Precursor Systems Analyses of Automated Highway Systems

RESOURCE MATERIALS

Automated Check-Out

U.S. Department of Transportation
Federal Highway Administration

Publication No. FHWA-RD-95-094
March 1995

FOREWORD

This report was a product of the Federal Highway Administration's Automated Highway System (AHS) Precursor Systems Analyses (PSA) studies. The AHS Program is part of the larger Department of Transportation (DOT) Intelligent Transportation Systems (ITS) Program and is a multi-year, multi-phase effort to develop the next major upgrade of our nation's vehicle-highway system.

The PSA studies were part of an initial Analysis Phase of the AHS Program and were initiated to identify the high level issues and risks associated with automated highway systems. Fifteen interdisciplinary contractor teams were selected to conduct these studies. The studies were structured around the following 16 activity areas:

> (A) Urban and Rural AHS Comparison, (B) Automated Check-In, (C) Automated Check-Out, (D) Lateral and Longitudinal Control Analysis, (E) Malfunction Management and Analysis, (F) Commercial and Transit AHS Analysis, (G) Comparable Systems Analysis, (H) AHS Roadway Deployment Analysis, (I) Impact of AHS on Surrounding Non-AHS Roadways, (J) AHS Entry/Exit Implementation, (K) AHS Roadway Operational Analysis, (L) Vehicle Operational Analysis, (M) Alternative Propulsion Systems Impact, (N) AHS Safety Issues, (O) Institutional and Societal Aspects, and (P) Preliminary Cost/Benefit Factors Analysis.

To provide diverse perspectives, each of these 16 activity areas was studied by at least three of the contractor teams. Also, two of the contractor teams studied all 16 activity areas to provide a synergistic approach to their analyses. The combination of the individual activity studies and additional study topics resulted in a total of 69 studies. Individual reports, such as this one, have been prepared for each of these studies. In addition, each of the eight contractor teams that studied more than one activity area produced a report that summarized all their findings.

Lyle Saxton
Director, Office of Safety and Traffic Operations Research and Development

NOTICE

TECHNICAL REPORT DOCUMENTATION PAGE

1. Report No.	2. Government Accession No.	3. Receipent's Catalog No.

4. Title and Subtitle Automated Check-out	5. Report Date
	6. Performing Organization Code
7. Authors L. Turan, P. Ioannou, M.G. Safonov, D. Smith, D. Damos	8. Performing Organization Report No.
9. Performing Organization Name and Address University of Southern California Center for Advanced Transportation Technologies Los Angeles, CA 90089-2562	10. Work Unit No. 11. Contract or Grant No. DTFH61-93-C-00196
12. Sponsoring Agency Name and Address Federal Highway Administration Turner-Fairbank Highway Research Center McLean, VA 22101-2296	13. Type of Report and Period Covered Final Report October 1993-October 1994 14. Sponsoring Agency Code

15. Supplementary Notes

16. Abstract

This report summarizes the research results in the Automated Check-out Activity Area. Situations in AHS where transition from automated to manual control takes place are analyzed. In particular, driver readiness testing to ensure safe and smooth transition from automated to manual control has been emphasized. We show that, by appropriate design considerations, driver readiness testing procedures can be created such that they measure driving performance directly, while they appear natural and reasonable to the driver. We present such a novel testing procedure which also ensures a safe, effective, and smooth transition from automated to manual driving mode. In this procedure, the authority of the automatic controller is gradually decreased, while the manual control authority is gradually increased. This gradual transfer of control continues as long as the driver is capable of performing the manual control part of this hybrid, automatic/manual controller. The system monitors the driver's progress, and accelerates or slows down the transfer of control from automatic to manual. The system will not sacrifice safety at any point; hence, whenever the driver's performance is determined to be unsatisfactory, the automatic control authority may be increased to adequately control the vehicle. This could be achieved by letting the automatic controller provide an admissible envelope of trajectories for manual control.

17. Key Words Automated Highway Systems, Check-out, Driver Diagnostics	18. Distribution Statement

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No of Pages	22. Price
Unclassified		68	

Executive Summary

The research team for Automated Check-out consisted of the University of Southern California (USC), Ford and Daimler Benz. The Center for Advanced Transportation Technologies at USC led the research effort. Professors Levent Turan, Petros Ioannou, and Michael G. Safonov were the researchers in this group. Professors David Smith and Diane Damos from the Department of Human Factors at USC have assisted with the human factors aspects of the study, and Ford and Daimler Benz provided consulting in various areas of automotive technology.

The underlying framework in this research is an evolutionary approach to vehicle and highway automation. This evolutionary deployment of AHS starts with the current traffic configuration at the lower end of automation, and goes all the way to a fully automated, synchronized configuration where human intervention is minimal. Hence, longitudinal and lateral control, lane changing, collision avoidance, route planning, etc. are all automated in a certain sequence, and slowly over a period of time. This leads to five intermediate, evolutionary levels of automation, which are called Evolutionary Representative System Configurations (ERSCs). In particular, ERSC1 involves automated headway and speed maintenance, ERSC2 introduces steering assist and rear-end collision avoidance, ERSC3 is the first level where we have hands-off/feet-off operation, ERSC4 has full collision avoidance, and the roadway provides direct control commands to each vehicle at ERSC5.

We have analyzed situations in AHS where transition from automated to manual control takes place. In particular, driver readiness testing to ensure safe and smooth transition from automated to manual control has been emphasized.

In order to analyze the check-out procedures, we need certain assumptions about the roadway configurations. With the purpose of keeping the treatment general, we introduced three conceptual representative entry/exit configurations: (1) Designated Entry/Exit with a Dedicated Entry/Exit Ramp; (2) Designated Entry/Exit without a Dedicated Entry/Exit Ramp; (3) Continuous Entry/Exit.

For each Evolutionary Representative System Configuration (ERSC), alternative scenarios describing the sequence of events in nominal operations are described. This clarifies the role of the driver, vehicle, and roadway in check-out operations and enables us to perform a functional analysis by constructing functional flow block diagrams, and performing a task analysis for critical functions of the driver. This task analysis will focus on key issues and risks related to check-out, rather than trying to be exhaustive and detail oriented.

There are four general functions involved in a check-out operation:

1. The system alerts the driver that exit operations should be initiated.
2. The system puts the vehicle in an operational region that is within the capabilities of the human driver. This will typically involve increasing the headway and reducing the speed.
3. The system performs a driver readiness test to assess readiness of the driver to resume control.
4. The control of the vehicle is transferred to the human driver.

Note that not all four functions will be present for every ERSC. In particular, the driver readiness tests are not expected to be introduced until ERSC3 where hands off/feet off operation starts. We show that, by appropriate design considerations, driver readiness testing procedures can be created such that they measure driving performance directly, while they

appear natural and reasonable to the driver. We present such a novel testing procedure which also ensures a safe, effective, and smooth transition from automated to manual driving mode. In this procedure, the authority of the automatic controller is gradually decreased, while the manual control authority is gradually increased (see Figure 1). This gradual transfer of control continues as long as the driver is capable of performing the manual control part of this hybrid, automatic/manual controller. The system monitors the driver's progress, and accelerates or slows down the transfer of control from automatic to manual. The system will not sacrifice safety at any point; hence, whenever the driver's performance is determined to be unsatisfactory, the automatic control authority may be increased to adequately control the vehicle. This could be achieved by letting the automatic controller provide an admissible envelope of trajectories for manual control. The speed of this procedure can also be adjusted as a function of the driver's performance, so that a skillful, alert, and fast responding driver could resume control within few seconds.

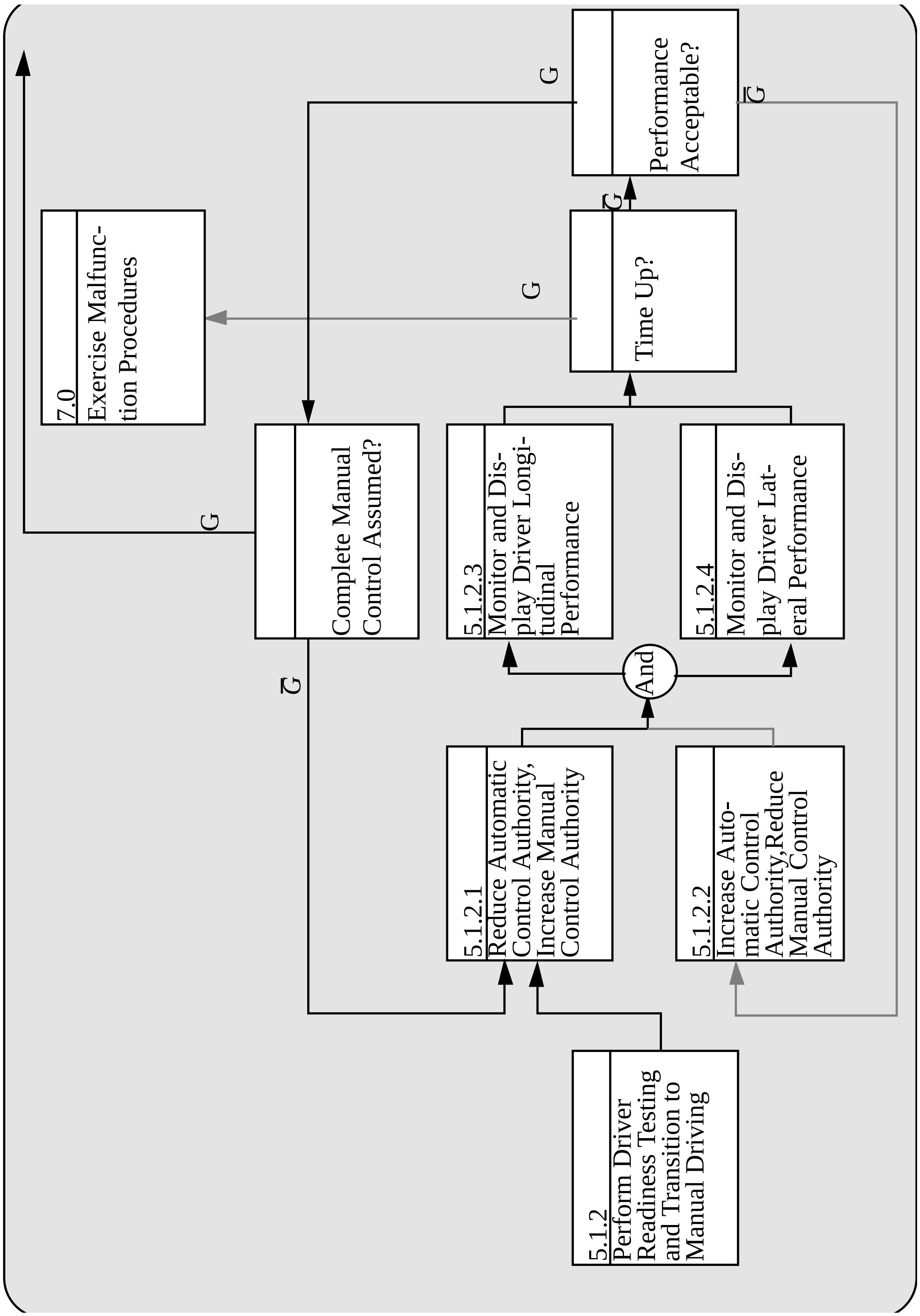

Figure 1: Detailed Flow Block Diagram of Driver Readiness Testing

The operator interface issues may be left to vehicle manufacturers and consumers to resolve within the context of competitive market forces. This process would also involve human factors experiments and experience.

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Introduction

Check-out refers to the situations where transition from automated to manual control takes place. Check-out involves three major elements: the vehicle, the driver, and the roadway. The activity area “Entry/Exit” deals with roadway issues. Hence, driver and vehicle issues will dominate the Automated Check-out activity area research efforts. In particular, the emphasis will be on driver readiness testing to ensure safe and smooth transition from automated to manual control.

For each Evolutionary Representative System Configuration (ERSC), alternative scenarios describing the sequence of events in nominal operations are described. This clarifies the role of the driver, vehicle, and roadway in check-out operations and enables us to perform a functional analysis by constructing functional flow block diagrams and performing a task analysis for critical functions of the driver. This task analysis will focus on key issues and risks related to check-out rather than trying to be exhaustive and detail oriented.

Recent research suggests that there are certain driver performance (e.g. erratic driver seat shifting and steering movements) and psychophysiological characteristics (heart and respiratory rates, blink rate, head nodding) that indicate the possibility of imminent unsafe driving behavior due to drowsiness and impairment [1,2,3,4] . These characteristics are, however, indirect measures of driving capabilities. We will show that, by appropriate design considerations, driver readiness testing procedures can be created such that they measure driving performance directly, while they appear natural and reasonable to the driver. We present such a novel testing procedure that also ensures a safe, effective, and smooth transition from automated to manual driving mode. Issues, risks, recommendations, and key findings are also discussed for each ERSC. In particular, the role of the driver, design, institutional, program, and instrumentation issues are analyzed.

The discussion for each ERSC is intended to be as self-contained as possible. Hence, applicable material from earlier ERSCs are repeated, rather than being referred to, in the text. Even though this inevitably leads to repetition, we believe that it enhances the readability of each ERSC section as an independent unit.

