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Development and Evaluation of a Vehicle Monitor Driver Interface

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NOTICE

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16. Abstract

This report describes precompetitive research concerning the design of an interface to warn drivers about vehicle malfunctions. Issues examined were: (1) in general, what do drivers understand about the operation and maintenance of the items of interest (e.g., oil, brakes); (2) how should warnings be structured; and (3) how well are the supporting graphics understood.

In the first experiment, 27 drivers were interviewed at a local licensing office. They were asked questions such as "What is an alternator for?" and "What happens if the brake fluid is too low?" For about half of the items, understanding was marginal at best. Warning messages were designed to overcome the difficulties noted.

In the second experiment, 60 drivers were shown 9 prototypical warning messages and selected the words they preferred. (For example, should the brake fluid message use the wording "low," "add," "refill," "replenish," "add some," or another choice?)

Using the preferred wording, 20 drivers were shown a mockup of a warning display in a third experiment. Drivers said what each warning meant and how they would respond. This experiment identified problems with specific warnings and the vehicle mimic.

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PREFACE

The United States Department of Transportation (DOT), through its Intelligent Vehicle-Highway Systems (IVHS) program, is aiming to develop solutions to the most pressing problems of highway travel. The goal is to reduce congestion and improve traffic operations, reduce accidents, and reduce air pollution from vehicles by applying computer and communications technology to highway transportation. If these systems are to succeed in solving the nation's transportation problems, they must be safe and easy to use, with features that enhance the experience of driving. The University of Michigan Transportation Research Institute (UMTRI), under contract to DOT, has undertaken a project to help develop driver information systems for cars of the future, one aspect of IVHS. This project concerns the driver interface — the controls and displays that the driver interacts with, as well as their presentation logic and sequencing. This is 1 of 16 reports that documents that work.

The project had three objectives:

- Provide human factors guidelines for the design of in-vehicle information systems.
- Provide methods for testing the safety and ease of use of those systems.
- Develop a model that predicts driver performance in using those systems.

Although only passenger cars were considered in the study, the results apply to light trucks, minivans, and vans as well because the driver population and likely use are similar to cars. Another significant constraint was that only able-bodied drivers were considered. Disabled drivers are likely to be the focus of future DOT research.

A complete list of the project reports and other publications is included in the final overview report.[1] To put this report in context, the project began with a literature review and focus groups examining driver reactions to advanced instrumentation.[2,3,4] Subsequently, the extent to which various driver information systems might reduce accidents, improve traffic operations, and satisfy driver needs and wants, was analyzed.[5,6,7] That analysis led to the selection of two systems for detailed examination (traffic information and cellular phones) and contractual requirements stipulated three others (navigation, road hazard warning, and vehicle monitoring).

Each system was examined separately in a sequence of experiments. In a typical sequence, patrons at a local driver licensing office were shown mockups of interfaces, and driver understanding of the interfaces and preferences for them was investigated. Interface alternatives were then compared in laboratory experiments involving response time, driving simulation, and other methods.[8] The results for each system are described in a separate report. (See references 9, 10, 11, 12, 13, 14.) To check the validity of those results, several on-road experiments were conducted in which performance and preference data for the various interface designs were obtained.[15,16]

In parallel with that work, UMTRI developed test methods and evaluation protocols, UMTRI and Bolt Beranek and Newman (BBN) developed design guidelines, and BBN worked on the development of the driver model.[17]

Many of the reports from this project were originally dated May, 1993, the initial end date of the project when reports were to be delivered. However, the reports were drafted when the research was conducted, over two years earlier for the literature review and feature evaluation, and a year earlier for the laboratory research and methodological evaluations. While some effort was made to reflect knowledge gained as part of this project, the contract plan did not call for rewriting reports to reflect recent findings.

This report contains three experiments related to the display of information on a vehicle monitoring system. The first two parts of this work were conducted in the fall of 1991, while the third part was conducted in late 1992. Within this report, experiment 1 investigated drivers' knowledge of motor vehicle operation; experiment 2 explored driver preferences for warning messages; and experiment 3 tested warning message understandability.

METRIC (SI*) CONVERSION FACTORS

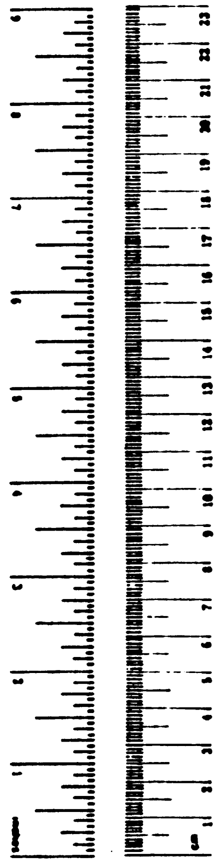
APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
	LENGTH			
in	inches	2.54	centimetres	cm
ft	feet	0.3048	metres	m
yd	yards	0.914	metres	m
mi	miles	1.61	kilometres	km
	AREA			
in²	square inches	645.2	millimetres squared	mm²
ft²	square feet	0.0929	metres squared	m²
yd²	square yards	0.836	metres squared	m²
mi²	square miles	2.59	kilometres squared	km²
ac	acres	0.395	hectares	ha
	MASS (weight)			
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams	Mg
	VOLUME			
fl oz	fluid ounces	29.57	millilitres	mL
gal	gallons	3.785	litres	L
ft³	cubic feet	0.0328	metres cubed	m³
yd³	cubic yards	0.0765	metres cubed	m³

NOTE: Volumes greater than 1000 L shall be shown in m³.

TEMPERATURE (exact)

°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

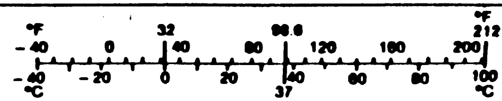


APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
	LENGTH			
mm	millimetres	0.039	inches	in
m	metres	3.28	feet	ft
m	metres	1.09	yards	yd
km	kilometres	0.621	miles	mi
	AREA			
mm²	millimetres squared	0.0016	square inches	in²
m²	metres squared	10.764	square feet	ft²
km²	kilometres squared	0.39	square miles	mi²
ha	hectores (10 000 m²)	2.53	acres	ac
	MASS (weight)			
g	grams	0.0353	ounces	oz
kg	kilograms	2.205	pounds	lb
Mg	megagrams (1 000 kg)	1.103	short tons	T
	VOLUME			
mL	millilitres	0.034	fluid ounces	fl oz
L	litres	0.264	gallons	gal
m³	metres cubed	35.315	cubic feet	ft³
m³	metres cubed	1.308	cubic yards	yd³

TEMPERATURE (exact)

°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



These factors conform to the requirement of FHWA Order 5190.1A.

* SI is the symbol for the International System of Measurements

TABLE OF CONTENTS

List of Tables

List of Figures

INTRODUCTION

This report concerns the development of an interface for providing drivers with information regarding the condition of their vehicle. The comparison of alternative formats for vehicle monitoring information has not been the central subject of any human factors research project. However, several studies have considered the understandability of a single format. Those studies considered how well people understand symbols, warning lights, text-based warnings, and gauges.

Studies of symbol understandability have been numerous.[18] When symbols are preferred, it is because they are more legible than their text equivalents and more likely to be understood across cultures. Recent research shows that some symbols, which have been used internationally for many years (e.g., oil pressure), still are not well understood.[19,20]

In terms of understanding warning lights, Green and Miller asked 76 drivers at a local driver licensing office to examine pictures of warning displays depicting malfunctions, state what the display was indicating, and state what action they would take.[21] Figure 1 shows an example of the warning display shown. The two rectangles next to each warning are for red and green light emitting diodes (LEDs), one of which was always illuminated. When the red LED adjacent to the radiator label (shown on the fluid level subpanel) was on, some drivers said they would replace the fan belt, an incorrect response. This simple display was misinterpreted quite often, with many of the warning lights being correctly identified less than 75 percent of the time. For the complete error rates, see table 1. More complex interfaces, which require moving through hierarchical menus or modes, would lead to unacceptable performance.

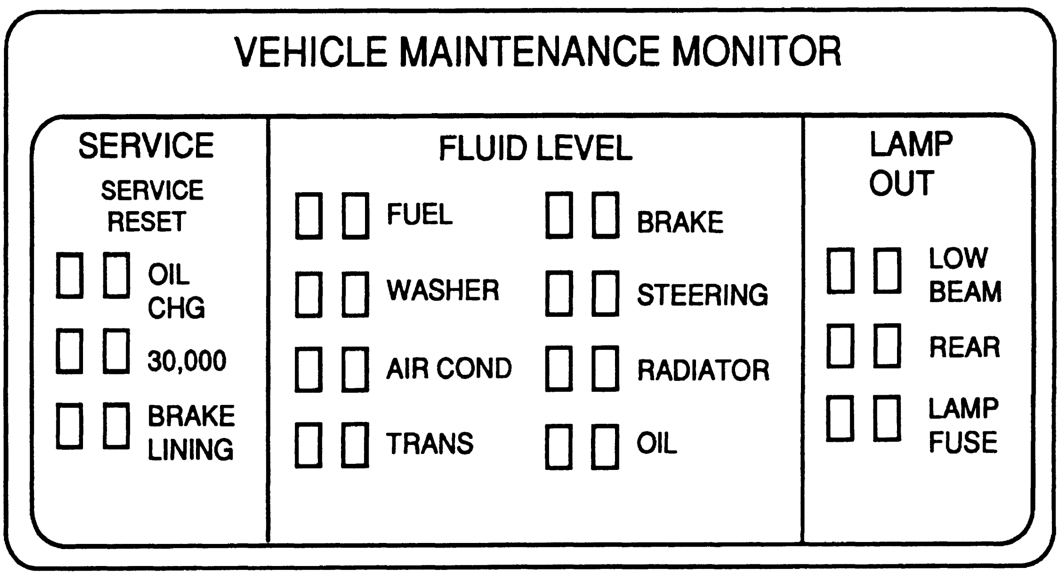


Figure 1. Vehicle maintenance monitor examined by Green and Miller.[21]

Table 1. Percent correct data from Green and Miller.[21]

Service	% Correct	Fluid Level	% Correct	Lamp Out	% Correct
Oil change	76	Fuel	89	Low Beam	79
30,000 check	69	Washer	89	Rear	82
Brake lining	76	Air Conditioner	55	Lamp Fuse	76
		Transmission	57		
		Brake	66		
		Steering	61		
		Radiator	47		
		Oil	86		

Only one study was found in the literature review that considered driver understanding of text-based in-vehicle warnings.[22] While it does not report any experimental data, it does specify message-wording options. The issue was whether the message context should be a statement of the symptom ("the engine is too hot"), what caused the warning to occur ("low coolant"), or what action to take ("add coolant"). The literature does not provide much guidance with regard to the context of warnings.

Warnings can also be presented using gauges, a topic on which much has been written.[23] In the most relevant study in the literature,66 drivers were shown slides of hypothetical instrument clusters while sitting in a vehicle mockup.[24] For each gauge, drivers identified its state (OK, too high, too low, or unsure) and what they would do about it (ignore it, stop immediately, etc.). The experiment demonstrated how small variations in gauge design related to understandability. Driver knowledge of vehicles had a major impact on which formats were understood. For example, many drivers had no idea what a normal engine temperature was; therefore, showing it as a numerical value (e.g., "193 °F") was meaningless to them. Critical to the selection of a display format is an assessment of driver knowledge of the problematic system.

Figure 2 shows some representative displays tested in a subsequent gauge interpretation experiment.[24] Drivers consistently performed better with gauges than with numeric displays, because few drivers knew the normal numeric values for automotive system levels. Performance was enhanced mostly by showing the normal range of a display, and somewhat less by color coding (e.g., changing the color of the digits of a numeric display). The particular labels on a scale (e.g., letters, words, digits, or even symbols) had little effect on performance once the normal range was identified .

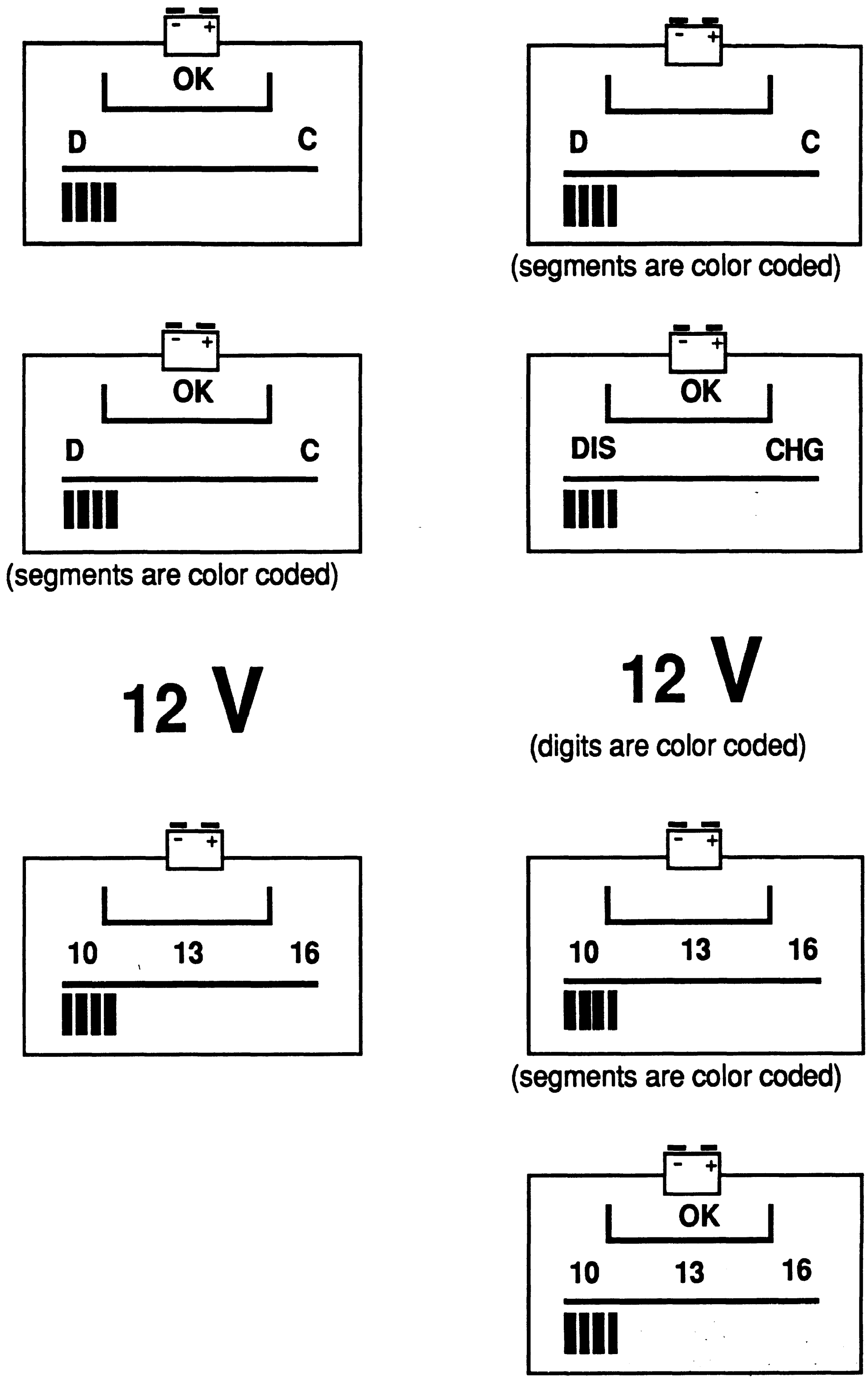


Figure 2. Representative displays for battery charge tested by Green.[24]

As a whole, these experiments show that drivers encounter difficulty interpreting what engineers might not consider to be complex displays. At issue is what level of performance is acceptable, which is task dependent. For example, there tend to be fewer errors in matching tasks than free response (naming) tasks because choices are limited. For symbols, there has been some discussion of 75 percent correct as a desired performance criterion.[18] If that criterion was applied here, only a few of the existing symbols, gauges, warning panels, and text displays would be acceptable.

