not include, for example, bezels or manufacturers' type numbers. (See Fig. 2 and SAE J1050a (January, 1977).)

3.4 Primary Driver Hand Controls—Those controls essential to the operation of a vehicle.

3.5 Secondary Driver Hand Controls—Those hand operated controls other than primary controls, intended for use by the driver when the vehicle is in motion for comfort and convenience, and those other controls not required for the principal operation of the vehicle.

4. *Design Criteria in Order of Priority*

4.1 The operational area of the following primary hand controls should be within the reach of a driver wearing a lap and shoulder restraint and the following secondary hand controls should be within reach of a driver wearing a lap belt only. (Reference SAE J287 (July, 1976), Driver Hand Control Reach.) *SAE J287 (July, 1976) defines reach capability under specific conditions of finger grasp control operation for two restraint conditions; a diagonal non-extending shoulder strap with lap belt and lap belt only. Fingertip operated controls may permit greater reach, while full hand grasp operated controls may result in lesser reach. In addition, a diagonal extending shoulder strap may permit greater reach than a non-extending shoulder strap.*

Primary Driver Hand Controls	Secondary Driver Hand Controls
Steering Control Gearshift Control Turn Signal Control Ignition Control Audible Horn Control Headlamp Dimmer Control Washer/Wiper Control(s) Headlamp Control Defroster Control Hazard Flasher Control Hand Brake	Headlamp Optical Warning Control Climate Control Radio Controls Vent Remote Control Cigarette Lighter Ashtray Accessory Controls

4.2 The audible horn control should be located on the steering control.

4.3 The display area of the following driver hand controls should be within view of the restrained driver with head movement so as to permit identification. Areas obscured by the steering control are defined in SAE J1050a (January, 1977), Describing and Measuring the Driver's Field of View.

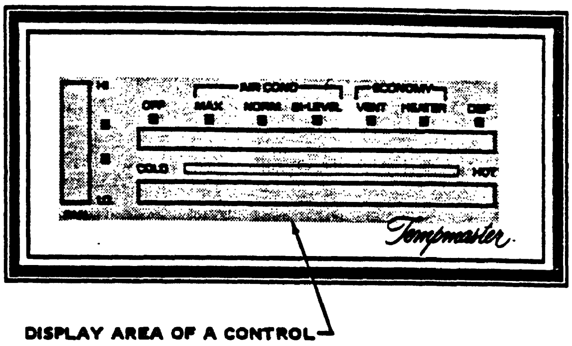

FIG. 2—DISPLAY AREA OF A CONTROL

Primary Driver Hand Controls	Secondary Driver Hand Controls
Washer/Wiper Control(s) Headlamp Control Defroster Control	Climate Control Radio Control Vent Remote Control Cigarette Lighter (except in the ashtray) Ashtray Accessory Controls

4.4 The following driver hand controls should be labeled with words or words and symbols.

Primary Driver Hand Controls	Secondary Driver Hand Controls
Washer/Wiper Control(s) Headlamp Control Defroster Control Hazard Flasher Control	Climate Control Functions Vent Remote Control Cigarette Lighter Ashtray Accessory Controls

4.5 The following driver hand controls should be located to the left of the reference plane. A differentiation between the operating modes of the headlamp control and the washer/wiper control(s) should exist.

Primary Driver Hand Controls	Secondary Driver Hand Controls
Turn Signal Control Headlamp Dimmer Control Washer/Wiper Control(s) Headlamp Control	Headlamp Optical Warning Control

4.6 The following driver hand controls should be located to the right of the reference plane.

Primary Driver Hand Controls	Secondary Driver Hand Controls
Gearshift Control Ignition Control Defroster Control Hazard Flasher Control	Climate Control Radio Controls Cigarette Lighter Ashtray

4.7 Controls not specifically mentioned in this recommended practice should be located insofar as possible in accordance with SAE publications concerning driver reach, control-locating performance, and expectancies.