Representative Entry/Exit Configurations

Before we go into the analysis of check-out, we will need an analysis framework. The Representative Entry/Exit Configurations presented in this section provides this framework along with the Evolutionary Representative System Configurations.

In order to analyze the check-in/out procedures, we need certain assumptions about the roadway configurations. With the purpose of keeping the treatment general, we introduce three representative entry/exit configurations (see Figure 2):

(1) Designated Entry/Exit with a Dedicated Entry/Exit Ramp
(2) Designated Entry/Exit without a Dedicated Entry/Exit Ramp
(3) Continuous Entry/Exit

These configurations are only conceptual. For a more detailed description of various entry/exit configurations, see [5] . The continuous entry/exit configuration requires the least amount of infrastructure changes, and therefore may be a good candidate for the early ERSCs. Designated entry/exit configurations provide a setting where the roadway may have more control over the entry/exit maneuvers. Designated entry/exit configuration also allows the auto lanes to be separated with barriers from the manual lanes, although this is not necessarily an inherent feature of the configuration. Dedicated ramps increase safety, and allow more control such as ramp metering, gate installation at entry points, etc., albeit with an increase in cost.

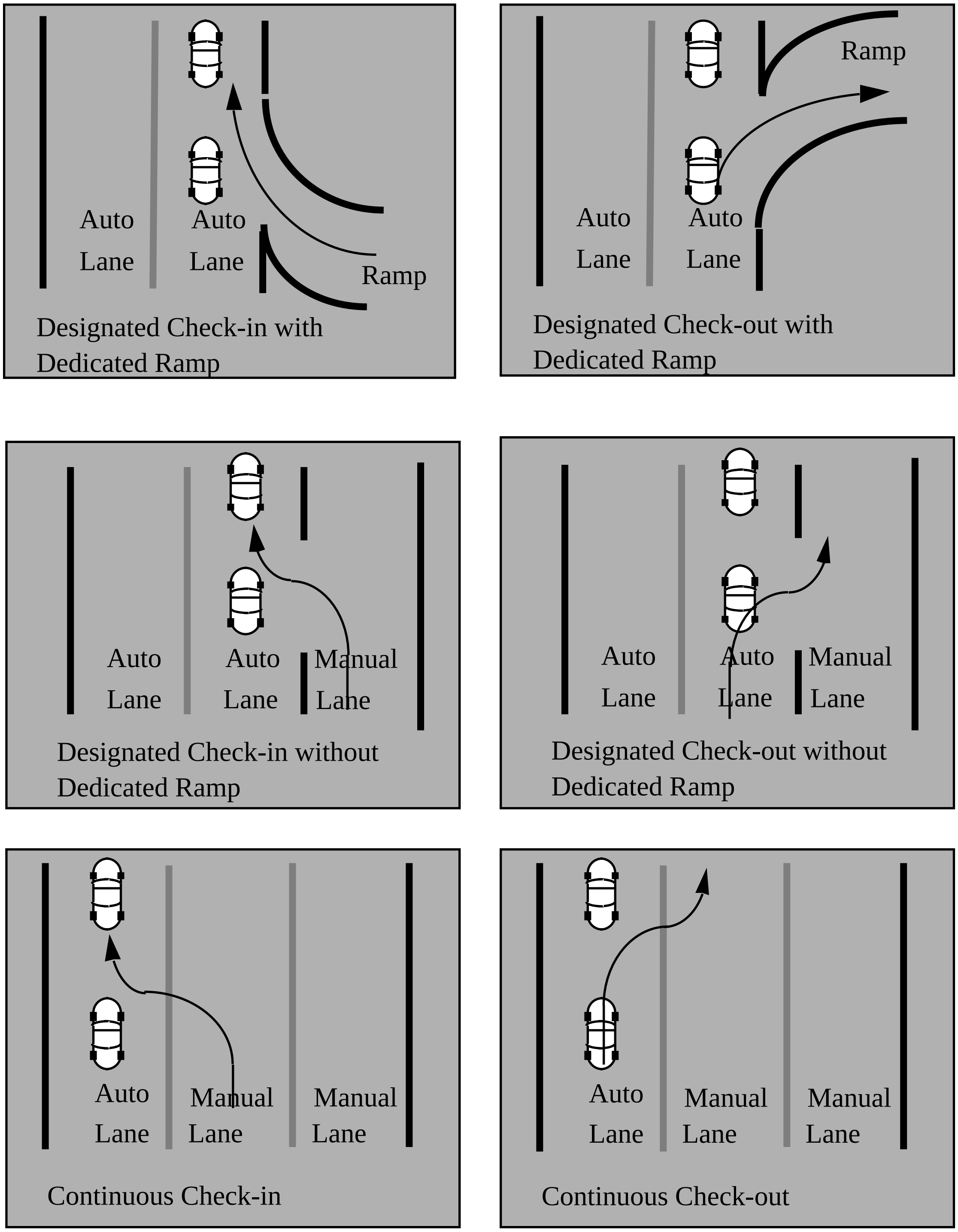

Figure 2: Entry Configurations Exit Configurations

Experimental Check-out Results on the Daimler Benz Simulator

Any design process involving human factors issues requires extensive experimentation. Since many check-out design aspects are dominated by human factors issues, an experiment geared specifically towards check-out procedures is of critical importance. One such experiment has been carried out in Germany using the Daimler-Benz Simulator, and the results are reported in [6] . We will briefly summarize this report in this section. It should also be pointed out that an extensive research effort examining the human factors issues in AHS is currently being carried out by Honeywell.

Description of the Daimler-Benz Control System and the Simulator Experiment:

The Daimler-Benz control system consists of a headway and speed maintenance system and a lane keeping system. The lane keeping system uses a video camera to detect lanes. The steering wheel turns as the vehicle is being steered automatically. The headway and speed maintenance system does not activate the brakes, and uses only the throttle. The automatic control system is activated by the driver by pressing the “AUTO” button. This button has a color-coded indicator light. When the automatic system is not ready, the indicator light is off. As soon as the system is ready, a “yellow” light comes up. When the driver presses the button to activate the control system, which can only be done when the yellow light is on, the light turns green, and the control of the vehicle is transferred over to the automated mode. This is accompanied by a HUD warning, where the word “PILOT” is displayed for five seconds. The automatic control system can be deactivated via one of several options: touching the brake or accelerator pedal, turning the steering wheel beyond a threshold, or pressing the “AUTO” button. There is a built-in resistance mechanism in the steering wheel to prevent accidental deactivation of the automated mode, and the driver has to overcome this resistance in order to deactivate the system via the steering wheel. This resistance is designed to be larger than the maximal force produced by the driver resting his/her arm on the steering wheel.

If the video camera is not capable of detecting the lane at any time during the automated mode, a gong sounds, and the control is immediately transferred over to the driver. This is accompanied with audio warnings which repeat the phrase “ATTENTION... DRIVE...” until the driver takes over the control of the vehicle, which is verified by a steering wheel movement of more than eight degrees. There may also be a tactile warning in the form of a vibration of the steering wheel (10 Hz.).

After 25 minutes of a fairly monotonous ride on the highway under automated control, the lane markers would disappear so that the video camera was not capable of detecting the lane anymore. This would prompt the transfer of control from automated to manual control. In some experiments, there was also an instruction site close to the end of the trip where the driver had to take over the control of the vehicle, and steer the vehicle in a lane that becomes narrower due to the construction site. About eighty drivers participated in the experiments.

Results of the Daimler Benz Simulator Experiment

The experiment results are summarized as follows:

- The transfer procedure from automated to manual control was found to be comfortable and reasonable by 66% of the drivers.
- The transfer procedure from automated to manual control was perceived to be safe by 82% of the drivers.
- The HUD warning was found to be appropriate by 75% of the drivers.
- The color-coding of the activate/deactivate button was found to be appropriate by 97% of the drivers.
- All drivers found it reasonable and logical that the steering wheel turns in response to the curvature during automated operations.

- Only 39% thought that the temporary resistance on the steering wheel was comfortable. In fact, 39% of the drivers even perceived it as been dangerous.
- None of the drivers took more than 2.5 seconds to resume control of the vehicle after being given a warning.
- While the audio warning was described as acceptable by 90% of the drivers, only 52% found the tactile warning acceptable.
- The drivers typically would not keep their hands on the steering wheel in automated mode.

Check-out Functions

There are four general functions involved in a check-out operation:

1. The system alerts the driver that exit operations should be initiated.
2. The system puts the vehicle in an operational region that is within the capabilities of the human driver. This will typically involve increasing the headway and reducing the speed.
3. The system performs a driver readiness test to assess readiness of the driver to resume control.
4. The control of the vehicle is transferred to the human driver.

Note that not all four functions will be present for each ERSC. In particular, the driver readiness tests are not expected to be introduced until ERSC3 where hands off/feet off operation starts. When driver readiness tests are introduced, the transition from automatic to manual control will be accomplished as part of the readiness tests in our approach.

Evolutionary Representative System Configuration One (ERSC1)
In this ERSC, the vehicle is responsible for headway and speed maintenance, and there is communication between the roadway and the vehicle. A blind spot detector assists the driver in lane changing maneuvers by providing warnings, and rear-end collision warnings alert the driver whenever there is a potential for a rear-end collision. The driver is responsible for steering and emergencies.

Designated Check-out with a Dedicated Ramp
In this scenario, the driver is responsible for guiding the vehicle to the exit ramp. Figure 3 illustrates this scenario conceptually. The functions of the driver, roadway, and vehicle in this scenario are described as follows:

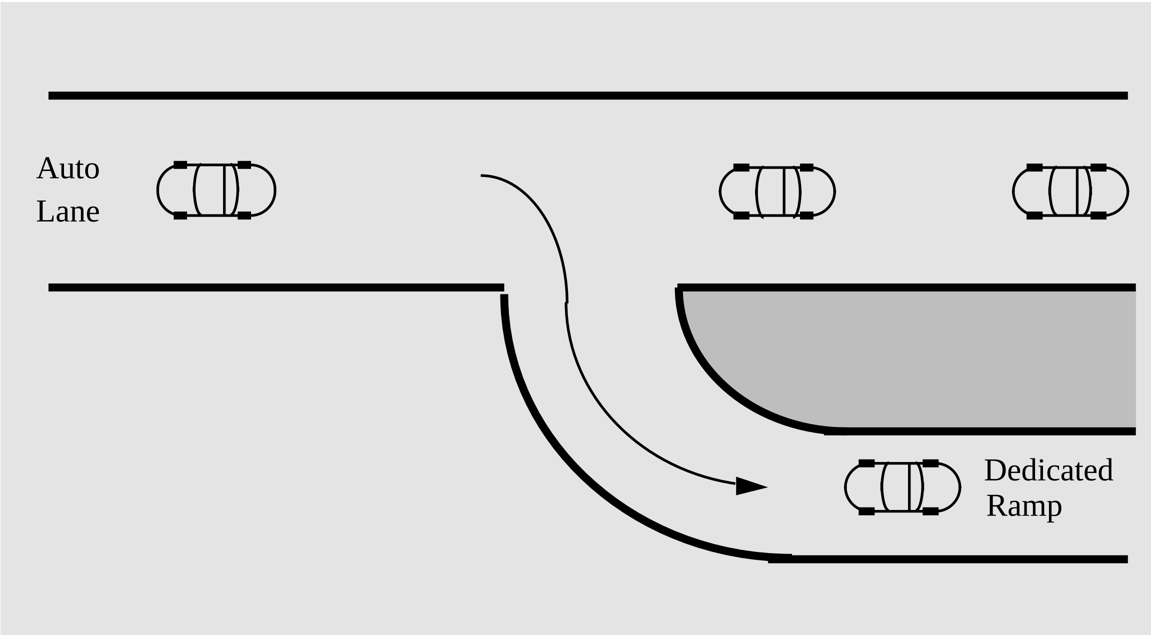

Figure 3: Designated Check-out with a Dedicated Ramp

Driver Functions: The driver takes over the longitudinal control of the vehicle, and guides the vehicle to the ramp. The driver is responsible for his/her readiness to resume longitudinal control, and for switching off the automated mode.
Vehicle Functions: The vehicle plays no active role in the check-out procedure.
Roadway Functions: Apart from providing the dedicated ramp, the roadway provides headway and speed recommendations, and traffic information to the vehicles. When the driver resumes control, headway and speed may be changed by the driver in order to execute the maneuver.

