Preliminary Human Factors Guidelines for Automated Highway System Designers (Second Edition)

VOLUME I: GUIDELINES FOR AHS DESIGNERS

Submitted to
Research and Development
Turner-Fairbank Highway Research Center
Federal Highway Administration
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FOREWORD

This is the first volume of a two-volume report. The report presents the results of a comprehensive examination of human factors considerations related to the human-centered design of Automated Highway Systems (AHS). The results are shown as preliminary guidelines that AHS designers may utilize to maximize the effectiveness and efficiency of system performance, ensure a high level of system safety, and to improve user acceptance. These guidelines were compiled from material pertinent to AHS in existing handbooks, guidelines, human factors engineering texts and articles, as well as analyses in the current research projects in this effort. This report will be of interest to all AHS designers involved in such activities as specification of functional requirements, determination of interface philosophy, selection of controls and displays, design of controls and displays, design of driver-system dialogues, and design of driver workspace.

Sufficient copies of the report are being distributed to provide a minimum of two copies to each FHWA regional and division office, and five copies to each State highway agency. Direct distribution is being made to division offices.

A. George Ostensen, Director
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Research and Development

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16. Abstract

Human factors can be defined as "designing to match the capabilities and limitations of the human user." The objectives of this human-centered design process are to maximize the effectiveness and efficiency of system performance, ensure a high level of safety, and maximize user acceptance. These objectives are achieved by systematically applying relevant information and principles about human abilities, characteristics, behavior, and limitations to specific design problems This handbook provides a source document for automated highway system (AHS) designers that will facilitate a human-centered design process for the AHS. It is the second edition of these guidelines (first edition is report RD-94-116) and includes the addition of key AHS attributes proposed by the National Automated Highway System Consortium, updates to the chapter on general guidelines for electronic visual displays, and the addition of several operational guidelines (chapter 10).

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yards	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
NOTE. Volumes greater than 1000 l shall be shown in m^3				
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5(F-32)/9 or (F-32)/1.8	Celcius temperature	°C
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.71	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1 103	short tons (2000 lb)	T
		TEMPERATURE (exact)		
°C	Celcius temperature	1.8C + 32	Fahrenheit temperature	°F
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

* SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380.

(Revised September 1993)

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Part I: Introduction

Why Human Factors?

A considerable amount of information about the effects on performance of vision, hearing, anthropometrics (body measurement data, both static and dynamic), user characteristics (age, gender, etc.), and the environment exists in the literature, and systems that are designed to integrate human capabilities and limitations into the design have a reduced potential for human error, improved system performance, and reduced training costs. Nevertheless, this information typically does not drive the design of systems or even influence system design decisions, despite evidence that the high incidence of human error in system operation is a direct function of the extent to which the system was designed without consideration of the personnel who use and maintain it.[(1)] There are at least two potential reasons for this failure to use the human factors literature in the system design process:

- The common misconceptions that humans are sufficiently flexible to compensate for design inefficiencies, that the system will compensate for the effects of personnel deficiencies, and that good engineering practice already considers the role of the human, and therefore no specialized human factors knowledge is necessary.[(2)]
- System designers and engineers are in fact rarely even exposed to this type of information. A recent study that examined over 200 engineering textbooks, publications, and handbooks published over the nearly 50-year period from 1938 to 1987, revealed that less than 21 percent of the documents had any mention of design issues involving human factors, or had any mention of human engineering issues.[(3)] Where they were mentioned, in many cases consideration of human factors issues was limited to one- or two-paragraph overviews.

Human factors is concerned with applying scientific data and principles of human performance to the design of systems and elements within those systems (e.g., controls, displays) to match the capabilities and limitations of the human user. The objectives of this human-centered design process are to maximize the effectiveness and efficiency of system performance, to ensure a high level of safety, and to maximize user acceptance. These objectives are achieved by systematically applying relevant information and principles about human abilities, characteristics, behavior, and limitations to specific design problems. The objective of this handbook is to provide a source document for automated highway system (AHS) designers that will facilitate a human-centered design process for the AHS.

It is to be noted that this is a preliminary handbook. Specifically in the area of operational guidelines (chapter l0), substantially more research and analysis will be required to confirm the validity of the guidelines presented and to develop additional guidelines.

The System Design Process

Figure 1 shows the major steps involved in the system design process, and table 1 shows where the relevant information for AHS design can be found.