After the research described in this report was completed, Baber and Wankling appeared in print.[25] In their experiment, 40 employees of an auto company were shown 20 warnings, 1 at a time, using a HyperCard program. They were asked to rate the urgency of the warnings on a scale of 1 (very urgent) to 5 (ignore) as quickly as possible. Warnings were shown in the following formats:

- Symbol alone.
- Symbol combined with action text ("stop and turn off engine").
- Symbol with a title.
- Symbol with a title and action text.

Decision times (to rate the urgency) were shortest for the symbol with a title and action text, and most accurate for the symbol with action text. (Text alone was not examined.) In general, providing more information is worse, because there is more information for users to process, although that was not the case here.

To develop text messages for the warnings of interest, the authors of this report needed to know:

- In general, what do drivers understand about the operation and maintenance of the systems of interest? (This information would suggest which warnings drivers might understand.)

- How should messages be structured? Should they say what is wrong, what to do, or both? Which words are preferred?

- How well are some of the supporting graphics understood?

Preliminary Design

The two major factors to be considered when designing a warning system are what information elements (warnings) it should display, and in what presentation format. Initial consideration of the information elements is described in previous reports.[5,26] That information, along with a review of the technology, led to a list of potential warnings. Presentation alternatives that were considered included speech, text, symbols, and gauges, as well as a combination of text and symbols. Those warnings could be accompanied by warning tones or other sounds. Text and symbols could be presented either on an instrument panel (IP) display or a head-up display (HUD). Early in the development of this system it became clear that the elements to be presented would be numerous. With so many possible warnings, it is likely that multiple messages would be active. When auditory warnings occur often, they are perceived as annoying.[27] As a result, speech was dropped as a presentation method (except for rare and extremely critical warnings where immediate attention is required).

Symbols were not chosen as the primary means for communicating warnings. For many of the new warnings, it would be necessary to develop new symbols. New warnings symbols would be produced by combining existing symbols (e.g., "air" and "filter" to form an "air filter" symbol). It has been found that the understanding of such warnings is poor, and far below the standards identified as "worst case acceptable."[28,29] For this reason, it was decided that symbols would be provided only in a supplemental role to fulfill the requirements of Federal Motor Vehicle Safety Standard 101.[30]

Another option, not considered in detail, was the use of gauges. There is not enough panel space to show all prospective warnings as gauges. While gauges could have been shared (there could be a location where a driver-selected gauge would appear), the selection process was considered to be unnecessarily distracting.[31]

The experimenters began this work by prototyping various mixed text and graphic systems in SuperCard. This was done to determine the feasibility of a system of this type. Several revisions were made, and when the basic issues of information content and format were settled, a scenario was developed to investigate prioritization and sequencing of the information presented. This led to a set of design assumptions and principles of operation for the prototype, which are described in the appendix. Since most of the warnings required neither constant monitoring, nor an instantaneous response (both of which would favor a HUD), an IP location was chosen for the display.

Purpose

This report describes three experiments. Experiment 1 investigated drivers' knowledge of the operation and maintenance of major automobile components to determine drivers' potential for understanding vehicle monitor warnings. This work was an extension of work done earlier by Green.[24]

The purpose of experiment 2 was to determine drivers' preferences for the vocabulary and structure of textual vehicle monitoring messages. A similar approach has been used previously.[32,33]

Experiment 3 tested a subset of warning messages developed as a result of the first two parts of this report. Only the most important and common messages were investigated, to reduce the data set to a manageable size. In this experiment, driver understanding of the messages was the issue.

EXPERIMENT 1 - VEHICLE MONITORING DRIVER KNOWLEDGE

Purpose

The purpose of this experiment was to determine how much drivers know, in general, about the operation and maintenance of their vehicles.

Method

Test Participants

Participants were patrons at the local driver licensing (secretary of state) office. Of the 27 drivers, there were 13 men and 14 women. They ranged in age from 19 to 44 years, with a mean age of 28. Education levels are shown in table 2. All of the drivers were native English speakers.

Table 2. Highest education level of subjects.

Level	# of subjects
Some high school	1
Some college	14
College degree	2
Some graduate school	4
Graduate school degree	6
Total	27

Test Materials and Equipment

In each interview, 25 open-ended questions were asked regarding different parts of an automobile that are commonly associated with failures or maintenance problems. For example, "What is an alternator for?" and "What happens if the brake fluid is too low?"

Other materials included a biographical form that requested information about the participant such as age, education, type of car driven, experience with advanced displays, etc. These materials can be found in the appendix.

Test Activities and Their Sequence

In the licensing office waiting area, the experimenter sat next to the subject, explained the instructions, and collected biographical data. The experimenter then asked the participant a series of open-ended questions regarding different aspects of automobile failures and maintenance. There was no prompting for further information after the participant's initial answer. The experimenter wrote down the participant's answer as precisely as possible. If the participant did not know, he or she was asked not to guess.

Results

Prior to administering the survey, a scoring key for the open-ended questions was developed. There were four levels of correctness – "correct" (completely correct); "partially correct"; "glimmer" (minimally correct); and "incorrect" (no correct information). The key was developed using several sources: Davis, *Automotive Reference: A New Approach - To the World of Auto/Related Information*; Society of Automotive Engineers SAE, *Glossary of Automotive Terms*; and Goodsell, *Dictionary of Automotive Engineering*.[34,35,36] The actual responses varied somewhat from the expected and some slight changes to the scoring key were made after the data were collected.

A summary of responses for each question and the criteria used for scoring appears in table 3. The number of incorrect responses varied from 0 (for "What happens if the radiator fluid is low") to 20 (for "What is the accessory drive belt for") out of 27. The mean error rate was 24 percent. This relatively large value suggests it may be difficult to get drivers to understand and respond appropriately to warnings for many functions.

Table 3. Questions tabulated for number of correct answers (n=27).

Question	Correct	Partial	Glimmer	Incorrect
1. What is an alternator for?	7	7	4	9
Correct: The alternator powers the electrical systems of the car and charges the battery. Partial (for either): Powers the electrical systems, or charges the battery. Glimmer: Involves electricity.				
2. What happens if the alternator doesn't work?	4	12	6	5
Correct: Battery slowly drains and car quits. Partial (for any): Battery dies, car won't start, or electrical power lost. Glimmer: Car dies, car won't run.				
3. What is special about antilock brakes?	14	7	0	6
Correct: Brakes won't lock when braking hard. Partial: Stops skidding.				
4. What happens if the antilock brakes don't work?	8	9	0	10
Correct: Brakes will work like normal brakes. Partial: Skidding will occur.				
5. What is the battery for?	18	3	5	1
Correct (for either): Starts the car, or runs the ignition during starting. Partial: Stores electricity for car. Glimmer: Electricity.				
6. What happens if the brake fluid is too low?	15	6	0	6
Correct (for either): Air gets in brake line and brakes get "mushy," or pushes farther to the floor. Partial: Brakes don't work.				

Table 3. Questions tabulated for number of correct answers (n=27) (continued).

Question	Correct	Partial	Glimmer	Incorrect
7. What do fuses do?	8	7	0	12
Correct: Break a current surge before it damages something in an electrical circuit. Partial: Monitor or control electrical circuit.				
8. What happens if a fuse blows?	15	9	0	3
Correct: Component connected to that fuse ceases to function. Partial: Some part of the car will not work.				
9. Why does the engine oil need changing?	7	14	0	6
Correct: Oil becomes abrasive and wears on the engine. Partial (for any): Wear will occur on the engine, oil gets contaminated, or oil breaks down loses viscosity.				
10. What happens if the engine oil (the dipstick level) is too low?	12	11	0	4
Correct (for either): Engine does not get lubricated properly and will wear faster, or engine does not get lubricated properly and heats up. Partial (for either): Engine may be damaged or engine overheats.				
11. What happens if the oil pressure is too low?	12	5	0	10
Correct (for any): Poor lubrication in engine may cause damage, oil not getting to all parts of engine may cause damage, or engine will burn up or be destroyed. Partial (for either): Lubrication in engine is reduced, or oil flow in engine is reduced.				
12. What does the oxygen sensor do?	2	5	3	17
Correct: Monitors oxygen in exhaust and adjusts fuel-air mixture entering engine. Partial: Adjusts fuel-air mixture. Glimmer: Monitors oxygen on air intake.				
13. What happens if the power steering fluid is too low?	20	4	0	3
Correct: Steering wheel gets hard to turn. Partial: Lose steering.				
14. What do the struts do?	7	15	0	5
Correct (for any): Act as shock absorbers and part of suspension, lateral stability, or shock absorbers and part of steering. Partial (for either): Act as shock absorbers, or stabilize car.				
15. What happens if the radiator fluid is too low?	27	0	0	0
Correct (for either): Engine overheats, or car overheats.				
16. What happens if the tire pressure is too low?	11	13	0	3
Correct (for two or more): Poor handling, lower gas mileage, faster tire wear, softer ride, unreliable steering, or increased risk of blowout. Partial (for any one): Poor handling, lower gas mileage, faster tire wear, unreliable steering, or increased risk of blowout.				

Table 3. Questions tabulated for number of correct answers (n=27).

Question	Correct	Partial	Glimmer	Incorrect
17. What happens if the tires are very worn?	7	20	0	0
Correct: Poor traction in wet or snowy conditions. Partial: Poor traction.				
18. What does wheel alignment refer to?	5	17	0	5
Correct (for two or more): Relationship of front tires to each other, relationship of front tires to steering wheel, or angle or front wheels to road (camber). Partial (for any): Relationship of front tires to each other, relationship of front tires to steering wheel, angle of front wheels to road (camber), or car drives straight without assistance.				
19. What happens if the wheels are not aligned?	11	15	0	1
Correct (for two): Car veers to one side, increased tire wear, decreased gas mileage, or decreased handling. Partial (for any): Car veers to one side, increased tire wear, decreased gas mileage, or decreased handling.				
20. What does the master cylinder do?	7	7	1	12
Correct: Provides fluid pressure for brakes or pumps brake fluid into brake lines. Partial: Puts pressure on brakes. Glimmer: Something to do with brakes.				
21. What is the clutch for?	9	13	3	2
Correct: Disengages the engine from the transmission for shifting gears or stopping. Partial: Permits changing or shifting gears. Glimmer (for either): Changes gears or transmission control.				
22. What does transmission fluid do?	2	16	0	9
Correct: Act as medium of power exchange between engine and drivetrain. Partial: Lubricates transmission.				
23. What do the shock absorbers do?	20	3	0	4
Correct (for either): Smoothes ride or keeps vehicle from bouncing. Partial: Stabilize car.				
24. What does the catalytic converter do?	6	11	2	8
Correct: Takes harmful elements out of exhaust. Partial: Controls emissions.				
25. What is the accessory drive belt for?	5	1	1	20
Correct: Runs alternator, air conditioner, or power steering off of engine. Partial: Create power for accessories, radio, fan, etc. Glimmer: Help alternator and water pump in case they break.				

Conclusions from Experiment 1

Based on criteria previously established, the warnings were broken into three groups.[18] The first group consists of items the experimenters believe drivers understand sufficiently to act accordingly when a warning is presented. Table 4 shows the items that were understood sufficiently, where 85 to 100 percent of drivers scored correct or partially correct. The second group consists of items on the border of sufficient understanding; these items will have to be carefully presented in a warning. The items with marginal understanding, 75 to 84 percent of drivers scoring correct or partially correct, are shown in table 5. The items in the third group were insufficiently understood, with less then 75 percent or drivers scoring correct or partially correct. See table 6.

Table 4. Items understood by 85 to 100 percent of participants (sufficient understanding).

Item	% correct
Blown fuse	89
Low engine oil level	85
Low power steering fluid	89
Low radiator fluid	100
Low tire pressure	89
Worn tire	100
Poor wheel alignment	96
Shock absorber function	85

Table 5. Items understood by 75 to 84 percent of participants (marginal understanding).

Item	% correct
Antilock brake function	78
Battery function	78
Low brake fluid	78
Reasons for engine oil change	78
Strut function	81
Clutch function	81

Table 6. Items understood by less than 75 percent of participants (insufficient understanding).