Designated Check-out without a Dedicated Ramp
In this his scenario, the driver is responsible for guiding the vehicle to the manual lane via the designated exit area. Figure 4 illustrates this scenario conceptually. The functions of the driver, roadway, and vehicle in this scenario are described as follows:

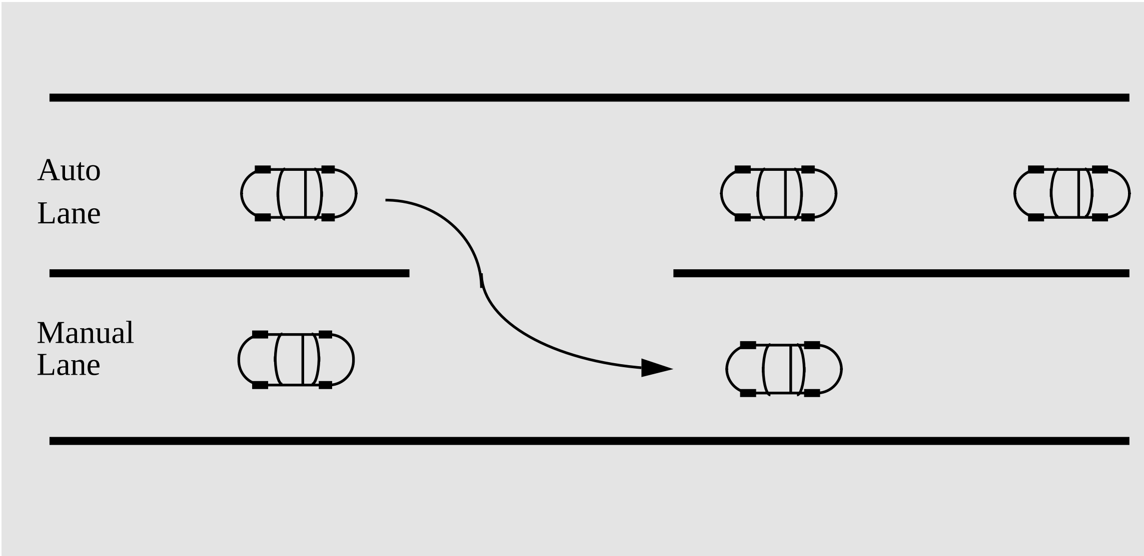

Figure 4: Designated Check-out without a Dedicated Ramp

Driver Functions: The driver takes over the longitudinal control of the vehicle, and guides the vehicle to the manual lane. The driver is responsible for his/her readiness to resume longitudinal control, and for switching off the automated mode.
Vehicle Functions: The vehicle plays no active role in the check-out procedure.
Roadway Functions: Apart from providing the dedicated and manual lanes, the roadway provides headway and speed recommendations, and traffic information to the vehicles. When the driver resumes control, headway and speed may be changed by the driver in order to execute the maneuver.

Continuous Check-out

In this his scenario, the driver is responsible for guiding the vehicle to the manual lane. Figure 5 illustrates this scenario conceptually. The functions of the driver, roadway, and vehicle in this scenario are described as follows:

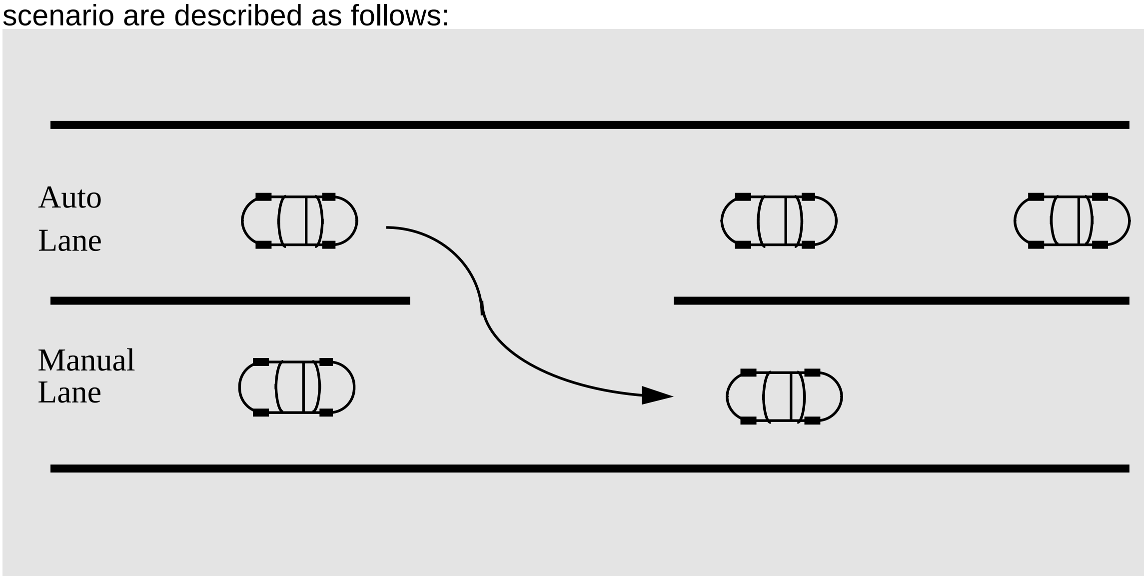

Figure 5: Continuous Check-out

Driver Functions: The driver takes over the longitudinal control of the vehicle, and guides the vehicle into the manual lane. The driver is responsible for his/her readiness to resume longitudinal control, and for switching off the automated mode.

Vehicle Functions: The vehicle plays no active role in the check-out procedure.

Roadway Functions: Apart from providing the dedicated and manual lanes, the roadway provides headway and speed recommendations, and traffic information to the vehicles. When the driver resumes control, headway and speed may be changed by the driver in order to execute the maneuver.

Functional Flow Block Diagrams

The functional flow block diagram shown in Figure 6 defines the various functions involved in the check-out process. The solid lines in this diagram correspond to nominal sequence of operations.

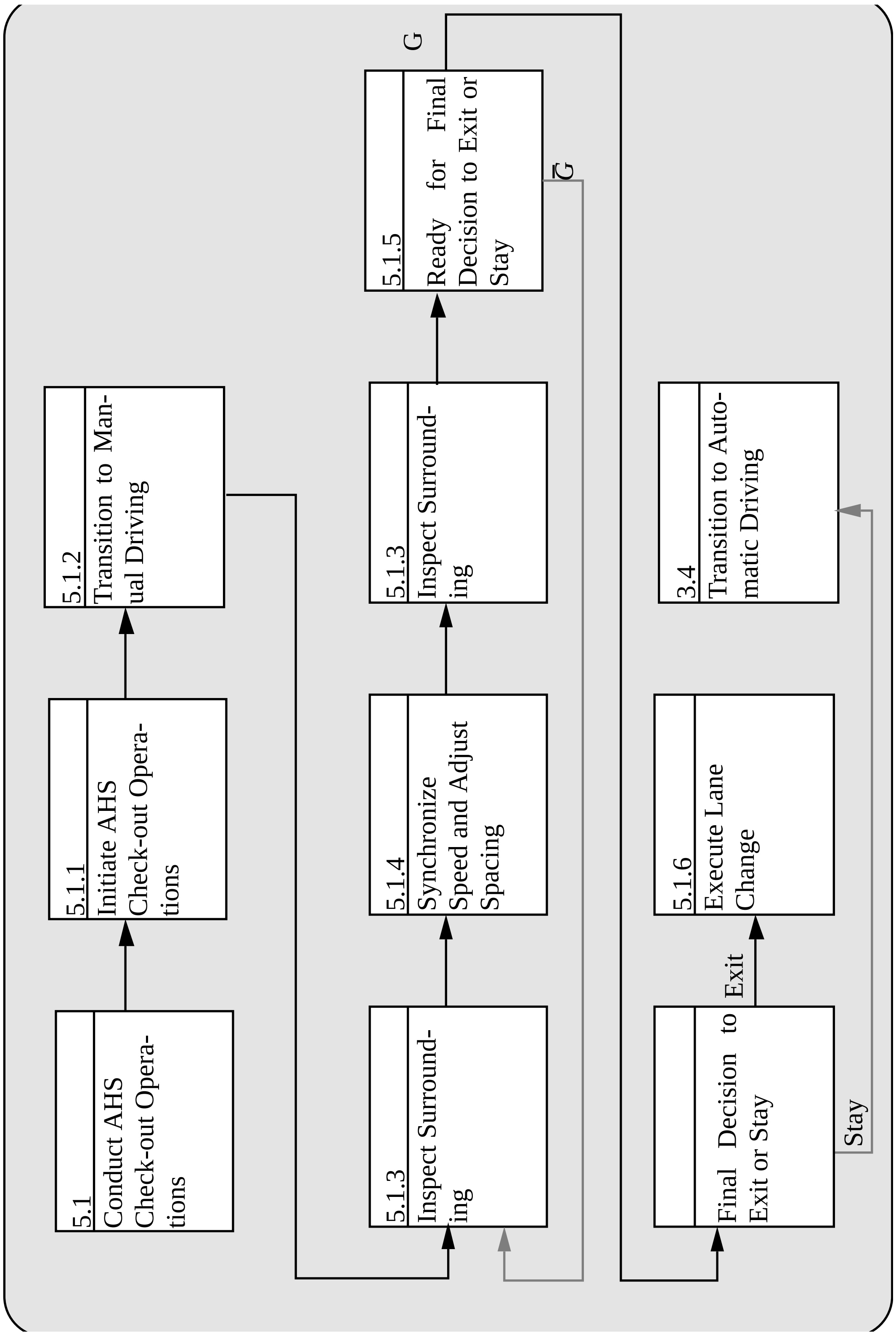

Figure 6: Top-level Check-out Flow Block Diagram for ERSC 1 (The solid lines correspond to nominal sequence of operations)

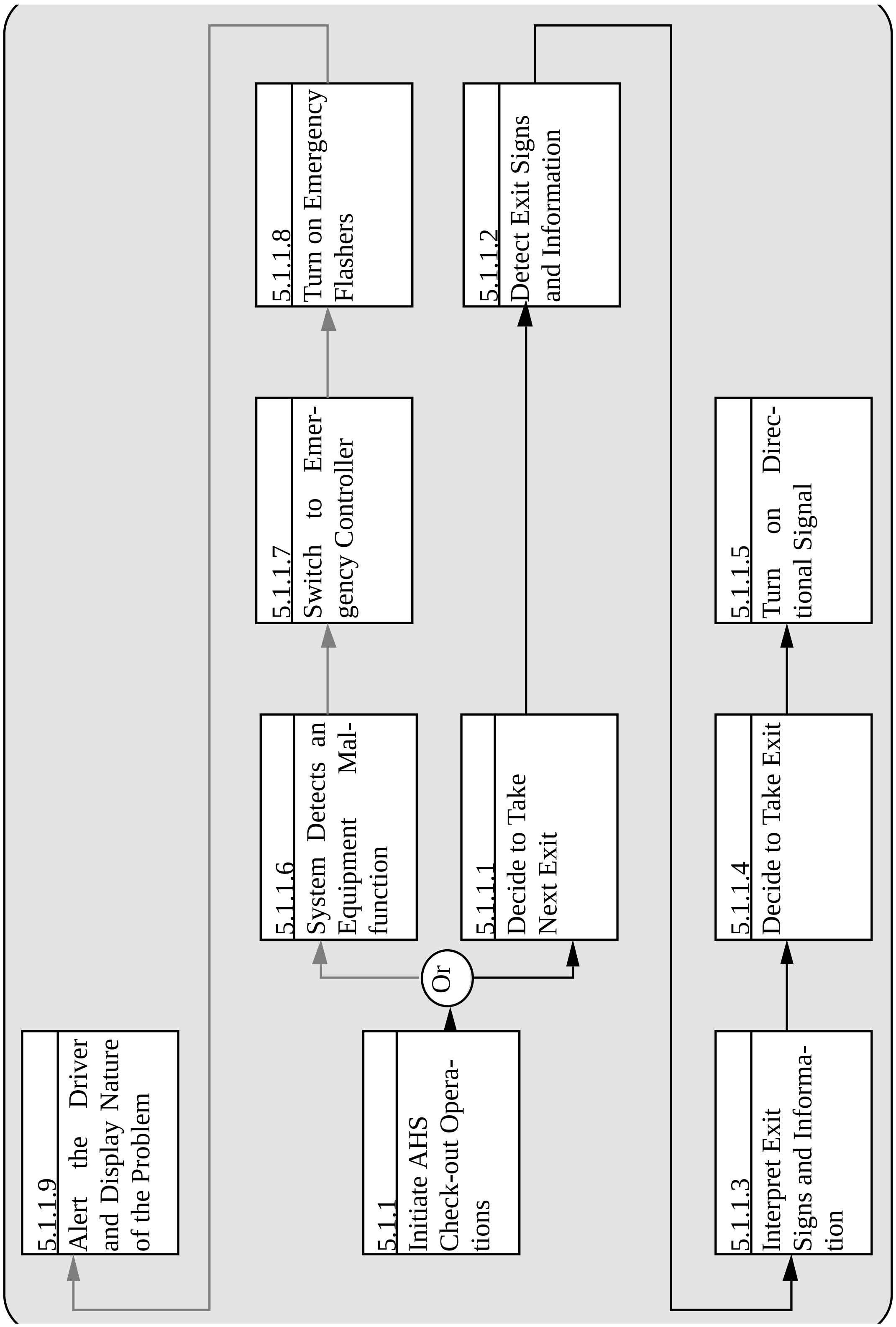

Figure 7: Detailed Flow Block Diagram of the Block 5.1.1 Initiate AHS Check-out Operations