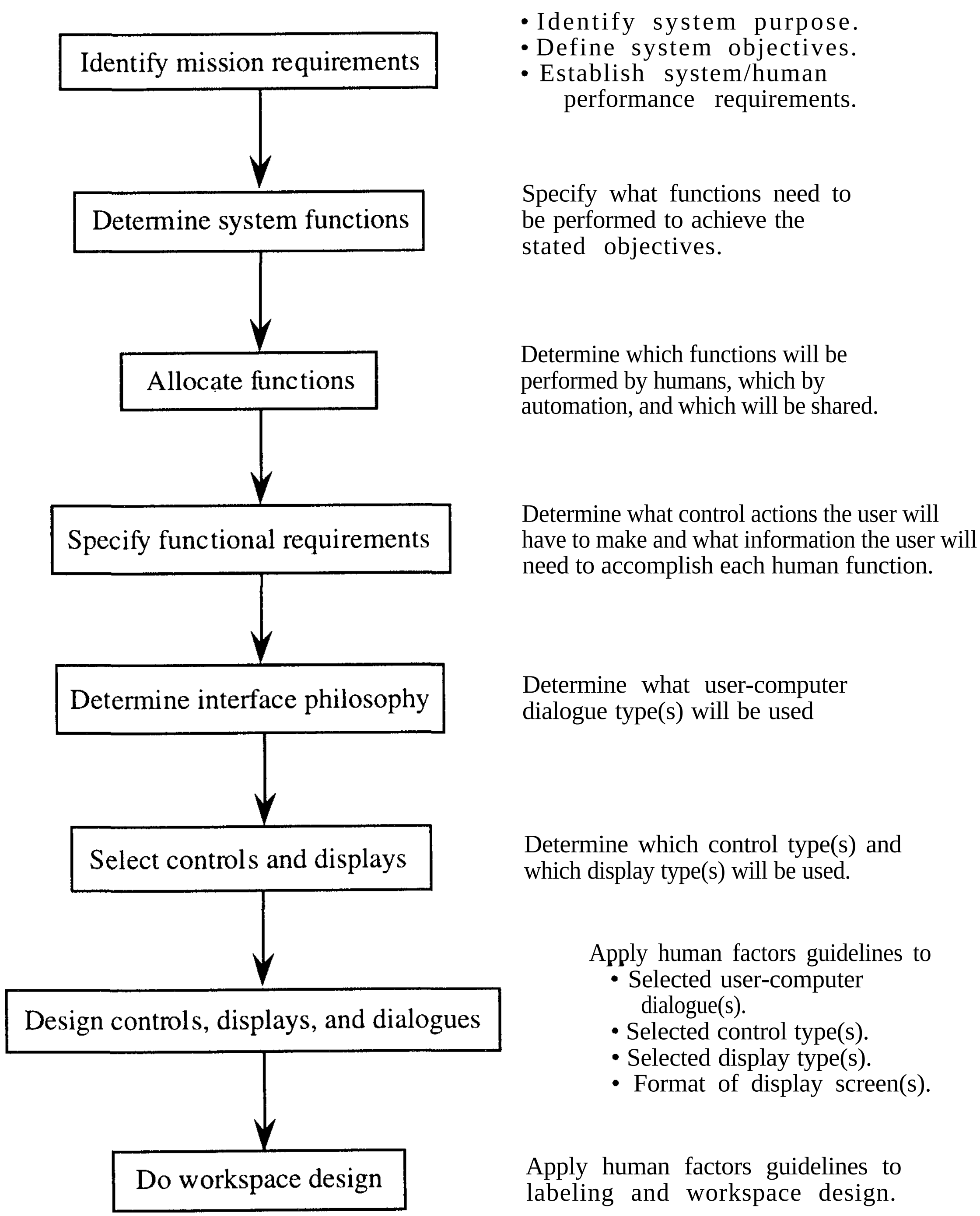

Figure 1. Major steps in the system design process.