Item	% correct
Alternator function	50
Alternator failure	59
Antilock brake failure	63
Fuse function	56
Low oil pressure	63
Oxygen sensor function	26
Master cylinder function	52
Transmission fluid function	67
Catalytic converter function	63
Accessory drive belt	22

Table 7 describes the questions that presented difficulty to drivers, and offers some suggestions that may increase understanding of that item. In general, there were problems both with understanding the failure of the item, and the consequences of the failure.

Table 7. Comments on selected items.

Q#	Item	Comment/Suggestion
1 & 2	Alternator	Drivers may benefit from a timer or countdown to complete battery drain resulting from a malfunctioning alternator.
4	Antilock brakes	In the event of antilock brake failure, drivers should be informed that the regular (power or manual) brakes still work.
7	Fuse	Drivers were unsure of fuses' function, but more knowledgeable about the consequences of a malfunctioning fuse.
8	Blown fuse	Based on drivers' knowledge of the consequences of a blown fuse, it would be helpful to tell them which system is affected by the blown fuse.
11	Low oil pressure	Many drivers did not know what low oil pressure meant. Information the drivers need regards the criticality of the situation and a time scale to complete engine failure. Low oil *pressure* needs to be distinguished from low oil *level*.
12	Oxygen sensor	The oxygen sensor was not well understood, perhaps better to refer to the generic, "emissions system."
20	Master Cylinder	Based on lack of driver understanding, the master cylinder may need to be associated with the brakes.
22	Transmission fluid	About half of drivers (16 of 27) stated the purpose of the transmission fluid was to lubricate, which is only half of its purpose. Using the example of engine oil, in which 23 of 27 drivers understood the consequences of low lubrication, it is safe to assume these 16 drivers sufficiently understand the criticality of transmission fluid, and will act accordingly when they see a warning.
24	Catalytic converter	Associating the catalytic converter with emissions might enhance drivers' compliance with a warning message.
25	Accessory drive belt	Better understanding could be achieved through use of the name of the system driven by the belt (i.e., air conditioner drive belt).

EXPERIMENT 2 - VEHICLE MONITORING SYSTEM MESSAGE STRUCTURE

Purpose

The purpose of this experiment was to develop messages for a vehicle monitoring system display and to determine which warning message format drivers prefer for a vehicle monitoring system.

Method

Test Participants

Drivers who were waiting in line at the local driver licensing office participated. The 60 drivers (35 men and 25 women) ranged in age from 18 to 62 years, with a mean age of 34. Educational levels are shown in table 8. Mileage range of drivers was from 1,000 to 40,000 miles a year, with a mean of 16,450. For cellular phone usage, 9 drivers indicated they owned cellular phones, and 21 indicated they had used a cellular phone. All but three of the drivers were native English speakers. Of the participants, 4 owned cars with HUDs and 13 had driven cars with HUDs.

Table 8. Highest education level of subjects.

Level	# of subjects
Some high school	1
High school degree	5
Some college	23
College degree	14
Some grad school	5
Grad school degree	11
Missing data	1
Total	60

Test Materials and Equipment

Message Development

Warnings can provide four types of information: (1) the symptom, (2) the problem, (3) the correction, or (4) the consequence of not correcting the problem. After some debate, warning the driver of the problem was thought to be the best strategy, in general, if only one type of information could be presented. (For a few items requiring driver maintenance, the preferred messages describe the correction.) When the design decision was made, it was thought that providing multiple pieces of information would lengthen decision time, something that Baber and Wankling have subsequently shown may not always be true.[25] Reasons for eliminating the other types of information were: (1) drivers may not be able to infer the problem from the symptom, (2) there may be more than one correction for a warning, and (3) the consequence may indicate numerous problems.

The vast majority of information elements on this system would be displayed as text, so driver understanding of these messages is critical. It is important to determine the best vocabulary for the average driver. Before this could be done, the potential warnings needed to be categorized for criticality.

Information Elements

From the list of vehicle monitoring information elements determined and prioritized in a previous task, warnings determined to be technically feasible by the year 2000 were sorted by the type of message.[26] Technical feasibility was determined from the literature, expertise of persons within UMTRI, and letters sent to select people in the auto industry.[37,38] Some elements not considered to be feasible remained on the list because they represented the range of warning types.

Table 9 presents the scheme used for classifying messages to drivers based on their criticality. The appendix contains the full list of information elements, their criticality, and possible warning messages.

Table 9. Message classification scheme.

Code	Information element classification
!	Driver attention/action critical
D	Driver will probably attend to this item
UM	Unscheduled maintenance
SM	Scheduled maintenance
DU	Driver expected to understand
DN	Driver not expected to understand
Stat	Not maintenance, for driver information

Message Structure Development

Emerging from similarities in the lists of different information elements were the following possible structured vocabularies. It is best to view the messages as a set (a vocabulary) and to pick terms to use throughout each type of message.[39,40] A message can be formed by choosing one word from each column to make a coherent message. Examples of possible vocabulary structures are shown below for various types of problems.

• (!,D,UM) Driver attention/action critical, driver will attend to this unscheduled maintenance problem

high	<item>
low	<problem>

• (D,UM) Driver will attend to this unscheduled maintenance problem (e.g., washer fluid, or fuel)

low	<item>
add	

• (SM) Service center regular maintenance non-critical

periodic	<item>	maintenance	required
regular		check-up	needed
scheduled		inspection	desired
normal		service	necessary
time for			recommended

• (UM) Service center maintenance important/critical

replace	<item>	maintenance	required
		repair	needed
		service	desired
		burned out	necessary

For items most drivers are expected to understand (e.g., washer fluid), the specific understood name could be used. For items the driver is not expected to understand, the item could be listed by the global system description (e.g., "brake maintenance" instead of "brake pad replacement," or "emission control system" instead of "O_2 sensor"). Some drivers, however, will prefer the more detailed description. Perhaps the combined format of "emission control system (O_2 sensor)" would satisfy both classes of drivers.

The most likely information elements for display were used to form example message structures for use in this experiment. Nine messages were selected and all possible vocabulary words determined. As shown in the appendix, the resulting nine structured messages formed the bulk of the questionnaire. There were two versions, with messages listed in alphabetical and reverse alphabetic order. Half of the subjects saw each version.

Test Activities and Their Sequence

Patrons arriving at the driver licensing office were approached and given a description of the experiment. While seated next to the subject, the experimenter explained the instructions and collected biographical data. The experimenter then reviewed an example warning message. Finally, the participant was left alone to complete the forms. Subjects were not compensated for their time.

Results

The responses of the 60 participants for each of the 9 warning message questions are summarized in tables 10 through 18. For each item, the number of participants who preferred that term is listed. Shown in italics are additional suggestions from participants. Where participants failed to select or indicate a preferred term, "[skipped]" is shown. Answers for "(none)" mean that participants selected a blank space in that part of the message structure; that is, a word was not necessary in that column to form a coherent message. The structure most preferred by drivers is specified, followed by a brief discussion. Preferences with an asterisk (*) are messages that combine drivers' preferences with any changes suggested by the authors.

For the accessory drive belt, drivers preferred the message beginning with the belt name followed by some kind of maintenance directive. See table 10. Because the system survey indicated that only 5 of 27 drivers knew what the accessory drive belt was, this term is not a good one to use. The most important component powered by the accessory drive belt is the alternator. Since 22 of 27 drivers knew the seriousness of a nonworking alternator, the message will be changed to "Alternator drive belt service needed." When a vehicle contains two drive belts, the belt that drives the alternator should be referred to as the "Alternator drive belt," even if it drives other systems as well. The other belt should be referred to by the system it powers.

Table 10. Preferences for accessory drive belt warning message structure.

30 (None)	**accessory drive belt**	15 service	18 (none)
25 Replace		14 loose or worn	16 needed
4 New		12 maintenance	16 required
1 Check		11 (none)	8 necessary
		8 repair	1 desired
			1 [skipped]

Preferences: Accessory drive belt service needed [or required]
*Alternator drive belt service needed
Accessory drive belt loose or worn
Replace accessory [alternator] drive belt

Commands ("add," "refill," "replenish," "add more") were preferred over conditions (low, running out of) for the brake fluid message. See table 11. Unfortunately, a command message may imply the total problem is the brake fluid level itself and not that the low fluid may indicate an underlying problem. In response to "Add brake fluid," drivers simply may add the fluid and continue on their way, never considering why brake fluid was needed. If the problem were serious, the level of fluid would drop relatively quickly and the message would reappear, perhaps prompting drivers to have the brake system checked.

Table 11. Preferences for brake fluid warning message structure.

19	Low	**brake fluid**	38	(none)
16	Add		12	needed
12	Refill		7	reservoir
5	(None)		1	tank
4	Replenish		1	levels
2	Running out of		0	bottle
1	Add more		1	[skipped]
1	*Check*			
0	Add some			

Preferences: *Add brake fluid
Low brake fluid

This message structure also applies to:
Power steering fluid
Transmission fluid
Clutch fluid

Based on informal driver feedback, the recommended message for the door warning is "Door open." While both preferred messages would be understood, as shown in table 12, "door open" uses more common vocabulary.

Table 12. Preferences for door warning message structure.

door	25	ajar
	25	open
	6	not closed
	2	(none)
	2	unlatched

Preferences: Door open
Door ajar

This message structure also applies to:
Hood
Trunk
Hatch
Fuel door

The overwhelming preference for a fuse warning message was "Replace fuse," as shown in table 13. Since 24 of 27 drivers understood that a particular system would no longer function if a fuse blew, it would be meaningful to drivers to provide the system associated with the blown fuse.

Table 13. Preferences for fuse warning message structure.

42	Replace	**fuse**	27	(none)
11	(None)		11	burned out
7	New		7	required
			6	needed
			5	necessary
			3	desired
			1	[skipped]

Preferences: Replace fuse
*Replace fuse (system)

As with the brake fluid warning, drivers were divided in their preferences for the headlamp command or condition message. Again, more drivers wanted the command message, "Replace headlight [or headlamp]." See table 14. The choice of "headlight" over "headlamp" may be a geographic one. Since 23 participants failed to select a preference between the 2 choices, presumably there is no strong preference. One participant wrote in "left or right," to indicate the particular headlight. In the system envisioned, this information is provided on the graphic. Participants in this experiment, however, were not shown the full prototype screen.

Table 14. Preferences for headlight/headlamp warning message structure.

32	Replace	**34**	**headlight**	22	(none)	36	(none)
23	(None)	**21**	**headlamp**	18	burned out	8	needed
3	New	23	[skipped]	8	out	8	required
1	*Left or Right*			7	service	5	necessary
1	[skipped]			2	maintenance	1	desired
				2	repair	2	[skipped]
				1	[skipped]		

Preferences: *Replace headlight
Headlight burned out

This message structure also applies to:
Brake light
Fog light
High beam
Tail light
Turn signal light
Back-up light

As before, drivers were split in their preference for a command or condition message for the oil warning message. The command structures containing the word "add" ("Add," "Add more," or "Add some") were slightly preferred over the condition "low oil," as shown in table 15. To remain consistent with the other messages where the command message is the preferred structure, "Add engine oil" is recommended. Also, for service that drivers are expected to perform themselves, the command word is appropriate.

Table 15. Preferences for oil warning message structure.

26	Low	35	engine	**oil**
22	Add	21	(none)	
5	Add more	4	[skipped]	
4	(None)			
1	Add some			
1	*Service*			
1	*Check*			

Preferences: *Add engine oil
Low engine oil
Add oil

There were many combinations selected for the strut/suspension message, with an almost even split between command and condition messages. Almost half of the participants (29 of 60) wanted the command "Replace," while the remaining half preferred a condition message, "shock [or strut or suspension] service [or maintenance] needed [or necessary]." See table 16. Since there are numerous, equally preferred words available to form a coherent condition message, the most preferred condition message is difficult to construct. Since the extent of the required suspension work may not be detectable by the sensor, "Suspension service needed" is suggested.

Table 16. Preferences for shock or strut/suspension warning message structure.

29	(None)	**18**	**shock or strut**	19	(none)	26	(none)
29	Replace	**18**	**suspension**	17	service	14	required
1	New	24	[skipped]	11	worn	11	needed
1	[skipped]			7	maintenance	8	necessary
				6	repair	1	desired

Preferences: Replace suspension
Replace shocks
Shock absorber service required
*Suspension service needed

This message structure also applies to:
Brake (pads/shoes)
Clutch plate

For the washer fluid message, the overwhelming message preference is "add [or refill] windshield washer fluid." See table 17. While the particular vocabulary choices varied because of the number of options, ("Add," "Refill," "Replenish," and "Add more") the command structure was preferred over the condition options, "Low windshield washer fluid," or "Windshield washer fluid needed."

Table 17. Preferences for washer warning message structure.

19	Add	34	windshield	**washer**	33	fluid	45	(none)
15	Refill	20	(none)		18	(none)	11	needed
14	Low	6	[skipped]		7	solvent	3	reservoir
5	(None)				1	liquid	1	tank
3	Replenish				1	[skipped]	0	bottle
2	Add more							
2	Running out of							
0	Add some							

Preference: *Add windshield washer fluid

This message structure also applies to:
Radiator fluid

Note: Windshield washer fluid and radiator fluid were separated from the other fluids (clutch fluid, brake fluid, etc.) because the former items are more likely to be maintained by the driver.

While "Improper/poor wheel alignment," (the condition message structure) was preferred, this could be misunderstood by drivers to mean they were not paying enough attention to steering the vehicle, not that service was needed. To avoid this possibility, the second preference "Wheel alignment service" is recommended. See table 18.

Table 18. Preferences for wheel alignment warning message structure.

25	Improper	**wheel alignment**	34	service	27	(none)
18	(None)		26	(none)	13	needed
16	Poor				11	required
1	[skipped]				8	necessary
					1	desired

Preferences: Wheel alignment service needed
Improper wheel alignment

This message structure also applies to:
Tire rotation

Note: Since a similar misunderstanding is unlikely for tire rotation, the word "service" should not be included in its warning message.