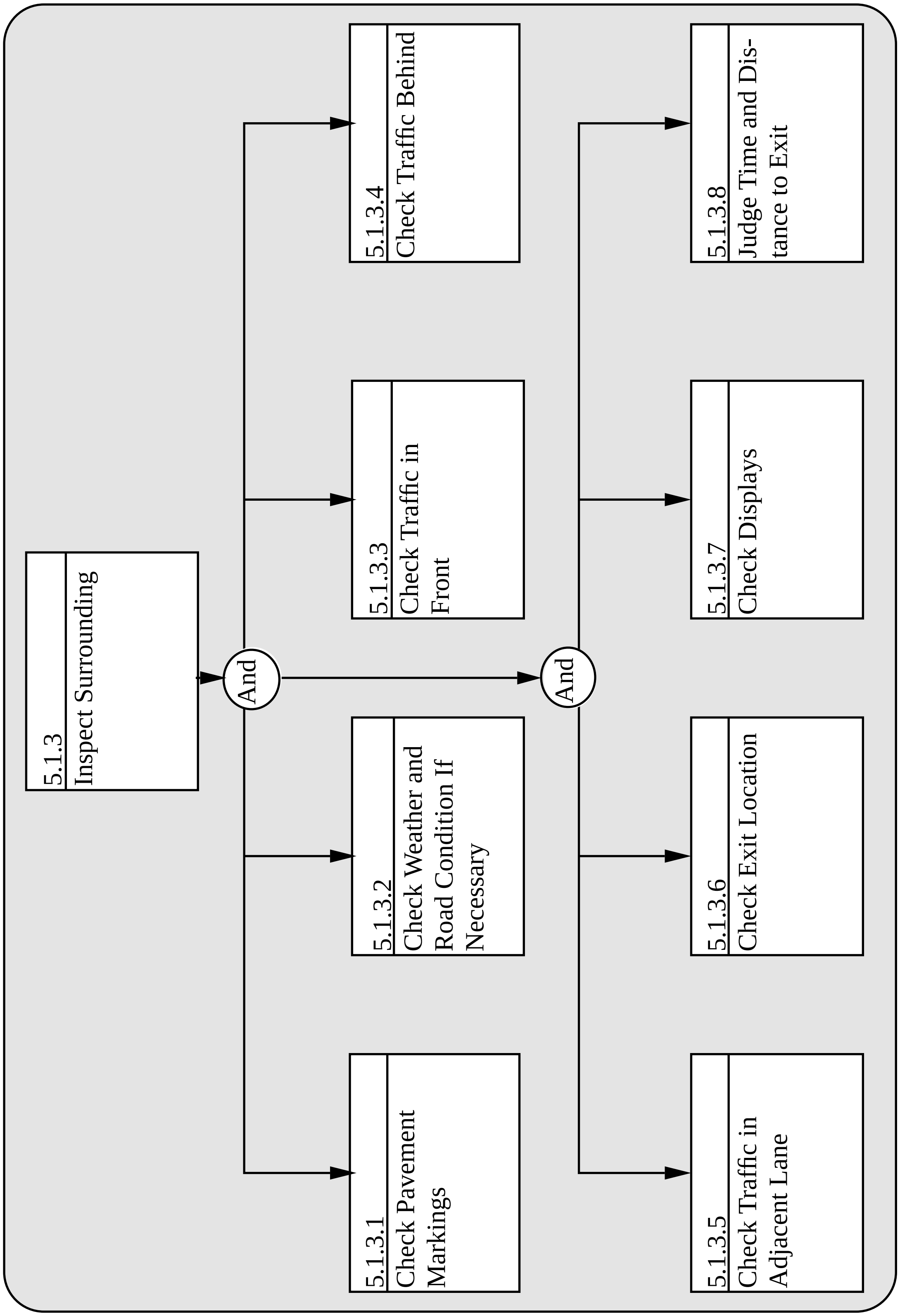

Figure 8: Detailed Flow Block Diagram of the Block 5.1.3 Inspect Surrounding

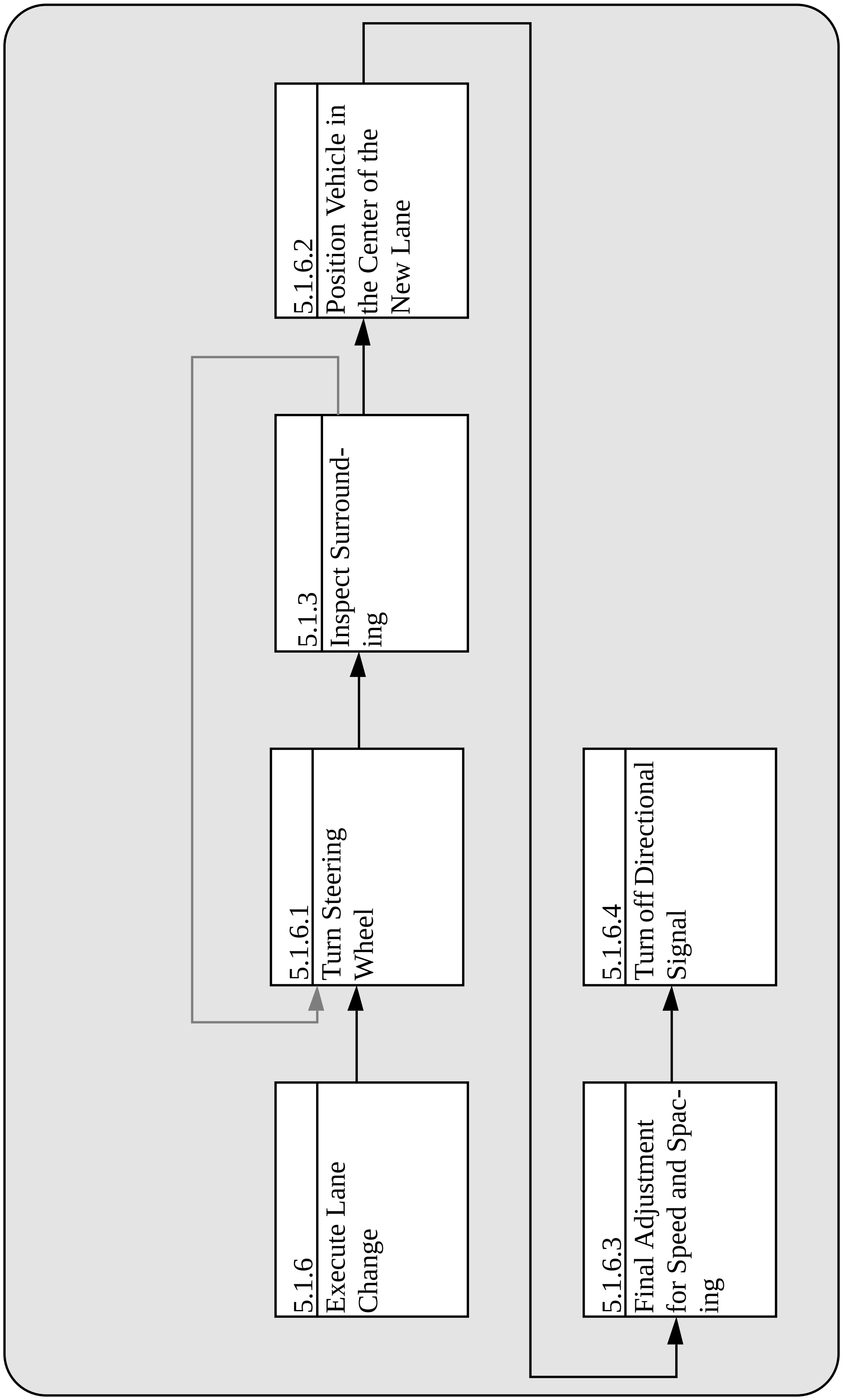

Figure 9: Detailed Flow Block Diagram of the Block 5.1.6 Execute Lane Change

Driver Readiness Testing

Since the driver is responsible for emergency braking, the driver needs to be alert throughout the trip. Therefore, we do not anticipate any need to actively test driver readiness at ERSC1.

Driver Task Analysis

In order to produce information that is relevant to the design of a human/machine system, a task analysis is typically performed. Although there is little agreement over how a task analysis should be performed, partly because of heavy problem dependence, task analysis is an established and frequently used tool [7,8,9] . It enables the designer to analyze systematically various human factors issues involved in the system. Our approach will be to pick certain operator tasks in the functional flow block diagrams and perform task analysis on them. The selection of the tasks to be subjected to task analysis will be based on their relevance to check-out operations and on their criticality. A task will be labeled as “very critical” if a failure in performing that task has a high potential of causing a serious accident. If a task is labeled as “critical”, the system performance will deteriorate in case of failure, but the potential for serious accident is fairly low. A failed task that is designated as “non-critical” will only cause slight performance degradation and usually will not be subjected to a task analysis. It should be noted that our task analysis will focus on key issues and risks, rather than trying to be exhaustive and detail oriented.

The task analysis is performed in the form of tables (Table 1, Table 2, Table 3, Table 4, and Table 5). The task numbers in these tables correspond to the numbers used in the functional flow block diagrams presented above. In these tables, first general information about the task is provided. Then, the stimulus or circumstance that prompts action is discussed under “Initiating Cue”. Operator interface issues are discussed under “Feedback” (providing information to the operator about the system operations) and “Control Functions” (receiving commands from the operator). Criteria for success of the task, speed of response, etc. are discussed under “Task Standards”, and factors that may affect the success of the task such as noise levels, illumination, poor equipment design, weather, etc. are discussed under “Task Conditions”. The next row, “Skills Required”, describes the operator skills (psychomotor, cognitive, memory) necessary to complete the task. Potential errors that might cause safety problems, their causes (inattention, memory lapse, time pressure, lack of feedback, poor equipment design, etc.), consequences of these errors on people or the system, and recovery points for these errors where they can be identified and recovered (e.g. alarm, second chance, etc.) are all discussed next. Finally, individual differences such as age, disability, and experience as they relate to the task are described. Each task is then assigned a criticality level as described above.

Table 1: Task Analysis for Task 5.1.1 Initiate AHS Check-out Operations

General	Task is similar to that of manual driving.
Initiating Cue	Signs, recognized surrounding, warning from roadway may prompt the task.
Feedback	Roadway exit warning, directional signal light indicator.
Control Functions	Directional signal
Task Standards	Nominal durations for the task are in general the same as in manual driving.
Task Conditions	Desirable to have consistent (standardized, e.g., location and style) and visible highway information. Task conditions e.g., weather and night, provide a highly variable task environment.
Skills Required	Cognitive, psychomotor (compatible with manual driving task)
Potential Errors	Failure to recognize signs and information, inability to read signs and receive information, deciding too late, forgetting to turn on signal (hierarchical task analysis, error analysis, workload analysis and human reliability assessment needed to determine full range and impact of human error and methods of error reduction for this and other tasks in check-out).
Causes of Errors	Non-alertness, poor eyesight and/or hearing disability, disorientation, memory problems, time pressure
Consequences of Errors	Too much delay prevents the vehicle from exiting
Recovery Points	Driver may get repeated warnings and be given the chance to exit as long as it is not too late
Individual Differences	Certain drivers, the older, disabled, visually impaired and foreign, for example, may need considerably more time in this phase of check out to reduce stress and confusion. Transitional errors may be especially important for these groups. Under low illumination conditions older drivers visibility distances for viewing text signs may be problematic [10].
Criticality	Critical

Table 2: Task Analysis for Task 5.1.3 Inspect Surroundings

General	Task is analogous to that of manual driving.
Initiating Cue	Requires design of signal indicating completion of transfer of control. Because driver may already have begun inspection of surroundings, this signal will need to be either auditory or auditory/visual to attract attention.
Feedback	Not Applicable
Control Functions	Not Applicable
Task Standards	Inspection of rear view mirror, right side mirror and turning head and shoulders to look through right side and rear windows are involved. Duration is comparable to that involved in manual driving.
Task Conditions	Environment, roadway conditions, traffic situation and distractions (e.g., rain, complex traffic, low visibility, glare) may significantly increase time for inspection.
Skills Required	Estimation of distances and judgment about gap needed for lane changing.
Potential Errors	Failure to detect objects, vehicles, roadway boundaries etc.
Causes of Errors	Non-alertness, poor eye sight and/or hearing disability, disorientation, time pressure, poor perceptual skills, poor and/or slow spatial judgment
Consequences of Errors	Potential collision
Recovery Points	Blind spot warnings (design issues involve attention -getting, directional cues, easily discriminated from competing and background signals, and intensities below the threshold for startle [11]), warnings from other drivers, subsequent surrounding inspection.
Individual Differences	Accident statistics, citations and self report data all indicate that older drivers have difficulty in merging, changing lanes, and exiting maneuvers. Limited upper body mobility adversely impacts the older person's ability to scan to the rear when backing, turning, and merging [12,13] . Similar issues for disabled drivers. Data suggests persons over 65 may be over represented in lane change/merge crashes [14] .
Criticality	Critical

Table 3: Task Analysis for Task 5.1.4 Synchronize Speed and Adjust Spacing

General	Task is similar overall to the task in manual driving.
Initiating Cue	Completion of Surrounding Inspection
Feedback	Not Applicable
Control Functions	Throttle/brake pedal actuation
Task Standards	Nominal times and task standards are similar to manual driving [15] .
Task Conditions	Weather, physical characteristics of roadway (curves, grade), low illumination
Skills Required	Specific cognitive skills of spatial judgment and psychomotor tracking are necessary to position the vehicle for exit.
Potential Errors	Failure to synchronize and adjust spacing
Causes of Errors	Non-alertness, poor eye sight and/or hearing disability, disorientation, time pressure, poor perceptual skills, poor and/or slow spatial judgment
Consequences of Errors	While the probability of an accident occurring during this task is low, if they do occur, errors could result in a catastrophic accident here and during the subsequent exit. Otherwise, delay in exiting is the only consequence
Recovery Points	Repeat the process.
Individual Differences	Individual differences (e.g. age and driving skills) in the judgment of spacing needed to confidently execute exit.
Criticality	Critical