- Identify mission requirements. The objectives of a system are not always well defined, and this can lead to inadequate or inappropriate design solutions. Specific information regarding system and human performance objectives, established during this step, will be used to evaluate the success of the final design.
- Determine system functions. A functional analysis indicates what capabilities the system must have to meet its objectives, but does not specify which agent will perform the function (the human or the automation) or how the function will be implemented. For the AHS, several scenarios were first developed to provide different frameworks that might satisfy the overall objectives of the automated highway system.[4] These scenarios show how the mission requirements might be accomplished given alternative designs varying in levels of automation and highway configuration (separation of automated traffic from manual traffic, grouped vs. individual vehicles, etc.). Analysis of the scenarios led to the development of a list of functions needed to support the various activities included in them.
- Allocate functions. The allocation of functions involves, in general, two activities: assessing the relative abilities of the human and the automation to perform each function, and assessing the workload associated with each function to ensure that acceptable performance is achieved. Based on these considerations, each function is assigned to the automation or to the human (or it might be recommended that responsibility for some functions be shared). (It should be noted that other factors, like cost, might influence the allocation decision; the method presented is based only on human factors considerations.) Since there are different visions of what the AHS might look like (i.e., the scenarios), the allocation of functions may differ across those visions. For example, a scenario that envisions an early implementation of an AHS might allocate lane changing to the human, while a scenario that envisions a later implementation might allocate that same function to the automation. In any case, data on human vision, audition, cognitive processing, information storage, reaction time, and the like must be examined to ensure that the proposed allocation is compatible with human capabilities and limitations.
- Specify functional requirements. This entails describing at a high level what control actions the user will have to make and what information he/she will need to accomplish each of the functions allocated to the human. These requirements are specified at a level that neither demands particular control or display choices nor excludes particular control or display choices.
- Determine interface philosophy. At this step, a decision is made as to how, in general, the user will interact with the system. This choice is made from a variety of dialogue types (e.g., menu selection, command language) and is based on such things as whether the user is considered to be casual or expert and how much training the user can be expected to have.
- Select controls and displays. The first activity is to define the human task sequences. For the AHS, the tasks might include steering, adjusting gap size, inputting a destination, and the like. For each task, the initiating condition(s), the cognitive component, and the outcome(s) are specified. The specific information that the user will need and the specific controls he/she will require to accomplish

each task are identified during this step. For example, if the user is going to steer his/her vehicle into an adjacent lane, he/she will need to know what the environmental conditions are, what the traffic conditions are, at what speed his/her vehicle is traveling, whether there are potential obstacles in the lane, and so on. Some of this information will come from direct observation, while other information (e.g., on obstacles) may come in part from onboard sensor systems' annunciations on a head up display. On the control side, the driver will use the turn signal indicator, steering wheel, brake, and accelerator to effect the change. For other functions/tasks (e.g., specifying one's destination), more of the information will be provided by AHS-specific displays in the vehicle, and more of the control actions will be accommodated by AHS-specific controls. Choices of controls and displays are made in part based on "when to use" information such as that provided in this handbook.

- Design controls, displays, and dialogues. In this step, human factors guidelines are applied to the specific display type(s), control type(s), and user-computer dialogue type(s) selected for the particular AHS implementation, as well as general guidelines for user-computer interactions. These guidelines can be found in this handbook.
- Do workspace design. This involves determining the specific locations of displays and controls so as to produce an appropriate workflow within the physical constraints imposed by the workspace, as well as determining the dimensions of the workstation so as to accommodate the physical characteristics of the user population. In addition, principles about labeling, color use, functional grouping, and the like are applied during this step to ensure an interface that matches the capabilities and limitations of the user population. Again, the applicable guidelines can be found in this handbook.

Although the process has been shown and discussed as if it were linear, it is in fact typically not. Rather, there are often modifications to earlier steps as the design team gains information from later steps, and the final design is the evolutionary product of often-significant iteration of the system design steps. Following the design process, there is typically a test and evaluation phase during which the design is subjected to critical analysis-perhaps in some combination of simulator and road tests-to determine whether it in fact meets the stated requirements.

Table 1. Where to find information needed for AHS design.

System Design Process Step (see figure 1)	Where to Find the Information
Identify Mission Requirements	First-generation scenarios from this contract and from the National Automated Highway System Consortium.[4,5]
Determine System Functions	Preliminary definition of AHS functions from this contract.
Allocate Functions	Allocation of AHS functions from this contract. *(Table continued on next page.)*

Table 1. Where to find information needed for AHS design (continued).

System Design Process Step (see figure 1)	Where to Find the Information
Specify Functional Requirements	For preliminary information and control requirements, user-system transactions in volume II of this handbook; for detailed information and control requirements, task analysis from this contract.
Determine Interface Philosophy	For when to use the user-computer dialogue types discussed in this handbook, guidelines 432, 448, and 472.
Select Controls and Displays	For when to use the control and display types discussed in this handbook. tables 39 and 42.
Design Controls, Displays, and Dialogues	For guidelines on controls, chapters 3 and 4; for guidelines on displays, chapters 5 and 6; and for guidelines on user-computer dialogues, chapter 9.
Do Workspace Design	For reach distances, chapter 2, for workspace design, chapter 7; and for labeling, chapter 8.