Conclusions from Experiment 2

In many cases, there was a slight preference for command (what to do) over condition messages, whether or not the driver is likely to correct the problem personally. To develop a set of consistent messages, the ending words "service needed" were used on condition messages where appropriate. Table 19 summarizes the results of preferences for warning message structure, as described (in the same order) in the results section. The problematic item appears in boldface.

Table 19. Final warning messages based on driver preference.

Question #	Message
1.	**Alternator drive belt** service needed
2.	Add **brake fluid** Add **power steering fluid** Add **transmission fluid** Add **clutch fluid**
3.	**Door** open **Hood** open **Trunk/hatch** open **Fuel door** open
4.	Replace **fuse** (number) (system)
5.	Replace **headlamp** Replace **brakelamp** Replace **fog lamp** Replace **high-beam lamp** Replace **tail lamp** Replace **turn signal lamp** Replace **back-up lamp**
6.	Add **engine oil**
7.	**Suspension service** needed **Brake service** needed **Clutch plate service** needed
8.	Add **windshield washer fluid** Add **radiator fluid**
9.	**Wheel alignment service** needed **Tire rotation** needed

EXPERIMENT 3 - DRIVER LICENSING OFFICE TEST OF VEHICLE MONITORING WARNING MESSAGES

Purpose

The purpose of this experiment was to determine drivers' understanding of 15 vehicle monitoring system warnings.

Method

Test Participants

The 20 participants (11 men and 9 women) who were waiting in line at a driver licensing office ranged in age from 17 to 69 years, with a mean of 33. The highest level of education participants had completed ranged from "some high school" to "graduate school degree." Overall, 17 participants reported owning domestic model vehicles, and 3 owned foreign models. The mean model year of their vehicles was 1988 (ranging from 1980 to 1992). Drivers reported their annual mileage varied from 2,000 to 35,000 miles (mean of 17,000). Additionally, their reported computer usage varied from "a few times a month or less" to "more than a few times a week." Participants were given a choice of snack foods when they completed the experiment.

Test Materials and Equipment

Fifteen paper reproductions of displays for a vehicle monitoring system were used. (Copies of the test card graphics are included in the appendix.) The border on the "severe" and "moderately severe" messages was color coded (red and yellow), as was the location of the problem tire, turn signal lamp, or door. Otherwise, the displays were white on black. The 15 warning messages and their color-coding are shown in table 20. Copies of the biographical forms and experimental procedure are also in the appendix.

Table 20. Warning messages and their color-coded severity presented to drivers.

#	Color Code	Warning Message
1	-	Low fuel
2	yellow	Worn tire
3	red	Low oil pressure!
4	yellow	Engine temperature near high
5	red	High engine temperature!
6	-	Replace turn signal lamp
7	-	Replace air filter
8	yellow	Antilock brake system failure
9	-	Low tire pressure
10	-	Add engine coolant
11	red	Power brake failure!
12	yellow	Worn tire
	-	Replace turn signal lamp
13	-	Oil change needed 500 miles
14	yellow	Oil change 200 miles overdue
15	-	[trunk and door open]

Test Activities and Their Sequence

Patrons arriving at the local driving licensing office, were approached and asked if they would be willing to participate. Willing drivers were read the following scenario:

> *I want you to envision that it is 5 to 10 years in the future. You are driving by yourself in your 1-year-old sedan to meet a friend in East Lansing, 1 hour away. It is around 2 PM on a nice fall day, and you are driving on the expressway. You just left your home in Ann Arbor 5 minutes ago.*

Participants were then shown the first card depicting the simulated vehicle monitoring system, and asked the following questions:

> *What is this telling you?*
> *What would you do about this?*
> *In terms of your trip, when would you do that?*

The experimenter repeated these questions for each card and recorded responses on a data sheet. The order of the cards was fixed. For 9 of the 15 situations, there was an additional follow-up question to clarify responses, or to gather more detailed information. For example, for the "worn tire" warning, participants were asked if they could identify which tire was worn. There were minor inconsistencies across experimenters when asking the follow-up questions and recording responses to them. Participants held the stack of cards, and flipped them when cued. After participants finished all the cards, they completed a short biographical form. When done, they were thanked and compensated.

Results

Post-Study Response Classification

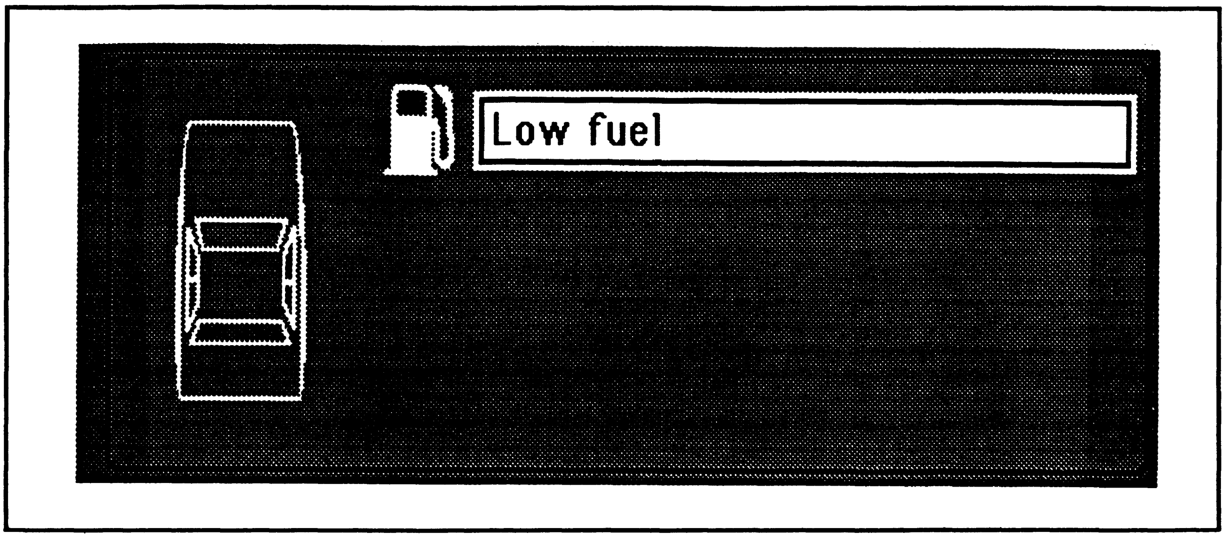
For each of the 15 sample displays, responses to each question were grouped together based on their similarity. For example, responses such as "I need to put air in the tire" and "low tire pressure," were categorized together. For this question, nonresponses (no response) were grouped with those who simply reread the message verbatim. The most common responses to "what would you do about this," were (1) check the problem, or (2) repair the problem. For nonresponses to this question it was assumed that drivers would initially check the problem. Responses to "when would you do this?" sometimes evoked specific distances in response. For most of the messages, however, there were five basic responses:

1. Immediately, on the highway (meaning either on the side of the road, or while on the highway)
2. Turn back to Ann Arbor (about 5 minutes or 5 miles away)
3. At the next exit or next service station (assuming there is a gas station at each exit, and it is no more than 5 miles away)
4. In East Lansing (1 hour or 60 miles away)
5. After returning to Ann Arbor following the trip (after at least 120 miles or a few days)

Responses to Vehicle Monitoring Warnings

The following section summarizes drivers' responses to the questions asked for each warning, followed by a brief discussion.

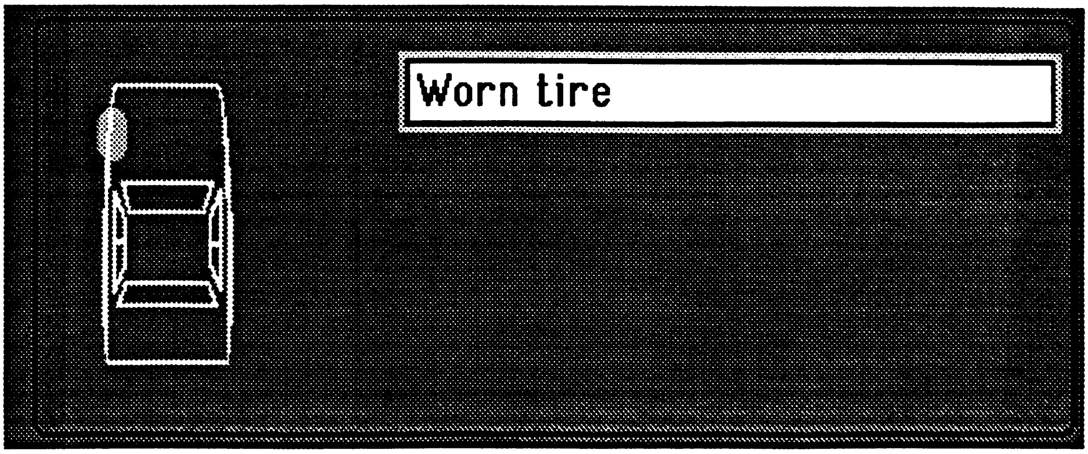
All drivers understood the low fuel message, and stated an appropriate means of solving the problem. See figure 3. Participants also gave a reasonable time frame (under 50 miles) for buying gas (depending on the specific vehicle's gas mileage), except for two drivers who would likely run out of gas if they waited that long. It is possible that, with the gas gauge as a supplementary display, these two drivers would make a better estimate of the distance they could travel.



# responses	What does this mean to you?
20	I need more gas, low on fuel.
	What would you do about this?
20	Stop to get gas.
	When would you do this?
20	At next exit, or nearest service station.
	How long do you think you could go before you must get gas?
9	5 to 15 miles.
9	20 to 50 miles.
1	100 miles.
1	A few hours.

Figure 3. Low fuel warning and responses.

For the worn tire message, all participants understood that a tire was worn; however, two participants named the incorrect tire. See figure 4. Most people said they would inspect the tire before replacing it, suggesting that they were unsure of the exact amount of wear on the tire. About half of the subjects would pull over within about 5 miles, while the other half would wait more than 60 miles before they would either look

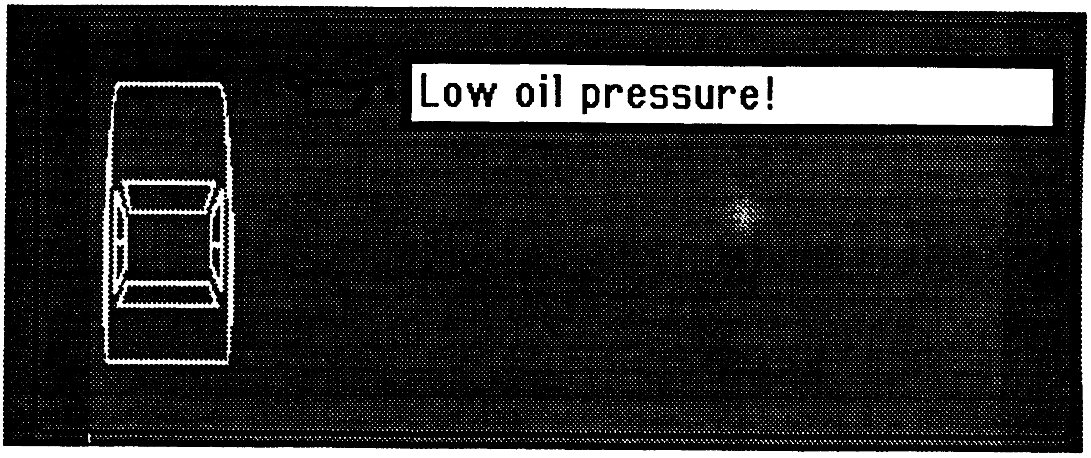


Note: Tire icon and text box border are yellow.

# responses	What does this mean to you?
20	Tire is worn, or getting bare.
	Which tire?
18	Left front.
2	Right front. [incorrect location]
	What would you do about this?
13	Inspect or check tire.
7	Replace tire.
	When would you do this?
1	Immediately, on highway.
11	At next exit, or nearest service station.
4	In East Lansing.
4	After returning to Ann Arbor, after the trip.
	How many miles do you think you can safely go on this tire?
3	Up to 20 miles.
4	21 to 50 miles.
2	60 miles, or all the way to East Lansing.
3	100 to 200 miles.
4	Couldn't tell from message only or it depends on how the tire looks.
4	[No response.]

Figure 4. Worn tire warning and responses.

While half the drivers reread the low oil pressure message out loud, a variety of responses was given by the participants, as shown in figure 5. Judging by the action that drivers would take to solve the problem, this indicates that most drivers do not understand the difference between low oil level and low oil pressure. Only two participants explicitly stated that there could be a problem with the oil pump, while the others suggested that the oil level was low. If this message indicated a malfunctioning oil pump, then drivers would not be able to drive much beyond the next available exit (a few miles at best). Whether the drivers clearly understood the message or not, at least most of them indicated they would stop soon.



Note: Oil icon and text box border are red.

# responses	What does this mean to you?
1	Needs oil change.
9	Oil pressure low.
6	Low oil level.
2	Need to check oil.
2	Oil sending unit (pump) has gone out.
	What would you do about this?
13	Have oil [level] checked by driver or at service station.
7	Add oil.
	When would you do this?
6	Immediately, on highway.
11	At next exit, or nearest service station.
3	In East Lansing.

Figure 5. Low oil pressure warning and responses.