Table 4: Task Analysis for Task Final Decision to Exit or Stay

General	As in the case with manual driving this involves completing cognitive appraisal of the surrounds and the final decision to initiate exit.
Initiating Cue	Specific cue is completion of Surrounding Inspection Task, then the approach of the exit and other environment cues, such as the traffic conditions and time judged necessary to complete highway exit.
Feedback	Not Applicable
Control Functions	Not Applicable
Task Standards	Time required is comparable to manual driving. The time involved depends upon the complexity of the decision to be made. Absolute time heavily depends upon task conditions and individual differences, e.g., traffic, weather, illumination, roadway, age, and experience.
Task Conditions	Weather, physical characteristics of roadway (curves, grade).
Skills Required	Estimation of distances and judgment about gap needed for lane changing [16,17] .
Potential Errors	Error of omission: Failure to decide to exit when it should be initiated. Error of commission: Decision to exit when it should not be initiated.
Causes of Errors	Non-alertness, time pressure, poor and/or slow spatial judgment, slow decision process
Consequences of Errors	Consequences depends upon whether it is an error of omission or commission. The first may cause delay and thus influence efficiency of traffic flow the second increases the probability of an accident.
Recovery Points	Until the decision to initiate exit is made the driver may abort and return to reappraisal of the surround or return to auto driving.
Individual Differences	Generally decision times increase with age. For simple tasks this increase is small, for complex tasks it represents most of the increase in response time observed [12,18] .
Criticality	Very Critical

Table 5: Task Analysis for Task 5.1.6 Execute Lane Change

General	Psychomotor task is essentially the same as in manual driving.
Initiating Cue	Decision to exit
Feedback	Not Applicable
Control Functions	Steering wheel movements
Task Standards	Durations same as in manual driving.
Task Conditions	Weather, low illumination, traffic density and speed are examples of conditions that may affect the time to make change lanes.
Skills Required	For the experienced driver this is a highly practiced psychomotor task.
Potential Errors	Improper maneuver, poor control in the new lane
Causes of Errors	Non-alertness, poor eye sight and/or hearing disability, disorientation, time pressure, poor perceptual skills, poor and/or slow spatial judgment, slow decision process
Consequences of Errors	Approximately 4% of crashes and 0.5% of fatalities are of the lane change merge variety. Some 95% of crashes are the angle/sideswipe and only 5% of a rear end variety [14] .
Recovery Points	Blind spot warning signals require careful human interface design. Design issues involve attention - getting, directional cues, easily discriminated from competing and background signals, and intensities below the threshold for startle [11] .
Individual Differences	Accident statistics, citations and self report data all indicate older drivers have difficulty in merging, changing lanes, and exiting maneuvers. Data suggests persons over 65 may be over represented in lane change/merge crashes [14] .
Criticality	Very Critical

1. Issues, Risks, and Recommendations

Design Issues:

Since ERSC1 is very similar to manual driving conditions, few specific design issues beyond those currently available or in development by the auto industry are expected for check-out.

Driver Issues:

The major driver issues emerging at ERSC1 check-out that distinguish it from the traditional manual driving situation are first the kinds and extent of support information (signs, in vehicle displays, warnings) that would enhance acceptance, efficiency and safety at this level of automation. There are a wide variety of studies and guidelines for operator interface that are applicable at ERSC1. (See references 19,20,7,21,22,8,23,24,25,26,27.) There are alternative display technologies, e.g. Head-up displays (HUD), Liquid Crystal Displays (LCD), Light-Emitting Diode (LEDO), computer generated voice message, sudden vehicle acceleration/deceleration (jerk), and tactile feedback. The interface can be continuous, or perhaps more appropriately activated when a driver action is needed or at the driver's request. The concept of generating progressively stronger warnings may be applied to devise an operationally acceptable interface. How to design the best user interface for AHS operations is still an open issue, and involves selecting a display technology, type and duration of warnings, user controls type and location, etc. Ultimately, experiments on simulators and actual vehicles will need to be carried out to determine the system characteristics that make the system appear natural to the driver, the best way to present the data to the driver, and the most convenient way for the driver to input commands.

User acceptance is the second important issue [28,29] . Since many functions at this ERSC are expected to be developed independent of AHS, user friendliness to ensure public acceptance should be integrated into the design process by the manufacturer for each function. The Daimler-Benz study is a good example for this kind of effort [6] .

The possibility that the ERSC1 level of automation will pose special acceptance and user problems for the elderly, disabled and inexperienced drivers is a third issue. These sub-populations should be routinely incorporated in simulator and vehicle studies done for check-out at this level of automation and special studies conducted on acceptance and usability under a variety of anticipated highway conditions.

Institutional Issues:

Legal and liability issues are very important for the deployment of AHS [30] . Therefore, designing a fail-safe system is a basic requirement.

Another major issue for implementation of AHS is dedicating a lane to AHS operations. Construction of a new lane will be costly, and taking away an existing lane from manual traffic may provoke major political turbulence [31,32] . It may therefore be necessary to consider scenarios in which various ERSC level vehicles coexist in the early phases of the deployment.

Program Issues:

Many functions at this ERSC are expected to be developed independent of AHS. Working out details of dedicating a lane will be the major activity required. The deployment schedule will depend on the availability of independently developed components.

User Type Issues:

There are no specific user type issues at this ERSC.

Key Findings

- Many functions at ERSC1 are identical or very similar to the manual driving situation. In particular, no specific driver readiness test should be necessary at this level.
- The operator interface issues may be left to vehicle manufacturers and consumers to resolve within the context of competitive market forces. This process would also involve human factors experiments and experience.
-

Evolutionary Representative System Configuration Two (ERSC2)
At ERSC2, the vehicle is responsible for rear-end collision avoidance, and provides lane departure warnings to the driver. Steering assist is also introduced at ERSC2 so that the automatic controller aids the driver in lane keeping control.

Designated Check-out with a Dedicated Ramp
In this scenario, the driver is responsible for guiding the vehicle to the exit ramp. Figure 3 illustrates this scenario conceptually. The functions of the driver, roadway, and vehicle in this scenario are described as follows:
Driver Functions: The driver takes over the longitudinal control of the vehicle, and guides the vehicle to the ramp. The driver is responsible for his/her readiness to resume longitudinal control, and for switching off the automated mode.
Vehicle Functions: The vehicle may alert the driver to indicate that the driver needs to resume control (e.g. vehicle detects a malfunction, previously declared exit is approached). The vehicle also increases the inter-vehicle gap to a value that is within the capabilities of the human driver before releasing the longitudinal control of the vehicle. This is required, since with the introduction of collision avoidance, the headway may be reduced to a value that is beyond the range of manual driving conditions. Steering assist control authority is then gradually decreased to ensure a smooth transition to manual steering.
Roadway Functions: Apart from providing the dedicated lane with lane keeping reference aids, the roadway provides headway and speed recommendations, and traffic information to the vehicles. When the driver resumes control, headway and speed may be changed by the driver in order to execute the maneuver.

Designated Check-out without a Dedicated Ramp
In this scenario, the driver is responsible for guiding the vehicle to the manual lane via the designated exit area. Figure 4 illustrates this scenario conceptually. The functions of the driver, roadway, and vehicle are described as follows:
Driver Functions: The driver takes over the longitudinal control of the vehicle, and guides the vehicle to the manual lane. The driver is responsible for his/her readiness to resume longitudinal control, and for switching off the automated mode.
Vehicle Functions: The vehicle may alert the driver to indicate that the driver needs to resume control (e.g. vehicle detects a malfunction, previously declared exit is approached). The vehicle also increases the inter-vehicle gap to a value that is within the capabilities of the human driver before releasing the longitudinal control of the vehicle. Steering assist control authority is then gradually decreased to ensure a smooth transition to manual steering.
Roadway Functions: Apart from providing the dedicated lane with lane keeping reference aids, the roadway provides headway and speed recommendations, and traffic information to the vehicles. When the driver resumes control, headway and speed may be changed by the driver in order to execute the maneuver. The roadway may slow down the manual traffic (e.g., via signs) in order to aid the exiting vehicles to perform their maneuvers.

Continuous Check-out
In this his scenario, the driver is responsible for guiding the vehicle to the manual lane. Figure 5 illustrates this scenario conceptually. The functions of the driver, roadway, and vehicle in this scenario are described as follows:
Driver Functions: The driver takes over the longitudinal control of the vehicle, and guides the vehicle into the manual lane. The driver is responsible for his/her readiness to resume longitudinal control, and for switching off the automated mode.
Vehicle Functions: The vehicle may alert the driver to indicate that the driver needs to resume control (e.g. vehicle detects a malfunction, previously declared exit is approached). The vehicle also increases the inter-vehicle gap to a value that is within the capabilities of the human driver

before releasing the longitudinal control of the vehicle. Steering assist control authority is then gradually decreased to ensure a smooth transition to manual steering.
Roadway Functions: Apart from providing the dedicated lane with lane keeping reference aids, the roadway provides headway and speed recommendations, and traffic information to the vehicles. When the driver resumes control, headway and speed may be changed by the driver in order to execute the maneuver.

Functional Flow Block Diagrams

The functional flow block diagram for ERSC2 is very similar to the one discussed for ERSC1, and is therefore omitted in this section.

Driver Readiness Testing

Since the driver is responsible for lateral control, the driver needs to be alert throughout the trip. Therefore, we do not anticipate any need to actively test driver readiness at this level of ERSC.

Driver Task Analysis

The driver task analysis for ERSC2 is very similar to the one discussed for ERSC1, and is therefore omitted in this section.

Issues, Risks, and Recommendations

Design Issues:
ERSC2 is very similar to manual driving conditions, and only few specific design issues beyond those currently available or in development by the auto industry arise for check-out. Among these issues are developing a control strategy which increases the gap to a value that is within the capabilities of the human driver, and the implementation of gradual turning off of the steering assist function to ensure a smooth transition to manual steering.
Driver Issues:
The major driver issues that distinguish ERSC2 check-out from the traditional manual driving situation are first the kinds and extent of support information (signs, in vehicle displays, warnings) that would enhance acceptance, efficiency and safety at this level of automation. There are a wide variety of studies and guidelines for operator interface that are applicable at ERSC2. (See references 19,20,7,21,22,8,23,24,25,26,27.) There are alternative display technologies, e.g. Head-up displays (HUD), Liquid Crystal Displays (LCD), Light-Emitting Diode (LEDO), computer generated voice message, sudden vehicle acceleration/deceleration (jerk), and tactile feedback. The interface can be continuous, or perhaps more appropriately activated when a driver action is needed or at the driver's request. The concept of generating progressively stronger warnings may be applied to devise an operationally acceptable interface. How to design the best user interface for AHS operations is still an open issue, and involves selecting a display technology, type and duration of warnings, user controls type and location, etc. Ultimately, experiments on simulators and actual vehicles will need to be carried out to determine the system characteristics that make the system appear natural to the driver, the best way to present the data to the driver, and the most convenient way for the driver to input commands.
User acceptance is the second important issue [28,29] . Since many functions at this ERSC are expected to be developed independent of AHS, user friendliness to ensure public acceptance should be integrated into the design process by the manufacturer for each function. The Daimler-Benz study is a good example for this kind of effort [6].
The possibility that the ERSC2 level of automation will pose special acceptance and user problems for the elderly, disabled and inexperienced drivers is a third issue. These sub-populations should be routinely incorporated in simulator and vehicle studies done for check-out at this level of automation and special studies conducted on acceptance and usability under a variety of anticipated highway conditions.

Institutional Issues:
Legal and liability issues are very important for the deployment of AHS [30] . Therefore, designing a fail-safe system is a basic requirement.
Another major issue for implementation of AHS is dedicating a lane to AHS operations. Construction of a new lane will be costly, and taking away an existing lane from manual traffic may provoke major political turbulence [31,32] . It may therefore be necessary to consider scenarios in which various ERSC level vehicles coexist in the early phases of the deployment.
Program Issues:
Many functions at this ERSC are expected to be developed independent of AHS. Working out details of dedicating a lane will be the major activity required. The deployment schedule will depend on the availability of independently developed components.
User Type Issues:
There are no specific user type issues at this ERSC.

Key Findings

- Many functions at ERSC2 are identical or very similar to the manual driving situation. In particular, no specific driver readiness test should be necessary at this level.
- The vehicle should create a large enough gap before transferring the control of the vehicle, so that the driver resumes control in a driving situation that is compatible with the relative slowness and imprecision of human response.
- When check-out is initiated, the steering assist function is expected to be turned off gradually so as to ensure a smooth transition to manual steering.
- The operator interface issues may be left to vehicle manufacturers and consumers to resolve within the context of competitive market forces. This process would also involve human factors experiments and experience.

Evolutionary Representative System Configuration Three (ERSC3)

At ERSC3, automated lane keeping is introduced. Additionally, the blind spot sensor is improved to provide lateral collision warnings and communication between vehicles is used to coordinate lane change and entry/exit maneuvers.