5. *References*

5.1 SAE J287 (July, 1976), Driver Control Reach.

5.2 SAE J1048 (September, 1974), Symbols for Motor Vehicle Controls, Indicators, and Tell-Tales.

5.3 SAE J1050a (January, 1977), Describing and Measuring Driver's Field of View.

5.4 J. J. McGrath, "Driver Expectancy and Performance in Locating Automotive Controls," SAE SP 407, presented at SAE Automotive Engineering Congress and Exposition, February 23-27, 1976.

5.5 SAE J1139 (September, 1977), Supplemental Information Driver Hand Controls Location for Passenger Cars, Multi-Purpose Passenger Vehicles, and Trucks (10 000 GVW and Under).

5.6 SAE J1100a (September, 1975), Motor Vehicle Dimensions.

APPENDIX G - SAE INFORMATION REPORT J1139

SUPPLEMENTAL INFORMATION—DRIVER HAND CONTROLS LOCATION FOR PASSENGER CARS, MULTI-PURPOSE PASSENGER VEHICLES, AND TRUCKS (10 000 GVW AND UNDER)—SAE J1139

SAE Information Report

Report of Human Factors Engineering Committee approved September 1977.

This information report should be used as a supplement to SAE J1138 (September, 1977), Design Criteria—Driver Hand Controls Location for Passenger Cars, Multi-Purpose Passenger Vehicles, and Trucks (10 000 GVW and Under). It is intended to provide additional information which is important to the automotive designer and engineer in the process of designing, developing, and engineering the instrument panel.

1. General—The question of driver hand controls location is a complex one. While there is a general feeling that decrements in performance in locating and operating controls may affect the safety with which a vehicle is operated, there is no solid evidence linking accidents with the inadvertent operation of automotive controls or to the inability to locate an essential control in a timely manner.

The Anacapa studies and final SAE report SP407 indicate that errors and response times increase when hand controls are not located in their expected location and that this offers the potential for a decrement in operator performance. The measure or consequence of the decrement has not yet been determined and may never be determined in a totally objective manner.

However, if there is a potential improvement in operator performance, which could be achieved by the location of certain hand controls, then that is the goal.

Numerous studies, including Anacapa,[1] indicate that drivers quickly adapt to a new control within a new environment after the first trial, with both response time and error rates reaching *own car* levels. Other studies, again including Anacapa, show a number of drivers reporting *own car* control location difficulties.

The Anacapa "Analysis of Expectancies of European Drivers and the Commonality of Automotive Controls Location on European Cars" study (Ref. 6), has demonstrated that driver populations have distinct control location expectancies and that these expectancies vary by country and by car type. Although the Anacapa studies show that there are decrements in response time and error performance when a control is located in an area other than the expected one, the European driver study (247.1) shows that the drivers make an attempt to adapt to the unfamiliar vehicle environment.

The Anacapa study (Ref. 4), demonstrates that expectancy is based on the driver's total experiences not just his most recent experience. This may account for those drivers still reporting the control location difficulties with their own cars after extended use as shown in the "Problem Incidence Survey—Own Car Drivers". These results suggest that some degree of location standardization ought to improve driver performance for both the first use and the extended use situation.

One of the most important factors in the Anacapa research affecting the driver's ability to locate controls was the presence or absence of labeling. Labeling was found to be essential to locating controls and significantly improved driver's performance. However, the results indicate that for comparably labeled controls, the actual location versus the expected location was the primary factor.

One additional finding which should not be ignored concerning instrument panel controls locations, but may be of even more importance in multi-function controls, is the *clutter effect*. There is a clutter effect if too many or varied controls are located in a given area. As the number of controls increase, so do the errors and response times.

It is assumed from the comparison of the findings in the Anacapa European and Japanese driver study versus the American driver study and from the fact that the current American production cars already possess a greater degree of commonality in controls location than do the European and Japanese cars, that the American drivers have a higher degree of expectancy and therefore better performance. It shows that there is less commonality of controls locations on European and Japanese cars and that as a consequence the Probability of Confirmed Expectancy by those drivers in their cars is less than American drivers in American cars.

Based upon the available research information it is concluded that certain practices should be adhered to in the design, development, and engineering of the instrument panel.