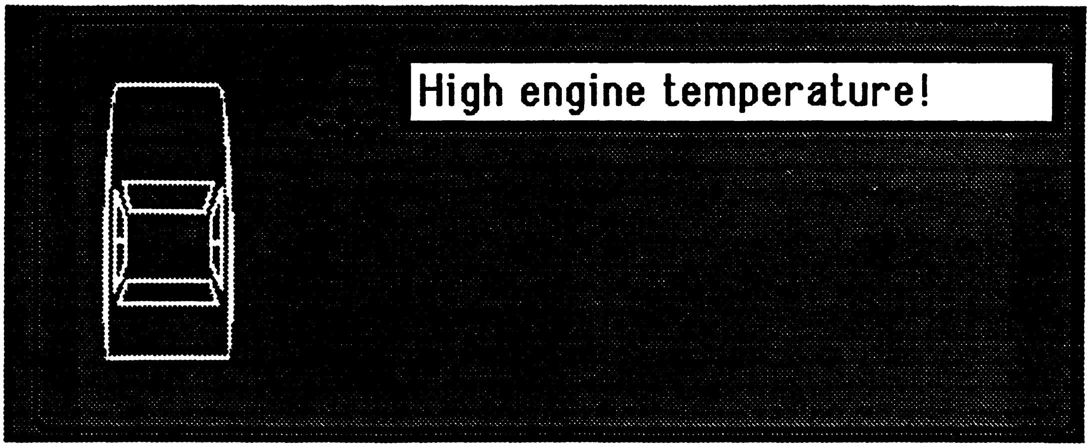
The general meaning of the engine temperature near high warning, that the engine was getting too hot, was understood by all participants. See figure 6. This message was intended as a warning before the following message ("high engine temperature"); however, two drivers suggested that the engine had already overheated. In addition, judging by the immediacy of drivers' intended time to act, all but one person would interrupt their trip (perhaps unnecessarily) to let the engine cool, when simply turning on the heat or slowing down might be sufficient to drive the car safely to a more convenient location for further checking.

Note: Temperature icon and text box border are yellow.

# responses	**What does this mean to you?**
15	Engine is getting too hot, temperature too high, etc.
2	Car or engine has overheated.
3	Low on engine coolant, radiator fluid, or water.
	What would you do about this?
17	Slow down, or stop to let it cool, or check it.
1	Change oil.
2	Turn heat on.
	When would you do this?
11	Immediately, on highway.
8	At next exit, or nearest service station.
1	In East Lansing.

Figure 6. Engine temperature near high warning and responses.

In response to the high engine temperature warning, most drivers did not say that the engine was already too hot, nor did they indicate that they would respond any more quickly to this warning than the previous one (engine temperature getting hot). See figure 7. One participant noted that this message was the same as a previous one, it meant something worse. There did not seem to be a clear difference in the responses to these two messages. In addition, no one mentioned the color coding difference.

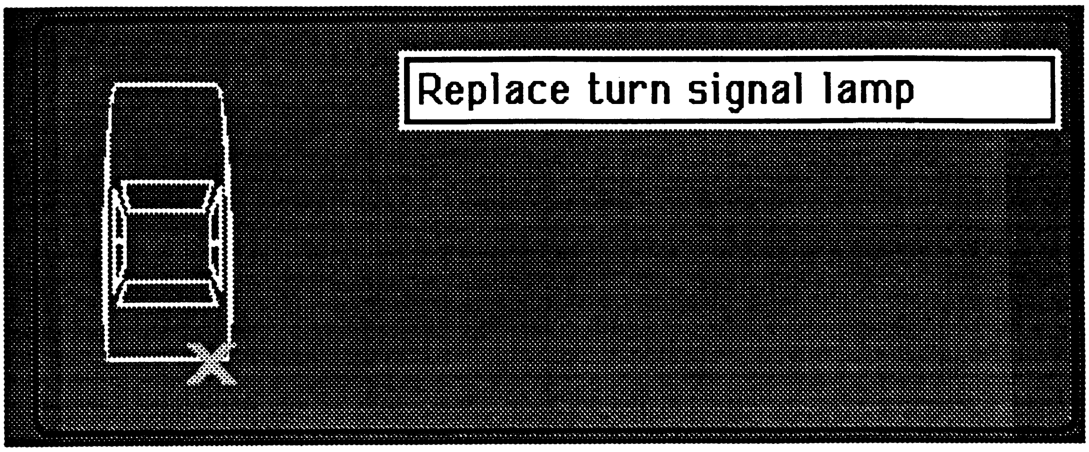


Note: Temperature icon and text box border are red.

# responses	What does this mean to you?
16	Engine getting hot, is overheating. [One said it was same as previous warning.]
4	Engine has overheated. [One said it was worse than previous warning.]
	What would you do about this?
13	Stop the car or stop at service station. [No reason given.]
6	Stop and wait, let the car cool.
1	Change oil.
	When would you do this?
11	Immediately, on highway.
9	At next exit, or nearest service station.

Figure 7. High engine temperature warning and responses.

Only one participant was uncertain about which type of lamp needed to be replaced for the replace turn signal lamp message. See figure 8. Most drivers' answers suggested that this was not an immediate problem, judging by their reported delay in making the repair. Although there was a lack of overall identification of the problematic lamp, this error would presumably be discovered upon inspection of the lights.

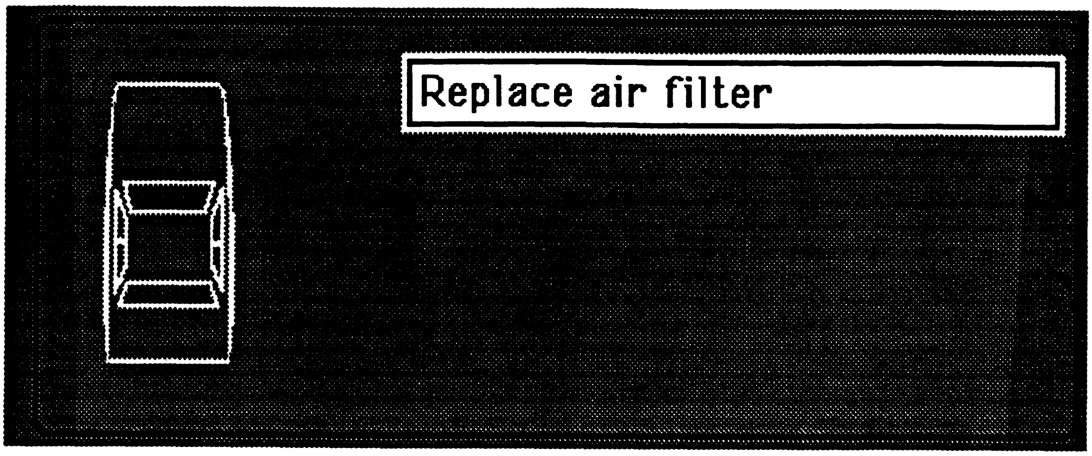


Note: Lamp out icon ("X") is yellow.

# responses	What does this mean to you?
19	Turn signal lamp is out.
1	Not sure if brake light or turn signal lamp is out.
	What would you do about this?
20	Get replaced.
	When would you do this?
1	Turn back to Ann Arbor, if I had a bulb.
3	At next exit, or nearest service station.
4	In East Lansing.
10	After returning to Ann Arbor, after the trip.
2	Not until I got pulled over.
	Which light is it?
16	Right rear.
1	Left front. [incorrect location]
2	Right side. [Didn't say front or rear.] [incorrect location]
1	[No response.]

Figure 8. Replace turn signal lamp warning and responses.

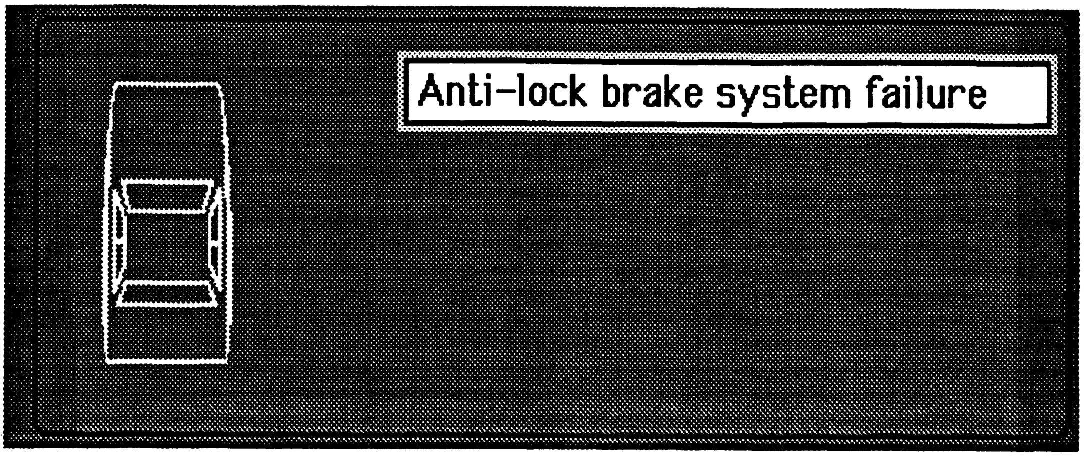
For the replace air filter warning, all drivers had a clear understanding that the air filter needed to be changed. See figure 9. Interestingly, all but one participant said they would replace the air filter without mentioning that they would inspect it first. The majority of drivers would likely wait a few days before replacing it, indicating that it is not a priority item.



# responses	What does this mean to you?
20	Replace air filter, air filter is dirty.
	What would you do about this?
19	Change or replace the air filter.
1	Check air filter, or ignore for now.
	When would you do this?
2	At next exit, or nearest service station.
4	In East Lansing.
11	After returning to Ann Arbor, after the trip.
3	At next scheduled oil change or tune up.

Figure 9. Replace air filter warning and responses.

For the antilock brake system failure warning, half of the drivers explicitly stated that the antilock brake system had failed, while the other half only mentioned that the power brakes were not working properly. See figure 10. It is unclear if these participants knew the distinction between the two brake systems. Despite some confusion, most drivers would take action very soon, within a few minutes, to investigate the problem. Their expectations for how the brakes would respond was almost equally divided, with responses varying from "no brakes" to "brakes OK." This suggests that the warning message needs revision.



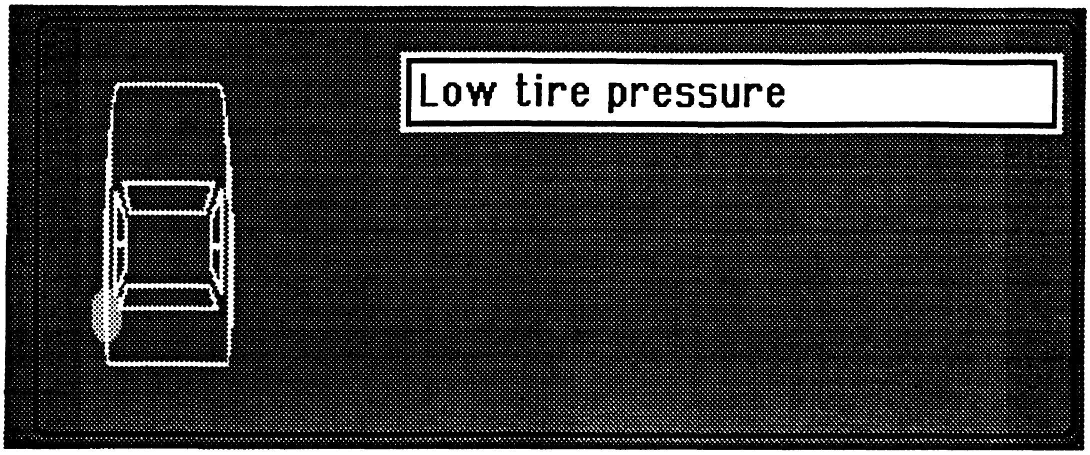
Note: Text box border is yellow.

Figure 10. Antilock brake system failure warning and responses.

# responses	What does this mean to you?
11	Anti-lock brakes or system not working.
7	Brakes or brake system not working or failed.
2	Unsure if anti-lock brakes or regular brakes have failed.
	What would you do about this?
3	Stop or pull over.
10	Go to a service station to get them checked.
6	Test brakes, pump brakes.
1	Continue on trip.
	When would you do this?
6	Immediately, on highway.
2	Turn back to Ann Arbor.
8	At next exit, or nearest service station.
2	In East Lansing.
2	After returning to Ann Arbor, after the trip.
	What would happen if you stepped on the brake?
2	Don't know what to expect.
3	No brakes.
5	Brakes would lock, jam, or not work fully.
3	Brakes would work.
7	[No response.]

Figure 10. Anti-lock brake system failure warning and responses (continued).

All participants understood the meaning of the low tire pressure message, and would respond in an appropriate and timely manner. See figure 11. Participants were not asked the location of the affected tire, as they had already been asked that information in the "worn tire" message.

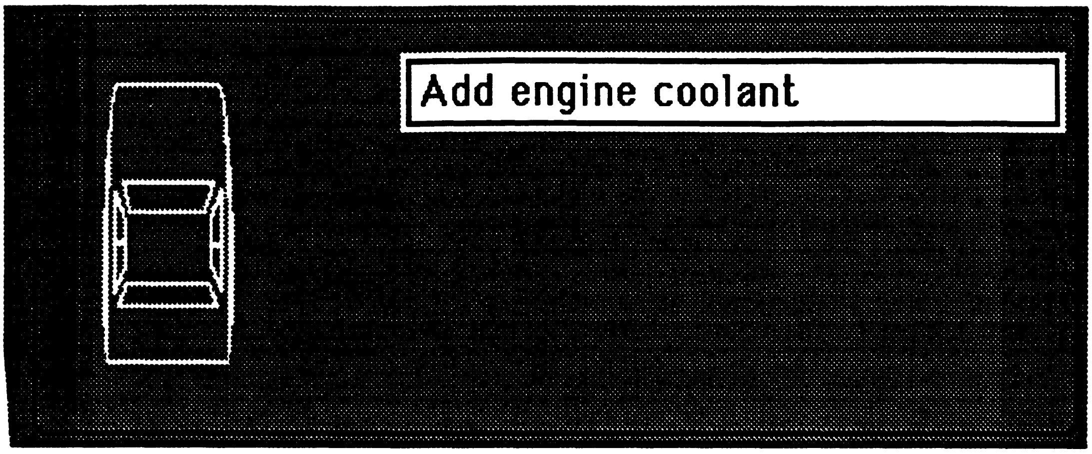


Note: Tire icon is yellow.

# responses	What does this mean to you?
20	Low tire pressure, need air in tire.
	What would you do about this?
15	Fill tire with air.
4	Check tire.
1	Reduce speed first (then check tire).
	When would you do this?
2	Immediately, on highway.
14	At next exit, or nearest service station.
4	In East Lansing.

Figure 11. Low tire pressure warning and responses.