As previously discussed, there are four general system functions involved in a check-out operation. For ERSC3, we have the following specific functions:

1. The system may alert the driver that exit operations should be initiated. This could be prompted by a system detected malfunction for which the driver is part of the malfunction management strategy, or the vehicle may be approaching the intended exit previously declared by the driver.
2. The system puts the vehicle in an operational region that is within the capabilities of the human driver. This will involve increasing the headway and reducing the speed, such that the human driver is capable of resuming control.
3. The system performs a driver readiness test to assess readiness of the driver to resume control.
4. The control of the vehicle is transferred to the human driver.

In our approach, the last two steps will be combined into one. We will discuss the details of the driver readiness test.

Designated Check-out with a Dedicated Ramp

Check-out Scenario I

In this scenario, the driver is responsible for guiding the vehicle onto the exit ramp. Figure 3 illustrates this scenario conceptually. The functions of the driver, roadway, and vehicle in this scenario are described as follows:

Driver Functions: The driver may initiate the check-out operations, she/he takes over the control of the vehicle, and guides the vehicle to the ramp.

Vehicle Functions: The vehicle may alert the driver that check-out operations should be initiated. This could be prompted by a system detected malfunction for which the driver is part of the malfunction management strategy, or the vehicle may be approaching the intended exit previously declared by the driver. Then the vehicle puts itself in an operational region that is within the capabilities of the human driver, and supervises the driver readiness testing.

Roadway Functions: Apart from providing the dedicated lane with lane keeping reference aids, the roadway provides headway and speed recommendations, and traffic information to the vehicles.

Check-out Scenario II

In this scenario, the vehicle guides itself automatically onto the exit ramp using the lane keeping function. The functions of the driver, roadway, and vehicle in this scenario are described as follows:

Driver Functions: The driver may initiate the check-out operations, and she/he takes over the control of the vehicle on the ramp.

Vehicle Functions: The vehicle may alert the driver that check-out operations should be initiated. This could be prompted by a system detected malfunction for which the driver is part of the malfunction management strategy, or the vehicle may be approaching the intended exit previously declared by the driver. Then the vehicle guides itself automatically onto the exit ramp, puts itself in an operational region that is within the capabilities of the human driver, and supervises the driver readiness testing.

Roadway Functions: Apart from providing the dedicated lane with lane keeping reference aids, the roadway provides headway and speed recommendations, and traffic information to the vehicles.

Designated Check-out without a Dedicated Ramp

In this check-out scenario, the driver is responsible for guiding the vehicle to the manual lane via the designated exit area. Figure 4 illustrates this scenario conceptually. The functions of the driver, roadway, and vehicle in this scenario are described as follows:

Driver Functions: The driver may initiate the check-out operations, she/he takes over the control of the vehicle, and guides the vehicle into the manual lane using the lateral collision warnings.

Vehicle Functions: The vehicle may alert the driver that check-out operations should be initiated. This could be prompted by a system detected malfunction for which the driver is part of the malfunction management strategy, or the vehicle may be approaching the intended exit previously declared by the driver. Then the vehicle puts itself in an operational region that is within the capabilities of the human driver, and supervises the driver readiness testing. The vehicle also provides lateral collision warnings.

Roadway Functions: Apart from providing the dedicated lane with lane keeping reference aids, the roadway provides headway and speed recommendations, and traffic information to the vehicles. The roadway may also help in gap synchronization in the manual lane via roadway signs or signals.

Continuous Check-out

In this check-out scenario, the driver is responsible for guiding the vehicle into the manual lane. Figure 5 illustrates this scenario conceptually. The functions of the driver, roadway, and vehicle in this scenario are described as follows:

Driver Functions: The driver may initiate the check-out operations, she/he takes over the control of the vehicle, and guides the vehicle into the manual lane using the lateral collision warnings.

Vehicle Functions: The vehicle may alert the driver that check-out operations should be initiated. This could be prompted by a system detected malfunction for which the driver is part of the malfunction management strategy, or the vehicle may be approaching the intended exit previously declared by the driver. Then the vehicle puts itself in an operational region that is within the capabilities of the human driver, and supervises the driver readiness testing. The vehicle also provides lateral collision warnings.

Roadway Functions: Apart from providing the dedicated lane with lane keeping reference aids, the roadway provides headway and speed recommendations, and traffic information to the vehicles. The roadway may also help in gap synchronization in the manual lane via roadway signs.

Functional Flow Block Diagrams

The functional flow block diagram shown in Figure 10 defines the various functions involved in the check-out process. The solid lines in this diagram correspond to nominal sequence of operations. Note that these functional flow block diagrams represent all scenarios discussed above except the one where the vehicle guides itself automatically onto the exit ramp.

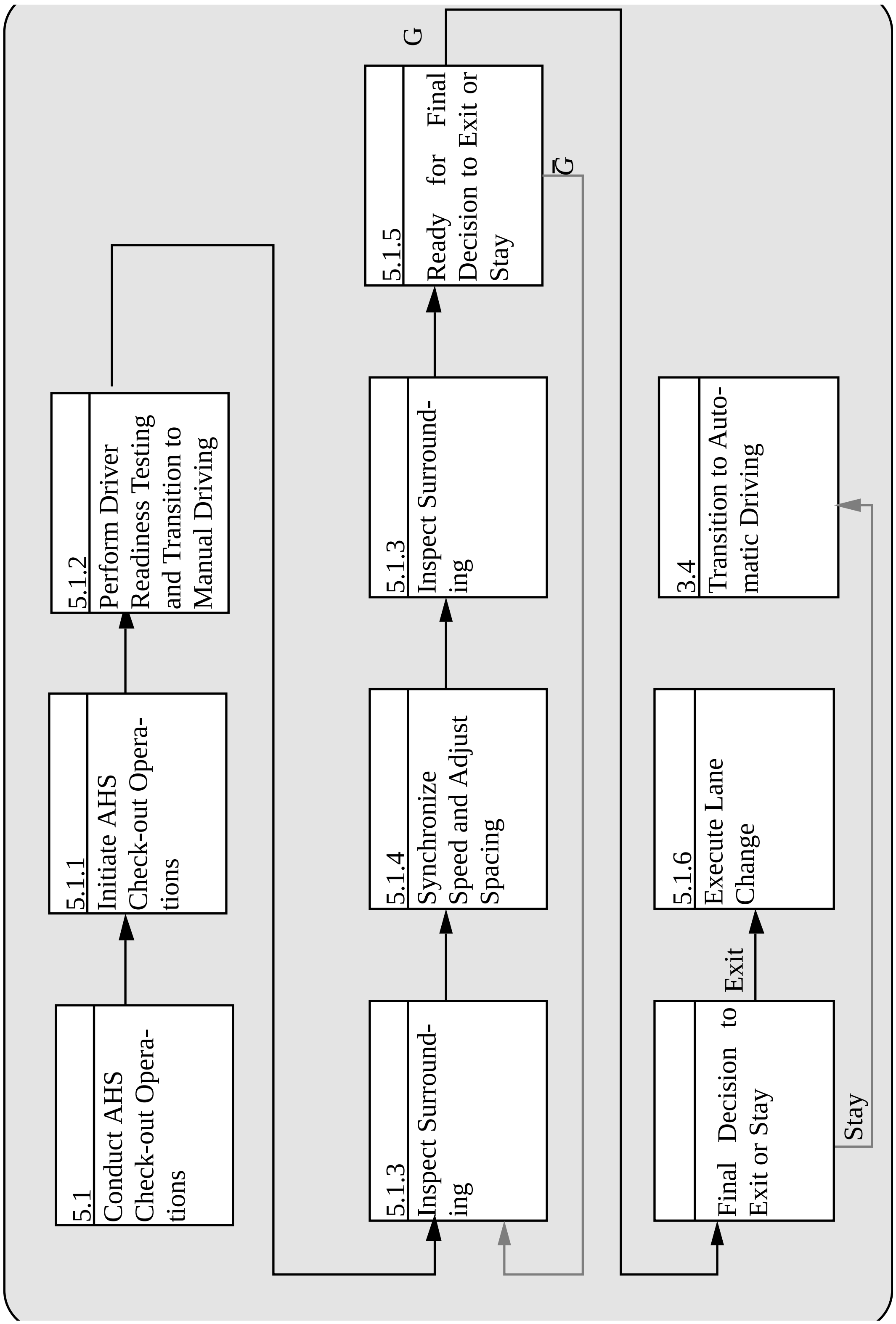

Figure 10: Top-level Check-out Flow Block Diagram for ERSC3 (The solid lines correspond to nominal sequence of operations).

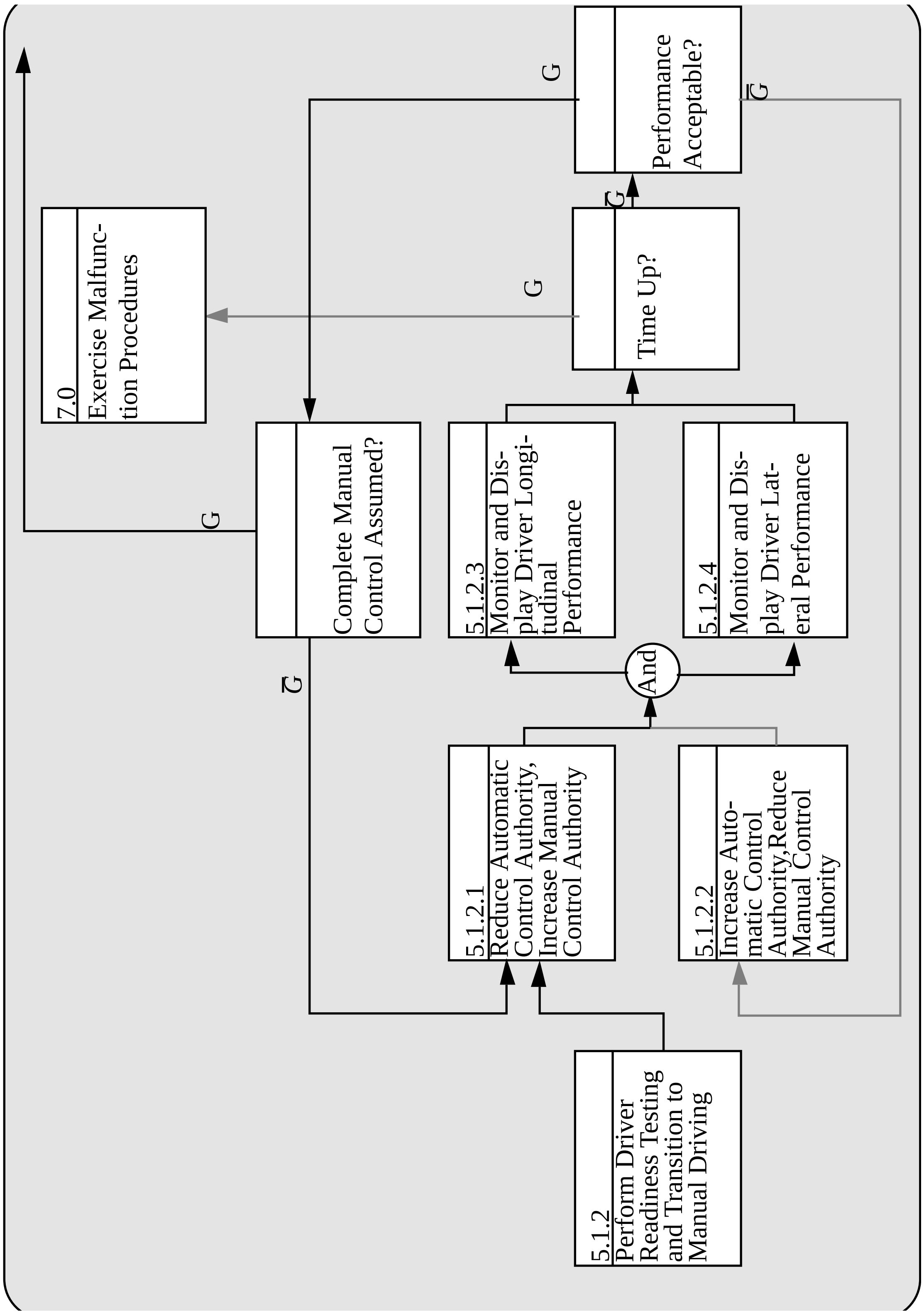

Figure 11: Detailed Flow Block Diagram of the Block 5.1.2 Perform Driver Readiness Testing and Transition to Manual Driving