Incorporated in this report are positive proposals as well as design practices which should be avoided.

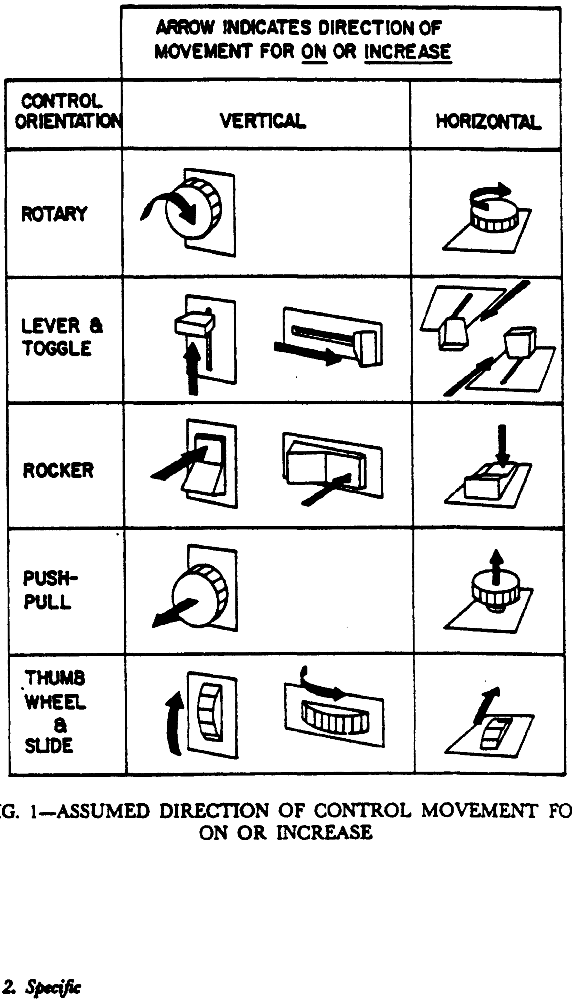

FIG. 1—ASSUMED DIRECTION OF CONTROL MOVEMENT FOR ON OR INCREASE

2. Specific

2.1 Cigarette Lighter—It is expected to be near or in the ashtray.

2.2 Vent Remote Control—A relocation in an area other than its expected location to the right of the reference place causes performance decrements and should be avoided. It is expected to be incorporated in or located near the climate control.

2.3 Hood Release—A location in an area other than its expected location to the left of the reference plane would be inconvenient.

3. Operation—The conclusions of this information report were made in consideration of the basic human factors guidelines on *direction of motion convention*. (See Fig. 1.)

4. Practices to be Avoided—Examples of the type of conditions which should be avoided:

4.1 Parking brake and hood release which are located side by side, and look alike.

4.2 Climate control which is designed in such a way as to have the appearance of a radio.

4.3 Ashtray which is difficult to locate.

5. Hazard Avoidance—Because of the high expectancy of the United States drivers to find certain essential operating controls on the same side of the reference plane or in the same area, care should be exercised in the design of controls to provide differences in: appearance, tactile recognition, and the modes of operation.

6. References

6.1 SAE J287 (July, 1976), Driver Control Reach.

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[1] Anacapa "Problem Incidence Survey Own Car Drivers."

6.2 SAE J1048 (September, 1974), Symbols for Motor Vehicle Controls, Indicators, and Tell-Tales.

6.3 SAE J1050a (January, 1977), Describing and Measuring Driver's Field of View.

6.4 J. J. McGrath, "Driver Expectancy and Performance in Locating Automotive Controls", SAE SP 407, presented at SAE Congress February 23-27, 1976.

6.5 SAE J1138 (September, 1977), Design Criteria—Driver Hand Controls Location for Passenger Cars, Muti-Purpose Passenger Vehicles, and Trucks (10 000 GVW and Under).

6.6 J. J. McGrath "Analysis of Expectancies of European Drivers and Commonality of Automotive Controls Location on European Cars", 247-1 September 26, 1974.