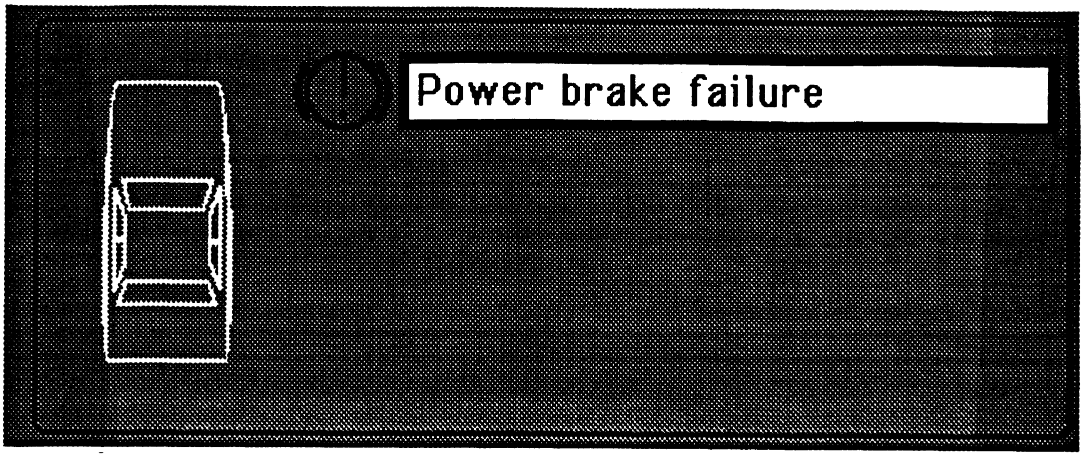
All participants understood that the engine coolant was running low, or mentioned a related problem for the add engine coolant warning. See figure 12. In addition, all indicated they would respond in an appropriate and timely manner.



# responses	What does this mean to you?
18	Engine coolant level is low.
1	Warning that engine is getting warm.
1	Need to have radiator checked.
	What would you do about this?
15	Add engine coolant.
3	Have it checked.
2	Stop and let it cool.
	When would you do this?
1	Immediately, on highway.
13	At next exit, or nearest service station.
6	In East Lansing.

Figure 12. Add engine coolant warning and responses.

With the power brake failure warning, the drivers were split on the degree with which the brakes were malfunctioning; half said they had no brakes, while the other half only mentioned they were not working correctly, not mentioning to what extent. See figure 13. This confusion is also reflected in responses to the extra question, where there was no consensus on the condition of the brakes.

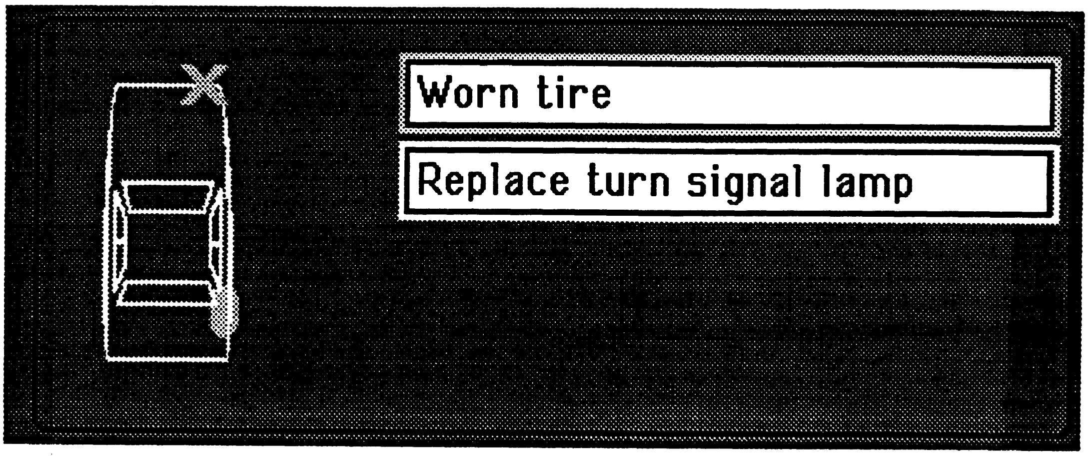


Note: Brake icon and text box border are red.

# responses	What does this mean to you?
10	Brake failure, no brakes.
10	Something wrong with power brakes, brakes not working correctly.
	What would you do about this?
5	Test brakes.
6	Pull over, slow down, or stop.
9	Go to next service station or exit, or find place to call tow truck, etc.
	When would you do this?
9	Immediately, on highway.
1	Turn back to Ann Arbor.
9	At next exit, or nearest service station.
1	After returning to Ann Arbor, after the trip.
	What would happen if you stepped on the brake?
6	Not sure.
7	Would be harder to apply brakes, or they might fail.
6	No brakes.
1	Brakes are still OK now.

Figure 13. Power brake failure warning and responses.

Everyone understood the meaning of the double warnings for worn tire and replace turn signal lamp warning here. See figure 14. In terms of the worn tire, responses were similar to the previous worn tire warning, perhaps the only difference was that drivers would wait to act on the problem a little further into the trip. For the broken turn signal lamp, drivers were more eager to resolve the problem sooner in the trip than when they received the solitary message. One participant made an off-hand remark about something possibly being wrong with the vehicle monitoring system since two messages were presented simultaneously. The biggest problem, however, was the difficulty that participants had in determining the correct location of the bad tire and lamp. Four participants got both the location of the bad tire and signal lamp incorrect. This was not just the case of mistaking the tire for the lamp. It should also be noted that a few participants' final answers to the extra question were different than their original one, suggesting that people either had difficulty determining the orientation of the car, or in distinguishing the tire (an oval icon) from the lamp out symbol (an "X").



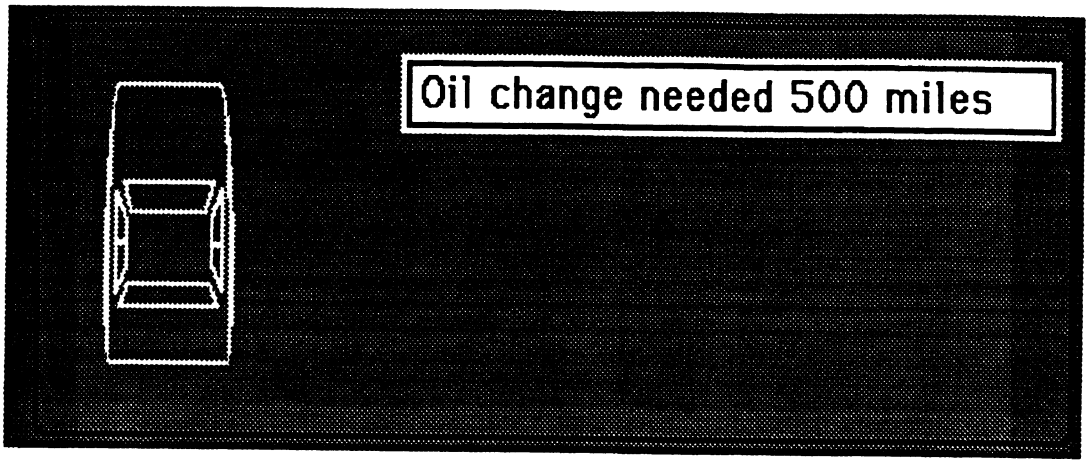
Note: Tire icon, lamp out icon ("X"), and text box border are yellow.

Figure 14. Dual message of worn tire and replace turn signal lamp warning and responses.

# responses	What does this mean to you?
20	Turn signal lamp broken, and tire worn.
	What would you do about this? (tire)
10	Check tire.
9	Replace tire.
1	Do nothing now.
	What would you do about this? (lamp)
6	Check lamp.
14	Replace lamp.
	When would you do this? (tire)
2	Immediately, on highway.
6	At next exit, or nearest service station.
7	In East Lansing.
5	After returning to Ann Arbor, after the trip.
	When would you do this? (lamp)
3	Immediately, on highway.
2	At next exit, or nearest service station.
4	In East Lansing.
11	After returning to Ann Arbor, after the trip.
	Which tire?
15	Right rear.
3	Right front. [incorrect location]
1	Left rear. [incorrect location]
1	[No response.]
	Which lamp?
14	Right front.
3	Right rear. [incorrect location]
1	Left rear. [incorrect location]
2	[No response.]

Figure 14. Dual message of worn tire and replace turn signal lamp warning and responses (continued).

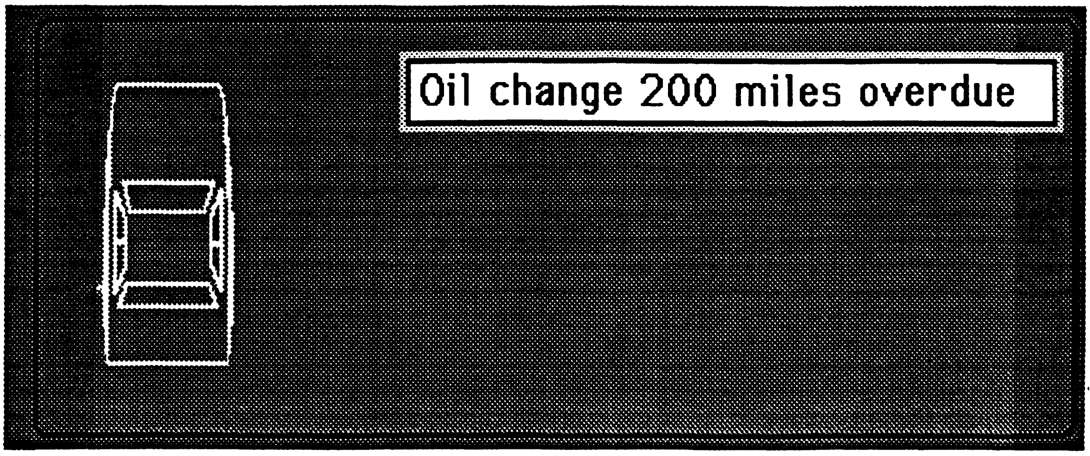
All drivers, except one, understood the meaning of the oil change needed 500 miles message. See figure 15. Interestingly, three drivers made comments about ignoring the message because they speculated this warning would be triggered by a timer (as opposed to an oil quality sensor). Likewise, in addition to the 3 who would ignore the message, 3 others said they would probably wait beyond the recommended 500 miles before changing the oil.



# responses	What does this mean to you?
16	Need to change the oil, in 500 miles.
1	Can't tell if it's due in 500 miles or was due 500 ago.
3	Means nothing, wouldn't consider it.. [Would ignore it.]
	What would you do about this?
16	Change oil.
4	Ignore message, or drive longer.
	When would you do this?
8	Before 500 miles.
6	In 500 miles.
3	Past 500 miles, up to 1000.
3	Ignore this message and use my own judgment.

Figure 15. Oil change needed 500 miles warning and responses.

Divers were more willing to respond quickly to the oil change 200 miles overdue message than to the message, oil change needed 500 miles. See figure 16. Except for the two participants who simply dismissed the oil change messages, all drivers would change the oil within the next few days.



Note: Text box border is yellow.

# responses	What does this mean to you?
18	Oil is really dirty, needs an oil change.
2	Means nothing, don't care. [Ignore.]
	What would you do about this?
18	Change oil.
2	Ignore for now.
	When would you do this?
10	Same day.
8	Within next few days.
2	Use my own judgment.

Figure 16. Oil change 200 miles overdue warning and responses.

All participants, except one, understood that a door and the trunk were open, or not fully closed for that warning. See figure 17. No follow-up questions were asked about which door. Despite the confusion with the car mimic orientation in the dual message (for headlamp and tire), no one said the front hood was open.

Note: Trunk and door icon are yellow.

# responses	What does this mean to you?
19	Trunk and door are ajar, or not closed securely.
1	Don't know.

Figure 17. Trunk and door open warning and responses.

Conclusions from Experiment 3

Conclusions from this research fall into two categories: general improvements to the warning monitor, and problems with specific warnings. With regard to general improvements, a few drivers had problems distinguishing the front from the back of the car mimic, and to a lesser extent the top from the underside. Drivers also did not realize that color coding was being used to indicate the seriousness of problems, though one driver did notice the exclamation mark for brake failure. Even when the seriousness was understood, drivers were reluctant to stop on the side of the highway. This may be attributed to personal safety issues (being struck by a car, robbery, etc.).

Finally, driver responses seemed to be influenced by their own experiences with monitoring systems. They do not seem to expect this system to be more intelligent than purely timer-based systems, systems with which they have had experience. These drivers were not given instruction on the accuracy of a system of this type, nor the criteria for warning presentation. (What does "Engine temperature near 'high'" mean exactly?)

The warnings listed in table 21 need further improvements.

Table 21. Warnings needing further improvement.

Q#	Message	Conclusions
3	Low oil pressure!	Drivers did not differentiate between oil *level* and oil *pressure.*
4 versus 5	Engine temperature near high versus High engine temperature.	Drivers did not distinguish the difference between an engine *nearing* high temperature, and one that has already reached a high temperature. The experimenters attempted to determine if a multimessage display of this type could give drivers the early-warning advantage of a gauge. This design was not effective in doing so.
8 versus 11	Antilock brake system failure versus Power brake failure!	Drivers did not distinguish clearly between the antilock brakes and the power brakes (especially the fact that power brakes are still available with antilock failure).
11	Power brake failure!	Most drivers did not realize the brakes would still be functional, but very difficult to press.
12	[Dual message.] Worn tire. Replace turn signal lamp.	One fifth of drivers had difficulty with this dual message, particularly in identifying the correct lamp and tire locations.
13 & 14	Oil change needed 500 miles. and Oil change 200 miles overdue.	A small number of drivers were reluctant (vehemently) to "believe" the accuracy of the system.

The purpose of a vehicle monitoring system is to help the driver avoid damaging the vehicle or causing an accident. In a sense, understanding of the message meaning is not as critical as when and how the driver will respond. For example, with low oil pressure, the vehicle will suffer permanent damage if the driver does not act immediately. In some circumstances, understanding the message may not be important if drivers respond in the desired manner. Misleading warnings, however, can alter the time when the driver would respond. As was found here, and has been reported previously, many drivers do not understand the basic workings of a car and it is therefore difficult to communicate what is wrong and what they should do.