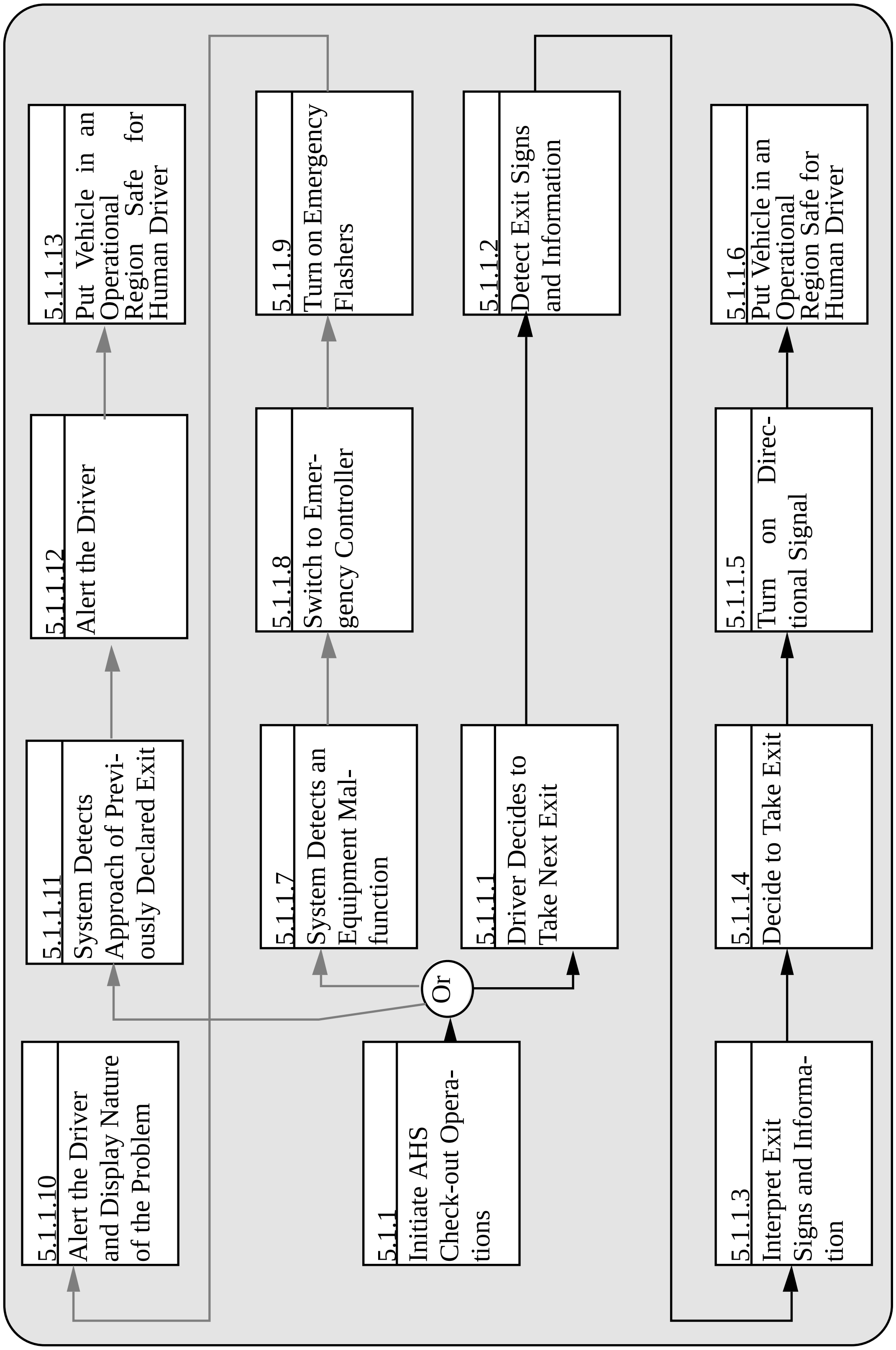

Figure 12: Detailed Flow Block 5.1.1 Initiate AHS Check-out Operations

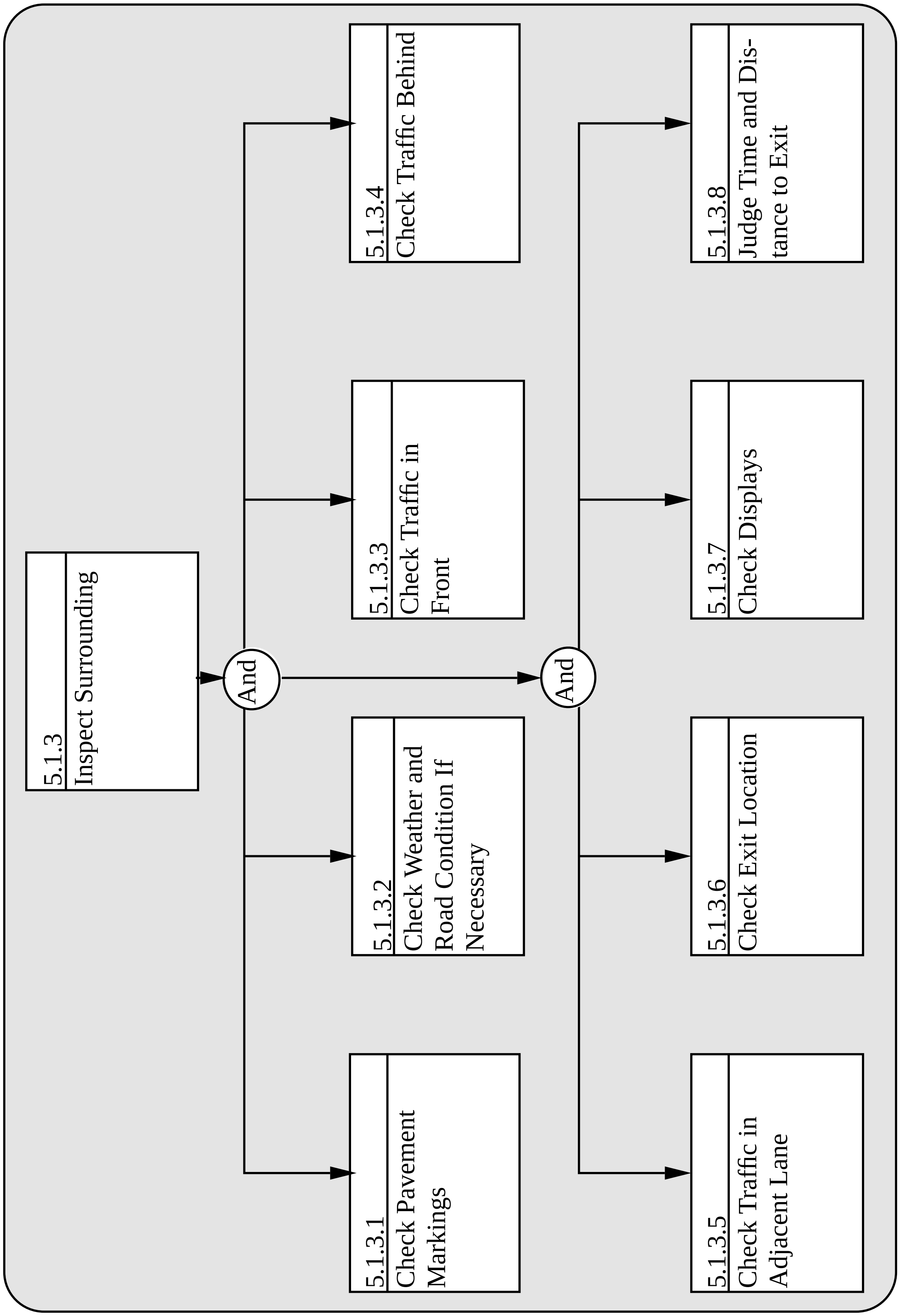

Figure 13: Detailed Flow Diagram of the Block 5.1.3 Inspect Surrounding

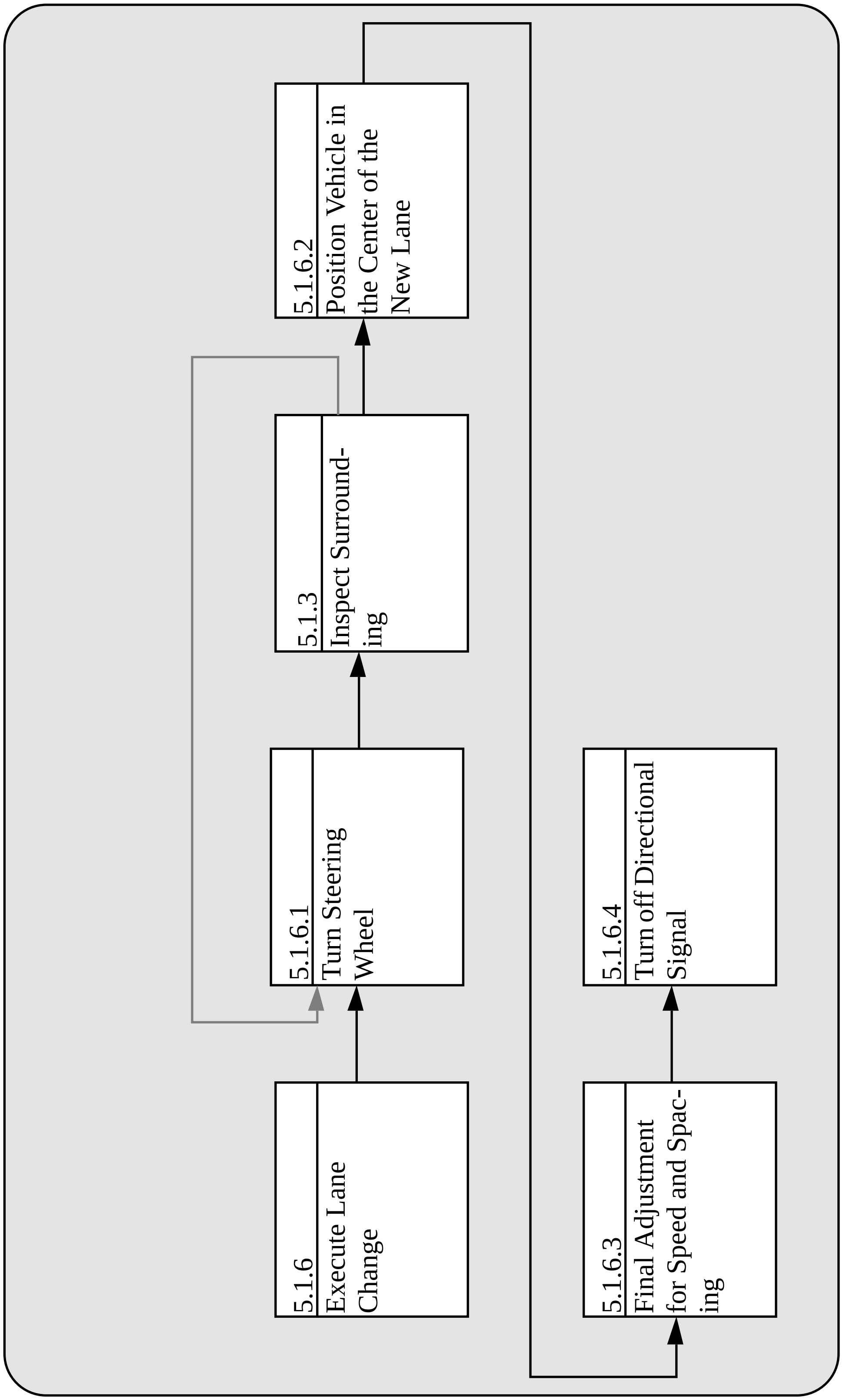

Figure 14: Detailed Flow Block Diagram of the Block 5.1.6 Execute Lane Change

Driver Readiness Testing

Driver readiness testing is a crucial part of the check-out procedures at ERSC3 since we have introduced hands-off/feet-off operation. The driver's alertness and ability to resume lateral and longitudinal control of the vehicle needs to be verified before control is transferred from automatic to manual.

Recent research suggests that there are certain driver performance (e.g. erratic driver seat shifting and steering movements) and psychophysiological characteristics (heart and respiratory rates, blink rate, head nodding) that indicate the possibility of imminent unsafe driving behavior due to drowsiness and impairment [1,2,3,4] . These characteristics are, however, indirect measures of driving capabilities. The direct way to assess driver readiness is to test the driving capabilities of the driver, that is driving performance, which is what we are really interested in evaluating after all. An example of such a procedure is described in Figure 11. This apparently novel driver readiness testing procedure measures driving performance directly, while it appears natural and reasonable to the driver. In this procedure, the authority of the automatic controller is gradually decreased, while the manual control authority is gradually increased. This gradual transfer of control continues as long as the driver is capable of performing the manual control part of this hybrid, automatic/manual controller. The system monitors the driver's progress, and accelerates or slows down the transfer of control from automatic to manual. The system will not sacrifice safety at any point; hence, whenever the driver's performance is determined to be unsatisfactory, the automatic control authority may be increased to adequately control the vehicle. This could be achieved by letting the automatic controller provide an admissible envelope of trajectories for manual control. As an example, the lane keeping automatic controller would reduce the authority of the automated part of the control system such that lane keeping is accomplished to within ten inches as opposed to the nominal tolerance of couple of inches. If the driver is capable of keeping the vehicle centered in the lane within the threshold set by the automatic controller (i.e. ten inches in this example), the threshold is further increased. The speed of this procedure can also be adjusted as a function of the driver's performance, so that a skillful, alert, and fast responding driver could resume control within couple of seconds.

If the highway is essentially straight and level, there is only light traffic, and there are no disturbances, it is conceivable that little input is necessary from the driver in order to control the vehicle adequately, so that the driver's alertness and driving capabilities are not measured with such a procedure. This problem is easily overcome with a design modification that artificially introduces disturbances into the system so that active driver input is required in order to control the vehicle. Introducing such a "persistently exciting" signal is a standard procedure in system identification, and the related design issues are well understood [33] . In the example of lane keeping, this would amount to introducing small artificial forces in the steering that the driver would need to compensate for in order to keep the vehicle centered in the lane.