Applying the Guidelines

In the literature, guidelines are often either too general or too specific, and as a consequence need to be adapted by the designer to a particular situation. Every effort has been made in this handbook to select, for a given topic area, only those guidelines that apply to the AHS, and to ensure that guidelines are worded so as to apply specifically to the AHS (by removing references that are clearly irrelevant for the AHS and/or by using the appropriate data to make a general guideline into an AHS-specific guideline). In addition, where original guidelines have been written, they have been written to be AHS specific.

Although the intent is for these guidelines to be applied early in the design process (see figure l), they can also be used to evaluate alternative system designs. When used as an evaluation tool, they can ensure AHS component systems conform to established principles, and can expose problem areas simply and quickly. This type of feedback can help AHS designers determine how existing or proposed designs may be improved or modified.

Structure of the Rest of the Handbook

There are two volumes to this handbook:

- Volume I, part II provides the human factors guidelines for controls and displays to be used on the AHS, and is divided into several chapters:
  - Chapter 1 provides an introduction to user-system transactions. These show the control actions the user will have to make and the information that will have to be provided to allow the user to carry out each activity on the automated highway system. These transactions form the foundation for an analysis of specific screen content and specific control types to be used on the AHS to accomplish each function.

- Chapter 2 shows the characteristics of the AHS user population along various dimensions (e.g., audition, vision). These data were used where appropriate to tailor guidelines to the automated highway system.
- Chapter 3 provides guidelines that are applicable to controls in general.
- Chapter 4 provides specific guidelines for each type of control selected for inclusion in the handbook. This chapter includes guidelines on the prevention of accidental actuation of controls.
- Chapter 5 provides guidelines that are applicable to electronic displays in general.
- Chapter 6 provides specific guidelines for each type of display selected for inclusion in the handbook.
- Chapter 7 provides guidelines for designing workspaces.
- Chapter 8 provides guidelines for the labeling of controls and other workspace elements.
- Chapter 9 provides guidelines for the user-computer dialogue types that were selected for inclusion in the handbook, and guidelines for system responsiveness to user commands.
- Chapter 10 provides operational guidelines derived from the comparable systems analysis and from experiments conducted as part of this contract. (5,6)
- Appendix A discusses how the controls for which guidelines have been written were chosen from among the larger group of possible controls.
- Appendix B discusses how the display types for which guidelines have been written were chosen from among the larger group of possible display types.

- Volume II shows complete user-system transactions. For the various phases of entering, driving on, and exiting the AHS, the conditions that initiate a driver action, the processing the driver does on that information, and the driver’s responses are provided.(4)

Part II: Guidelines for Controls and Displays for Use on the Automated Highway System

Chapter 1. Introduction to the User-System Transactions

In volume II of the handbook are high level transactions between the user and the system for various phases of AHS driving for each of three scenarios.[4] These transactions show the input to a driver action, how the driver processes the input, and the driver's response to the input (i.e., the output of the transaction). The present chapter is an introduction to those transactions.

Overview of an Automated Highway System

Although there are many visions of what the automated highway system will be like, they share many features in common. The central concept is for an automated system(s) to control some aspects of the driving task, typically steering, braking, and accelerating. In addition, depending upon the level of automation, the system will provide either a collision warning so the driver can take evasive action, or will do automated collision avoidance. In projected early implementations of the automated highway system, all automated control will reside solely on the vehicle. In later implementations, automated control will reside on the vehicle, and a roadside system will coordinate the activities of all vehicles on the system.

Seven visions, or scenarios, have been formally developed as part of this contract to define the human factors aspects of the automated highway system. The National Automated Highway System Consortium (NAHSC) has taken a different approach, choosing to identify key attributes of an AHS rather than defining specific scenarios. Brief descriptions of the scenarios and key attributes are presented in the subsections that follow.