OVERALL DISCUSSION

While there is considerable literature on the general topic of warnings, there is little specific research on automotive warnings, except for research on symbols. Evaluations of warnings in this context are needed.

The literature suggests that complex warning symbols for the functions of interest are unlikely to be understood by drivers. A warning system that relied upon text, supplemented by existing ISO symbols and a mimic, was developed. Because of the large number of candidate messages, standard structures were developed to present text. This makes the warning format consistent, thus improving understanding. Also, assuming drivers understand the automotive terminology being presented, each message does not need to be tested. However, as was shown here, there may be some exceptions to the message construction rules. (For example, the wheel alignment message is "wheel alignment service needed," while the word "service" is omitted in the tire rotation message.)

Drivers' knowledge of the operation and maintenance of their vehicles varied. National surveys of driver knowledge have not been conducted, though one previous UMTRI experiment provides some sense of what drivers know.[21] In general, drivers have some understanding of many messages, but it is unclear what level of understanding is sufficient, desired, and achievable. In part, informing drivers of problems with their vehicles is difficult because drivers don't understand either the purpose of components of interest or how they function. In some cases, this problem could be resolved by referring to a more general problem, to the system to which the component belonges, or to a related component. For example, only half the drivers knew the master cylinder was part of the brake system. By referring to a problem with the master cylinder as a brake problem, greater understanding, and hence compliance, would result. The drawback of this strategy is that simplifying or modifying the warning may be misleading or less useful to more knowledgeable drivers.

Another message wording issue emerged from the message structure study. In general, drivers' preferences were for messages that were command-oriented, especially for items that they are likely to fix themselves. That is, they wanted to be told what to do to remedy the problem, rather than simply being told about the problematic condition.

In the final experiment drivers responded reasonably well to messages. Where problems did occur, they were often linked to incomplete knowledge of the problematic system. (For example, some drivers believed the "Power brake failure" warning meant they would be completely unable to stop.) This experiment also revealed two weaknesses in the current interface design. First, a few drivers had difficulty with the orientation of the car mimic with regard to the headlamp and tire location. There was no confusion between the hood and the trunk, which was probably due to the door icon also on the screen. Presumably drivers would see the door icons often and learn the orientation of the car mimic. Second, drivers sometimes did not notice that the color of a warning indicated the seriousness of the problem. This is probably partly due to the use of printed cards as stimulus, since colors, like red, are darker and less noticeable in ink, but are bright and more prominent as light.

In spite of these difficulties, the warning system was reasonably effective in informing drivers of vehicle malfunctions. It must be emphasized that the research conducted here was precompetitive. The goal here was not to develop a product but to evaluate warning elements, such as the use of a message structure and the selection of a recommended vocabulary. Improvements to the mimic and further testing are desired before the warning system proposed could be incorporated into a production vehicle.

Appendix A - Vehicle Monitoring Design Overview / Assumptions

The preliminary design for the vehicle monitoring system consisted of a visual display with supplemental auditory output to attract the driver's attention. The visual display consisted of four 1-line text windows and an automobile mimic. Messages would be presented to drivers based on their urgency according to the rules that follow. A possible detailed priority scheme is in appendix D.

1. If the warning is frequently displayed for regularly occurring events (e.g., door open when entering or exiting the vehicle), it would be presented visually (on the mimic) and would flash until it is corrected. Due to text message space constraints and ease of displaying the message graphically, it would not be accompanied by a text message.

2. If the warning did not need to be attended to immediately, it would be presented in the text window (and also, if appropriate, on the mimic) with no accompanying auditory cue. Thus, it would not interfere with the primary task of the driver.

   An example of a warning in this category is low washer fluid level.

3. Each message would have an assigned priority that would be reflected in the color of an indicator around each message: red for highly critical, demanding immediate action on the part of the driver; yellow for less critical; and white for status or low criticality messages. The message bar will blink for 1 minute to indicate the most recent warning. When the driver looks to the display in response to an auditory cue and there are multiple warnings, it is easy to locate the new warning. For consistency and to accommodate the driver to the interface, the bar around the most recent message should flash for 1 minute, whether or not it is the only message currently displayed. For messages that require an ISO symbol (low oil pressure, battery warning), it would be displayed to the left of the text message and would be the same color as the border around the message.

3a. The light around the message originally was a rectangular light beside the message. This was inconsistent with messages that had an ISO symbol associated with them, since the symbol would have to be in place of the rectangular light.

4. If a warning demands immediate attention, the light around the message line would flash. The off-duty cycle would be short so that the driver would be more likely to glance at the display when the visual is on. Since the warning demands immediate attention, an auditory cue also would sound.

   An example of a warning in this category is low oil pressure.

5. If the warning demanded immediate attention and was something that rarely occurred, the driver would be alerted by a voice stating the warning in addition

to the visual display (text and mimic, if appropriate). Due to the intrusiveness of the voice warning and the urgency that it conveys, this warning should be carefully designed so as not to be triggered inappropriately.

An example of a warning in this category is engine fire.

6. If less urgent warnings are not heeded, they would be upgraded to more urgent warnings as the situation necessitated.

   When the vehicle was started and there were unattended warnings, of any urgency, on the monitoring system, the auditory alert would again sound to draw the driver's attention to the system.

Multiple warnings in the text window would be prioritized in the following manner:

1. For warnings of the <u>same urgency</u>, most recent warnings would appear at the top of the text window and older warnings would be moved down accordingly.
2. For warnings of <u>different urgencies</u>, those that are more urgent would appear at the top of the text window, and less urgent warnings would be moved down accordingly.
3. If there were more than four warnings, less urgent warnings would not be displayed (on the mimic or in the text window for warnings that contained both a mimic and text) while the vehicle is in operation. The next time the vehicle is started, however, the additional warnings would be displayed; the screen with four warnings would alternate with the screen containing the additional warnings.

Appendix B - Preliminary Scoring Key

1. What is an alternator for?
SAE Definition: (Electric Alternating Current (AC) Generator) "An electric a-c generator or alternator is a device which transforms mechanical power into alternating current electrical power (a-c) by means of a field structure for excitation and a generating winding."

Correct: Generates alternating current for running electrical system.
Charges battery.
Incorrect: Changing gears.
Selecting which spark plug to fire.

2. What happens if the alternator doesn't work?
Correct: Battery will run dead (in 45 minutes to an hour, ignition only).
Battery will have to power systems that alternator would normally power.
Incorrect: Car stops immediately.

3. What is special about antilock brakes?
SAE Definition: "A braking system that automatically controls the slip ratio of one or more wheels of the vehicle during braking."

Correct: Keep car from skidding when braking hard.
Keep wheels from locking up.
Incorrect: Provide theft protection for wheels and/or hubcaps.
Keep car from skidding on a turn.

4. What happens if the antilock brakes don't work?
Correct: Brakes will function as they would without antilock system.
Incorrect: Will lose all braking ability.

5. What is the battery for?
SAE Definition: "A DC voltage source which converts chemical, nuclear, thermal or solar energy into electrical energy."
Davis Definition: "Electrochemical device used to produce and store electrical energy in chemical form." A 12 volt, lead acid is the common battery type in cars. Battery is charged "by passing a direct electrical current through a battery in the reverse direction."

Correct: Supplying power to run the starter.
Supplying power to the ignition during starting.
Incorrect: Running the lights/air conditioner/fan/radio etc.

6. What happens if the brake fluid is too low?
Davis Definition: "Special hydraulic fluid used in a brake system to operate brake pads and/or shoes...When a brake pedal is depressed, brake fluid is pumped to brake cylinders at each wheel. They control brake lining movement against the friction surfaces being used. The amount of pedal pressure determines amount of fluid

pumped and thus the degree of braking action." When brake fluid is low the brake pedal moves farther before becoming firm, or the brake pedal feels spongy.

Correct: Air can enter the brake line and cause pedal to become "mushy."
Air can enter the brake line and make it necessary to push pedal farther before brakes will slow the car.
Brakes will eventually stop working.
Incorrect: Brakes will lock up.

7. What do fuses do?
SAE Definition: "A device designed to interrupt the electrical circuit when subjected to overcurrents. This action is to be nonreversible, and the fuse is intended to be replaced after the circuit malfunction has been corrected."

Correct: Protect electrical parts from too much current.
Incorrect: Generate electricity.

8. What happens if a fuse blows?
Correct: System with blown fuse will stop working.
Incorrect: Can start a fire.

9. Why does the engine oil need changing?
Davis Definition: "Delaying oil changes only shortens the life of affected moving parts. Contaminated oil accumulates fine metal particles, sludge, gasoline, water, etc., which can corrode metal parts and act like "liquid abrasive" quickly wearing out moving part surfaces. The small added expense of frequent oil change intervals pays for itself in longer engine life, smoother and/or minimal wear on moving parts, and cheaper rebuilding of affected parts."

Correct: It becomes contaminated.
Oil breaks down/deteriorates.
Incorrect: Oil level gets low.

10. What happens if the engine oil (the dipstick level) is too low?
Correct: Engine will not receive adequate lubrication on all parts.
Engine may seize.
Engine will heat up.
Incorrect: none determined.

11. What happens if the oil pressure is too low?
Davis Definition: "Pressure developed by oil after leaving an engine's oil pump. It is usually measured near the pump's output side. As a general rule of thumb, 10 pounds oil pressure for every 1,000 rpm is considered adequate for lubrication requirements when using the type of oil recommended by the manufacturer. A lower pressure indicates oil system problems."

Correct: Engine will not receive adequate lubrication on all parts.
Engine will seize.
Engine will heat up.
Incorrect: none determined.

12. What does the oxygen sensor do?
Davis Definition: "Sensor mounted on an exhaust manifold to determine oxygen content in exhaust gas. The sensor generates a voltage signal from the difference in atmospheric and exhaust gas oxygen content. Oxygen content rises as the fuel mixtures becomes too lean with the voltage signal dropping close to zero. The signal is sent to an on-board computer to control an engine's air/fuel ratio for most efficient combustion. If the ratio stays low (rich fuel mixture) for several minutes, it will usually send a signal to the on-board computer to illuminate a check engine type warning light."

Correct: Controls fuel/air mixture in engine.
Important to emissions quality.
Resides in the exhaust manifold.
Incorrect: Determines air quality of car interior.

13. What happens if the power steering fluid is too low?
Davis Definition: "Steering system built to use hydraulic pressure for minimizing steering wheel turning effort...Power steering units of today allow drivers to steer manually if the pump malfunctions or an engine is not operating."

Correct: It becomes difficult to steer (worse than manual steering).
Incorrect: Car will be completely unsteerable.

14. What do the struts do?
Davis Definition: (Strut rod) "It is used to strengthen the lower control arm and reduce vibration. Strut bushings are used at the car frame to allow some give in the rod. When they become worn, the front end may vibrate and/or generate clunking sounds during braking or turning."
Goodsell Definition: (MacPherson strut) "Telescopic independently sprung suspension member incorporating damper, and fixed at its upper end to the body shell or chassis, the lower end being located by linkages which counteract transverse and fore and aft movement. The original system used an anti-roll bar for longitudinal location. Usually incorporated in a steered front suspension system."

Correct: Combination shock absorber and link to the suspension.
Bears the side loads.
Incorrect: none determined.

15. What happens if the radiator fluid is too low?
Davis Definition: (Radiator) "Tank-like device mounted directly in front of an engine and used to transfer heat in engine coolant to the outside air by circulating coolant through finned tubes...The process of cooling the engine coolant begins when it flows from the top of the engine into the top radiator tank. There it spreads out the flows into the tubes. As the coolant flows downward, it radiates heat to the tube fins which lose heat to air

passing through them. Cooled water then flows into a lower tank for routing back to the engine via the water pump."

Correct: Engine will overheat.
Lose interior heat.
Incorrect: none determined.

16. What happens if the tire pressure is too low?
Davis Definition: "Tire condition created when a tire's air pressure is lower than recommended. It causes overflexing of tire sidewalls which builds up excessive heat, increases rolling resistance, and increases out tread wear. Heat is one of the primary destroyers of tires. A front tire with less pressure than its counterpart can cause: hard steering, pulling to one side, and road handling problems."

Correct: Tires wear faster.
Less fuel efficient.
Poor handling.
Increased risk of blowout.
Tires get hot.
Incorrect: none determined.

17. What happens if the tires are very worn?
Correct: Poor traction (on wet roads and snow).
Increased risk of blow-out.
Incorrect: Poor traction on dry roads.

18. What does wheel alignment refer to?
Davis Definition: "Relationship exhibited by a car's wheels to each other and a road surface when straight and turned. Since rear wheels are fixed, most alignment adjustments are made to front wheels. Properly aligned wheels permit a car to steer a true course with the least effort and reduce tire wear to a minimum. Correct front wheel alignment is achieved when the proper relationship between the suspension system, steering system, and wheel alignment angles exists."

Correct: Front wheels point in the same direction.
Camber (wheel tilt) is adjusted correctly.
Steering wheel straight and front wheel straight are the same.
Incorrect: Whether front wheels and back wheels line up with each other.

19. What happens if the wheels are not aligned?
Davis Definition: "Condition created when front wheels do not track properly when a car is driven."

Correct: Car will not drive straight on its own.
Car will try to veer to one side.
Tires wear quicker.
Gas mileage goes down.
Incorrect: none determined.

20. What does the master cylinder do?
SAE Definition: "The primary unit for displacing hydraulic fluid under pressure in the brake system."
Davis Definition: "Device used in a hydraulic brake system to store brake fluid and force it to wheel cylinders when a brake pedal is pushed."

Correct: Pressurizes brake fluid.
Incorrect: Provide spark/fuel/air for rest of cylinders.
The primary cylinder in the engine.

21. What is the clutch for?
SAE Definition: (Manual clutch) "A clutch which must be disengaged by the operator to prevent engine stalling when the vehicle's forward motion is stopped."
Davis Definition: "Assemblage of components used to engage or disengage power from [an] engine to a transmission...A manually operated clutch is used only on manual transmission cars."