AHS Scenarios Developed for This Contract

- Free Agency/Self-Contained. All control systems are on the vehicle, which will allow automated collision warning/avoidance, speed control, and lane tracking. Lane changing will be done manually. Mixed manual and automated traffic will be in all lanes. Navigation will not be done by the AHS.
- No Barriers on the Highway with Individual Vehicles. The roadside system will set minimum gaps and maximum speeds for each vehicle, and coordinate activities among vehicles. Lane keeping, collision avoidance, and navigation to a driver-selected destination will be located on the vehicle. A transition lane will separate manual from automated lanes, and will be used to transfer control from the driver to the AHS prior to entry to an automated lane and from the AHS to the driver after

exit from an automated lane. Lane selection will be by the driver; the lane change will be executed by the vehicle when commanded by the roadside system.

- No Barriers on the Highway with Grouped Vehicles. This is essentially the same as the immediately preceding scenario, with the difference being that maneuvers in an automated lane will be by groups of vehicles rather than individual vehicles. The roadside system will coordinate group activities.
- Barriers on the Highway with Individual Vehicles. A transition lane will separate manual from automated lanes, and will be used to transfer control from the driver to the AHS prior to entry to an automated lane and from the AHS to the driver after exit from an automated lane. Barriers with gaps between them will separate the transition lane from the automated lane, and. will separate automated lanes. The roadside system will set minimum gaps and maximum speeds for each vehicle; the vehicle will do lane keeping, collision avoidance, and navigation to a driver-selected destination. Lane selection will be by the roadside system, with the vehicle executing the change.
- Barriers on the Highway with Grouped Vehicles. This is essentially the same as the immediately preceding scenario, with the differences being that vehicles will enter and exit automated lanes in groups, and maneuvers in an automated lane will be by groups of vehicles rather than individual vehicles. The roadside system will coordinate group activities.
- Segregated Highway with Individual Vehicles. Automated lanes will be physically separated from manual lanes; there is no transition lane in this scenario. Entrance to an automated lane will be via an automated entrance ramp. The roadside system will set minimum gaps and maximum speeds for each vehicle, while the vehicle will do lane keeping, collision avoidance, and navigation to a driver-selected destination. Lane selection will be by the roadside system, with the vehicle executing the change.
- Segregated Highway with Grouped Vehicles. This is essentially the same as the immediately preceding scenario, with the differences being that vehicles will enter and exit automated lanes in groups, and maneuvers in an automated lane will be by groups of vehicles rather than individual vehicles. The roadside system will coordinate group activities.

Key AHS Attributes Identified by the National Automated Highway System Consortium

The National Automated Highway System Consortium has identified six key attributes of an automated highway system:

- Dedicated lanes only or mixed traffic operations. With dedicated lanes, a continuous barrier would separate the automated traffic from the manual traffic.
- Deployment sequence and timing. Starting with adaptive cruise control-which would maintain both a set speed and a set intervehicle gap-and warning systems,

the issue is then how deployment would continue: would it be by dedicating a lane for fully automated vehicles, by adding capabilities toward full automation in mixed traffic, by dedicating a lane for use by partially automated vehicles, or in some other way?

- Distribution of intelligence and communication links. The key questions are where the decisions are made (e.g., by each vehicle independently, by vehicles sharing information with each other, by an intelligent roadside system) and "who" communicates information to "whom."
- Automated travel by individual vehicles or by groups of vehicles.
- Obstacle detection/avoidance or exclusion. To exclude obstacles from the roadway, barriers, fences, and the like would be constructed, and perhaps the roadway would even be covered to exclude airborne obstacles.
- Driver role when the vehicle is under automated control. Possibilities include allowing the driver to override automated control at any time, allowing the driver to override automated control under some conditions, and not allowing the driver to override automated control except in an emergency.(7)

Elements of a Transaction

An example transaction is shown in table 2. In that transaction, the driver decides to request an immediate exit from an automated lane. The generic features of transactions illustrated by the example are as follows:

- The transaction starts with information provided by the system.
- There is a "give and take" between the user and the system. The user performs some control action based on the system's input. In turn, the system provides new information, which is typically the precursor to further action by the user. The information provided might concern vehicle and/or system status (e.g., notification that an exit is closed due to an accident), a request for driver action (e.g., to confirm the driver's previous response), some type of alarm, or other information.
- There is often branching, where a given input can lead to multiple possible outputs (as shown in table 2) or where a given output can lead to multiple succeeding inputs.

Note also that the transactions do not indicate what specific controls are to be used, what specific information is to be presented, what display medium is to be used, how the information is to be formatted (including location on an electronic display surface, color use, etc.), and so on. Neither do the transactions exclude any particular control types, display media, and the like. Rather, they are written at a high level to show functionality and to form the basis for the next step in the design process.