Correct: Disengages engine from rest of drive system to make gear changing possible on manual transmission car.
Disengages engine from rest of drive system to make stopping without stalling possible.
Incorrect: Helping to stop the car.

22. What does the transmission fluid do?
Davis Definition: (oil (automatic transmission)) "Oil formulated for use in an automatic transmission and torque converter." (transmission (automatic)) "Transmission built to automatically make gear changes according to varying road and load conditions. Primary components include: a fluid coupling (torque converter); one or more planetary gear sets with associated drum, brake band, and clutch; mainshaft; and fluid control parts. Each gear set is controlled through fluid pressure which regulates brake band clamping and engages or disengages a respective clutch."

Correct: (On automatic cars:)
Lubricates gears.
Working hydraulic fluid in fluid coupling.
Incorrect: none determined.

23. What do shock absorbers do?
SAE Definition: "A device to control suspension motions by producing reactive forces that are functions of velocity and position."
Davis Definition: "Hydraulic mechanism used to dampen the up and down movement of a spring. A shock absorber is installed near a spring at each wheel location. There are different types, but they all serve the same purpose." (shock absorber action) "Operation of a shock absorber. Shock absorbers are installed to minimize sudden loading and unloading demands made on a cars' suspension springs. In so doing, they minimize wheel bounce."

Correct: Provide damping.
Incorrect: Provide spring support of car.

24. What does the catalytic converter do?
SAE Definition: "An assembly, including such major components as a structural shell, substrate, and the catalyst material. Depending on the type of catalyst - oxidation, reduction, or dual - this assembly decreases HC and CO emissions, or NOx emissions, or all three of these exhaust pollutants."
Davis Definition: "Small muffler-like device installed in an exhaust system ahead of the muffler, and designed to use heat and chemical changes to reduce the harmful emissions of automobile exhaust. Hydrocarbons and carbon monoxide are converted into water vapor and carbon dioxide, and NOx emissions are kept low."

Correct: Part of exhaust system, reduces harmful emissions from engine.
Burns up (oxidizes) harmful emissions from engine.
De-oxidizes harmful emissions from engine.
Incorrect: Changes leaded fuel into un-leaded fuel.
Does anything on the engine air intake.

25. What is the accessory drive belt for?
Davis Definition: (drive belt) "V-shaped belt used to transfer power from one shaft to another by means of pulleys. Common drive belts are fan and air conditioning belts."

Correct: Powers any high load systems directly off the engine.
Runs the air conditioner, power steering, alternator, (water pump, fan, air pump).
Incorrect: Back-up drive belt.

Appendix C - Ranked Information Elements and Possible Text Messages

The information elements in tables 22 through 28 are grouped by category and are listed with their ranking from the Task D vehicle systems monitor matrix. With each information element is a list of possible warning messages.

Table 22. Possible warning messages for immediate attention necessary, driver understood, unscheduled maintenance problems.

Rank	Information Element	Possible messages
14	Engine temperature	high engine temperature hot engine engine overheating engine is overheating engine overheated
20	Oil pressure	low/high engine oil pressure poor oil circulation - fatal fatal lack of oil pressure engine seizure imminent
22	Oil change	unscheduled oil change needed oil change needed now
21	Oil pump failing	oil pressure getting low
23	Oil level	low oil level add engine oil (10W-40) high engine oil level too much engine oil engine oil level (too) high excess engine oil excessive engine oil drain (some) engine oil

Table 23. Possible warning messages for a problem status report, where attention is critical, and which the driver is expected to correct.

Rank	Information Element	Possible messages
24	Doors open	no message
*	Fuel door open	no message
25	Hood open	no message
26	Trunk/Hatch open	no message

*Element not ranked in earlier task.

Table 24. Possible warning messages for an unscheduled maintenance problem which the driver is expected to correct.

Rank	Information Element	Possible messages
3	Tire pressure	low/high tire pressure
8	Engine coolant level	low engine coolant low radiator fluid radiator fluid (too) low add radiator fluid
12	Brake fluid level	low brake fluid (level) add brake fluid brake fluid level (too) low (additional) brake fluid needed
15	Low fuel warning	low fuel get gas
*	Oil level getting low	getting low on oil oil level getting low oil level down 1/2 quart
35	Washer fluid level	low washer fluid

*Element not ranked in earlier task.

Table 25. Possible warning messages for a scheduled maintenance problem the driver is expected to understand.

Rank	Information Element	Possible messages
13	Tire rotation needed	periodic tire rotation [required] regular rotate tires have tires rotated
48	Oil change	periodic/normal/regular oil change

Table 26. Possible warning messages for the driver's information.

Rank	Information Element	Possible messages
33	Fuel quality indicator	bad fuel/gasoline/gas/petrol (some) water in fuel fuel octane too low low fuel octane

Table 27. Possible warning messages for an unscheduled maintenance problem the driver is not expected to understand.

Rank	Information Element	Possible messages
16	Suspension health	poor suspension health check shock absorbers check shocks problem with: suspension suspension maintenance required
31	Engine coolant quality	poor engine coolant quality poor radiator fluid quality radiator fluid contaminated oil in engine coolant add anti-freeze to radiator radiator maintenance required
34	O_2 sensor health	faulty/defective/broken/bad oxygen sensor fuel injection system maintenance engine computer sensor fuel economy sensor
39	Steering fluid level	low (power) steering fluid level power steering fluid low add power steering fluid
40	Alternator maintenance	battery is being drained drain on battery car may not start next time (alternator) problem with alternator have alternator repaired
41	Battery current	low/high battery current battery maintenance (required)
42	Battery voltage	low/high battery voltage battery maintenance (required)
44	Drive belt loose	adjust drive belt tighten drive belt drive belt loose
46	Fuel pump shutoff	fuel shutoff fuel cutout

Table 28. Possible warning messages for an unscheduled maintenance problem the driver is expected to understand.

Rank	Information Element	Possible messages
1	Turn signal lamps	turn signal lamp [burned]out turn indicator bulb [burned] out blinker bulb [burned] out
2	Tire wear level	excessive tire wear worn out tire worn tire thin tire tread tire is worn
4	Brake lamps	brake lamp [burned] out brake bulb [burned] out
5	Tail lamps	tail lamp [burned] out presence bulb [burned] out tail light [burned] out rear lamp [burned] out
7	Brake maintenance	excessive brake wear worn brakes
9	Head lamps	head lamp [burned] out head light [burned] out bulb [burned] out
30	Transmission	transmission maintenance [required] gear box repair/fault/fix/service get transmission fixed
43	Catalytic converter health	emissions system repair replace catalytic converter catalytic converter needs replacement
*	Engine knock indicator	tune-up required (engine knock) engine misfiring
45	Engine timing	tune-up required (engine timing) timing adjustment needed
47	Fuse status	fuse (#) burned out (<system name>) <system name> fuse is out (#)
49	Bright head lamps	high beams [burned] out brights [burned] out
50	Fog lamps	fog lamp [burned] out

*Element not ranked in earlier task.

Appendix D - Prioritization of Messages

The prioritization of messages is shown in table 29.

Table 29. Maintenance problem priority.

Priority level 1:	Scheduled maintenance items that have just become due. How far ahead of the actual maintenance due date the item should appear is a question. (For testing purposes, it is 500 miles.)
Priority level 2:	Driver maintenance items of little immediate criticality (washer fluid, add oil, add radiator fluid). This priority is, of course, based on the assumption that the warning appears early in the criticality (e.g., being one pint of oil low is minor). The driver could be informed at this point as opposed to the system waiting until the quart low mark when the message would become of higher priority.
Priority level 3:	Unscheduled maintenance items.
Priority level 4:	Driver immediate attention and action items, such as low oil pressure.
Priority level 5:	Driver and occupant critical safety items, such as engine fire.

The vehicle monitoring warnings associated with each level of message priority is shown in table 30.

Table 30. Warning message priority.

Level 1:	No tone at first appearance, tone at engine start-up. No color bar around message (bar turns yellow if ignored for period of time, then red if ignored longer).
Level 2:	No tone at first appearance, tone at engine start-up. No color bar around message (bar turns yellow or red if situation worsens, i.e. one pint low on oil becomes one quart).
Level 3:	Tones at first appearance and engine start-up. Red bar around message. (Bar flashes if ignored for a period of time, or beeps to convey the severity of the problem.)
Level 4:	Tones and flashing red bar at first appearance.
Level 5:	Flashing red bar and speech.

If a scheduled maintenance item is ignored it moves up in priority level based on current miles relative to the actual miles at which maintenance is due.

If a driver maintenance item is ignored it moves up in priority level based only on increasing need for the maintenance.

If an unscheduled maintenance item is ignored the only recourse is for the system to become very annoying by beeping periodically or even adding speech.

The countdown timer beside the message indicates total miles until scheduled maintenance is due or total miles maintenance is overdue.

Possibly the easiest way to handle list prioritization is to give each item an internal priority number, say from 1 to 100 (100 highest priority) for each level of priority. For example:

Transmission maintenance (unscheduled)
- first appearance: 80
- ignored for 300 miles: 85
- ignored for 600 miles: 90 etc.

Oil change (scheduled)
- 500 miles from due: 5
- 200 miles from due: 20
- due: 30
- 200 miles overdue: 35
- 500 miles overdue: 50
- 1000 miles overdue: 60 etc.

The appearance of the yellow and red LEDs and the addition of tones or speech can then be assigned numbers.

e.g., Yellow LED at priority level 55
Red LED at priority level 75
tones and/or flashing at priority level 90
speech at priority level 95

Items are listed in the service window in order of decreasing priority and are re-ordered upon a change in priority of an item.

Appendix E - Experiment 2 Message Structure Study Form

Warning Messages for an Automobile Systems Monitor

Prepared by:
Marie Williams
Paul Green, Ph.D.

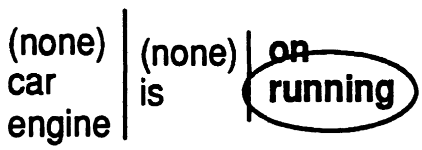
INSTRUCTIONS

We are designing a monitoring system for cars of the 21st century. Since you will be driving those cars, we want you to tell us how the instrument panel should be designed.

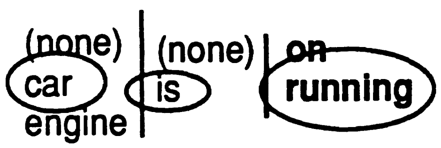
For example, suppose the car was so quiet you couldn't tell when it was running. A message on the instrument panel might use some of the following words:

(none)	(none)	**on**
car	is	**running**
engine		

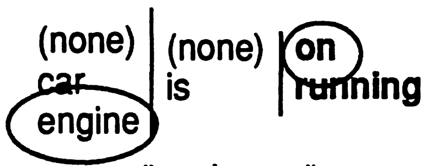
Circle the words that you would want in the message. For example, if you thought the message should be "running" then do this:



Some other possibilities are:



"car is running"



"engine on"

You must use one word from the **bold** column.

If you think of a word you prefer over those in a column, write it in on the line below that column.

1)

(None)	**accessory drive belt**	(none)	(none)
New		loose or worn	desired
Replace		maintenance	necessary
______		repair	needed
		service	required
		______	______

2)

(None)	**brake fluid**	(none)
Add		bottle
Add more		needed
Add some		reservoir
Low		tank
Refill		______
Replenish		
Running out of		
______		

3)

door	(none)
	ajar
	not closed
	open
	unlatched
	______

4)

(None)	**fuse**	(none)
New		burned out
Replace		desired
______		necessary
		needed
		required
		______

5)

(None)	**headlamp**	(none)	(none)
New	**headlight**	burned out	desired
Replace		maintenance	necessary
______		out	needed
		repair	required
		service	______
		______	

6)

(None)	(none)	**oil**
Add	engine	
Add more		
Add some		
Low		
________		

7)

(None)	**shock or strut**	(none)	(none)
New	**suspension**	maintenance	desired
Replace		repair	necessary
________		service	needed
		worn	required
		________	________

8)

(None)	(none)	**washer**	(none)	(none)
Add	windshield		fluid	bottle
Add more			liquid	needed
Add some			solvent	reservoir
Low			________	tank
Refill				________
Replenish				
Running out of				
________				

9)

(None)	**wheel alignment**	(none)	(none)
Improper		service	desired
Poor		________	necessary
________			needed
			required
			________

Appendix F - Experiment 3 Biographical Form

Vehicle Monitoring Systems Biographical Form Subject: [ ]

Date: [ ]

Name:____

Male Female (circle one) Age:______________

Occupation: ______________________________________

Retired or student: Note your former occupation or major

Education (circle highest level completed):

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

What kind of car do you drive the most?

Year:_________ Make:__________________ Model: ___________

Approximate yearly mileage: _________________

How often do you use a computer? (circle one)

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

Appendix G - Experiment 3 Procedure

Hi, I'm _______ and I'm with the University of Michigan Transportation Research Institute. Currently we're doing a study on a vehicle monitoring system. Would you be interested in answering a few questions and giving us your input on this system?

(if yes)
Great. This vehicle monitoring system would be an electronic display on the dashboard that would tell you about the status of parts of your car.

I'll be showing you some sample pictures from this system one at a time, and asking you some questions about them. (Keep in mind there are no wrong answers, I'm just interested in your opinions.) You should consider each of these pictures individually. In other words, they aren't related to each other.

Here's a scenario that I'd like you to keep in mind:

> **I want you to envision that it's 5 to 10 years in the future. You're driving by yourself in your 1 year-old sedan to meet a friend in East Lansing, 1 hour away. It's around 2 PM on a nice fall day, and you're driving alone on the expressway. You just left your home in Ann Arbor 5 minutes ago.**

This message comes up on your Vehicle Monitoring System. (show first card)

1. **First of all, what do you think it is supposed to be telling you?**

2. **What would you do about it?**

3. **In terms of your trip, when would you do this?**

(Plus any additional questions...)

(Continue for all 13 questions until done. Then ask participant to complete biographical form, and thank the participant.)

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