This driver readiness testing procedure could also be designed to account for individual driver characteristics. The driving behavior (speed of response, maneuver preferences, etc.) of the operator can be identified in manual driving conditions before the vehicle gets on the automated lane using the sensors. A neural network with a standard learning algorithm could be used for this purpose [34] . During the driver readiness testing, this identified model of the driver can be used to establish driver readiness.

The driver readiness procedure example presented above also ensures a safe, effective, and smooth transition from automated to manual driving mode, minimizing the transient errors due to transfer of control. It appears natural to the driver, and the driver dictates the speed of transfer.

Driver Task Analysis

In order to produce information that is relevant to the design of a human/machine system, a task analysis is typically performed. Although there is little agreement over how a task analysis should be performed, partly because of heavy problem dependence, task analysis is an established and frequently used [7,8,9] . It enables the designer to systematically analyze various human factors issues involved in the system. Our approach will be to pick certain operator tasks in the functional flow block diagrams, and perform task analysis on them. The selection of the tasks to be subjected to task analysis will be based on their relevance to check-out operations, and on their criticality. A task will be labeled as “very critical” if a failure in performing that task has a high potential of causing a serious accident. If a task is labeled as “critical”, the system performance will deteriorate in case of failure, but the potential for serious accident is fairly low. A failed task that is designated as “non-critical” will only cause slight performance degradation and usually will not be subjected to a task analysis. It should be noted that our task analysis will focus on key issues and risks, rather than trying to be exhaustive and detail oriented.

The task analysis is performed in the form of tables (Table 6, Table 7, Table 8, Table 9, Table 10, and Table 11). The task numbers in these tables correspond to the numbers used in the functional flow block diagrams presented above. In these tables, first general information about the task is provided. Then, the stimulus or circumstance that prompts action is discussed under “Initiating Cue”. Operator interface issues are discussed under “Feedback” (providing information to the operator about the system operations) and “Control Functions” (receiving commands from the operator). Criteria for success of the task, speed of response, etc. are discussed under “Task Standards”, and factors that may affect the success of the task such as noise levels, illumination, poor equipment design, weather, etc. are discussed under “Task Conditions”. The next row, “Skills Required”, describes the operator skills (psychomotor, cognitive, memory) necessary to complete the task. Potential errors that might cause safety problems, their causes (inattention, memory lapse, time pressure, lack of feedback, poor equipment design, etc.), consequences of these errors on people or the system, and recovery points for these errors where they can be identified and recovered (e.g. alarm, second chance, etc.) are all discussed next. Finally, individual differences such as age, disability, and experience as they relate to the task are described. Each task is then assigned a criticality level as described above.

Table 6: Task Analysis for Task 5.1.1 Initiate AHS Check-out Operations

General	Task is similar to that of manual driving.
Initiating Cue	Signs, recognized surrounding, warning from system may prompt the task.
Feedback	Roadway exit warning, directional signal light indicator.
Control Functions	Directional signal
Task Standards	Nominal durations for the task are in general the same as in manual driving.
Task Conditions	Desirable to have consistent (standardized, e.g., location and style) and visible highway information. Task conditions e.g., weather and night, provide a highly variable task environment.
Skills Required	Cognitive, psychomotor (compatible with manual driving task)
Potential Errors	Failure to recognize signs and information, inability to read signs and receive information, deciding too late, forgetting to turn on signal (hierarchical task analysis, error analysis, workload analysis and human reliability assessment needed to determine full range and impact of human error and methods of error reduction for this and other tasks in check-out).
Causes of Errors	Non-alertness, poor eyesight and/or hearing disability, disorientation, memory problems, time pressure
Consequences of Errors	Too much delay prevents the vehicle from exiting
Recovery Points	Driver may get repeated warnings and be given the chance to exit as long as it is not too late
Individual Differences	Certain drivers, the older, disabled, visually impaired and foreign for example, may need considerably more time in this phase of check out to reduce stress and confusion. Transitional errors may be especially important for these groups. Under low illumination conditions older drivers visibility distances for viewing text signs may be problematic [10] .
Criticality	Critical

Table 7: Task Analysis for Task 5.1.2 Perform Driver Readiness Testing and Transition to Manual Driving

General	Procedure to assess driver readiness and to transition from automatic to manual control
Initiating Cue	Warning from system
Feedback	Start testing display, performance of the driver display, percent completed display, steering wheel and accelerator/brake pedal movements
Control Functions	Steering wheel and accelerator/brake pedal action
Task Standards	Nominal durations depend on driver alertness and skill
Task Conditions	Weather, type of warnings, physical characteristics of roadway (curves, grade)
Skills Required	Cognitive, motor
Potential Errors	Failure to start testing, poor test performance, quitting test early
Causes of Errors	Non-alertness, poor eye sight and/or hearing disability, disorientation, time pressure, poor motor skills, poor perceptional skills, slow reaction time
Consequences of Errors	Too much delay prevents the vehicle from exiting
Recovery Points	Driver may get repeated warnings and be given the chance to complete the test as long as it is not too late
Individual Differences	Certain drivers, the older, disabled, and visually impaired, for example, may need considerably more time in this phase of check out. Transitional errors may be especially important for these groups.
Criticality	Critical

Table 8: Task Analysis for Task 5.1.3 Inspect Surrounding

General	Task is analogous to that of manual driving.
Initiating Cue	Requires design of signal indicating completion of transfer of control. Because driver may already have begun inspection of surrounding, this signal will need to be either auditory or auditory/visual to attract attention.
Feedback	Not Applicable
Control Functions	Not Applicable
Task Standards	Inspection of rear view mirror, right side mirror and turning head and shoulders to look through right side and rear windows are involved. Duration is comparable to that involved in manual driving.
Task Conditions	Environment, roadway conditions, traffic situation and distractions (e.g., rain, complex traffic, low visibility, glare) may significantly increase time for inspection.
Skills Required	Estimation of distances and judgment about gap needed for lane changing.
Potential Errors	Failure to detect objects, vehicles, roadway boundaries etc.
Causes of Errors	Non-alertness, poor eye sight and/or hearing disability, disorientation, time pressure, poor perceptual skills, poor and/or slow spatial judgment
Consequences of Errors	Potential collision
Recovery Points	Blind spot warnings (design issues involve attention -getting, directional cues, easily discriminated from competing and background signals, and intensities below the threshold for startle [11]), warnings from other drivers, subsequent surrounding inspection.
Individual Differences	Accident statistics, citations and self report data all indicate older drivers have difficulty in merging, changing lanes, and exiting maneuvers. Limited upper body mobility adversely impact the older person's ability to scan to the rear when backing, turning and merging [12,13] . Similar issues for disabled drivers. Data suggests persons over 65 may be over represented in lane change/merge crashes [14] .
Criticality	Critical

Table 9: Task Analysis for Task 5.1.4 Synchronize Speed and Adjust Spacing

General	Task is overall similar to the task in manual driving.
Initiating Cue	Completion of Surrounding Inspection
Feedback	Not Applicable
Control Functions	Throttle/brake pedal actuation
Task Standards	Nominal times and task standards are similar to manual driving [15].
Task Conditions	Weather, physical characteristics of roadway (curves, grade), low illumination
Skills Required	Specific cognitive skills of spatial judgment and psychomotor tracking are necessary to position the vehicle for exit.
Potential Errors	Failure to synchronize, and adjust spacing
Causes of Errors	Non-alertness, poor eye sight and/or hearing disability, disorientation, time pressure, poor perceptual skills, poor and/or slow spatial judgment
Consequences of Errors	The probability of an accident occurring during this task is low. However, if errors do occur, they could result in a catastrophic accident here and during the subsequent exit. Otherwise, delay in exiting is the only consequence.
Recovery Points	Repeat the process.
Individual Differences	Individual differences (e.g. age and driving skills) in the judgment of spacing needed to confidently execute exit.
Criticality	Critical

Table 10: Task Analysis for Task Final Decision to Exit or Stay

General	As in the case with manual driving this involves completing cognitive appraisal of the surrounds and the final decision to initiate exit.
Initiating Cue	Specific cue is completion of Surrounding Inspection Task, then the approach of the exit and other environment cues such as the traffic conditions and time judged necessary to complete highway exit.
Feedback	Not Applicable
Control Functions	Not Applicable
Task Standards	Time required is comparable to manual driving. The time involved depends upon the complexity of the decision to be made. Absolute time heavily depends upon task conditions, and individual differences, e.g., traffic, weather, illumination, roadway, age and experience.
Task Conditions	Weather, physical characteristics of roadway (curves, grade).
Skills Required	Estimation of distances and judgment about gap needed for lane changing [16,17] .
Potential Errors	Error of omission: Failure to decide to exit when it should be initiated. Error of commission: Decision to exit when it should not be initiated.
Causes of Errors	Non-alertness, time pressure, poor and/or slow spatial judgment, slow decision process
Consequences of Errors	Consequences depends upon whether it is an error of omission or commission. The first may cause delay and thus influence efficiency of traffic flow the second increases the probability of an accident.
Recovery Points	Until the decision to initiate exit is made the driver may abort and return to reappraisal of the surround or return to auto driving.
Individual Differences	Generally decision times increase with age. For simple tasks this increase is small, for complex tasks it represents most of the increase in response time observed [18,12] .
Criticality	Very Critical

Table 11: Task Analysis for Task 5.1.6 Execute Lane Change

General	Psychomotor task is essentially the same as in manual driving.
Initiating Cue	Decision to exit
Feedback	Not Applicable
Control Functions	Steering wheel movements
Task Standards	Durations same as in manual driving.
Task Conditions	Weather, low illumination, traffic density and speed are examples of conditions that may affect the time to make change lanes.
Skills Required	For the experienced driver this is a highly practiced psychomotor task.
Potential Errors	Improper maneuver, poor control in the new lane
Causes of Errors	Non-alertness, poor eye sight and/or hearing disability, disorientation, time pressure, poor perceptual skills, poor and/or slow spatial judgment, slow decision process
Consequences of Errors	Approximately 4% of crashes and 0.5% of fatalities are of the lane change merge variety. Some 95% of crashes are the angle/sideswipe and only 5% of a rear end variety [14] .
Recovery Points	Lateral Collision warning signals require careful human interface design. Design issues involve attention -getting, directional cues, easily discriminated from competing and background signals, and intensities below the threshold for startle [11] .
Individual Differences	Accident statistics, citations and self report data all indicate older drivers have difficulty in merging, changing lanes, and exiting maneuvers. Data suggests persons over 65 may be over represented in lane change/merge crashes [14] .
Criticality	Very Critical

Issues, Risks, and Recommendations

Design Issues:

The major design issue is the design of the driver readiness testing. We have shown that, by appropriate design considerations, driver readiness testing procedures can be created such that they measure driving performance directly, while they appear natural and reasonable to the driver. We presented such a novel testing procedure which also ensures a safe, effective, and smooth transition from automated to manual driving mode.

Driver Issues:

The major driver issue emerging at ERSC3 check-out that distinguish it from the traditional manual driving situation is how the driver readiness is going to be perceived by the driver. The specific readiness testing design characteristics and the kinds and extent of support information (signs, in vehicle displays, warnings) that would enhance acceptance, efficiency and safety will determine user friendliness. There are a wide variety of studies and guidelines for operator interface that are applicable at ERSC3. (See references 19,20,7,21,22,8,23,24,25,26,27.) There are alternative display technologies, e.g. Head-up displays (HUD), Liquid Crystal Displays (LCD), Light-Emitting Diode (LEDO), computer generated voice message, sudden vehicle acceleration/deceleration (jerk), and tactile feedback. The interface can be continuous, or perhaps more appropriately activated when a driver action is needed or at the driver's request. The concept of generating progressively stronger warnings may be applied to devise an operationally acceptable interface. How to design the best user interface for AHS operations is still an open issue, and involves selecting a display technology, type and duration of warnings, user controls type and location, etc. Ultimately, experiments on simulators and actual vehicles will need to be carried out to determine the system characteristics that make the system appear natural to the driver, the best way to present the data to the driver, and the most convenient way for the driver to input commands.

User acceptance is the second important issue [28,29] . Since many functions at this ERSC are expected to be developed independent of AHS, user friendliness to ensure public acceptance should be integrated into the design process by the manufacturer for each function. The Daimler-Benz study is a good example for this kind of effort [6]. The possibility that the ERSC3 level of automation will pose special acceptance and user problems for the elderly, disabled and inexperienced drivers is a third issue. These sub-populations should be routinely incorporated in simulator and vehicle studies done for check-out at this level of automation and special studies conducted on acceptance and usability under a variety of anticipated highway conditions.

Institutional Issues:

Legal and liability issues are very important for the deployment of AHS [30] . Therefore, designing a fail-safe system is a basic requirement.

Another major issue for implementation of AHS is dedicating a lane to AHS operations. Construction of a new lane will be costly, and taking away an existing lane from manual traffic may provoke major political turbulence [31,32] . It may therefore be necessary to consider scenarios in which various ERSC level vehicles coexist in the early phases of the deployment.

Program Issues:

Many functions at ERSC3 are expected to be developed independent of AHS. Working out details of dedicating a lane will be the major activity required. The deployment schedule will depend on the availability of independently developed components.

User Type Issues:

There are no specific user type issues at ERSC3.

Key Findings

- By appropriate design considerations, driver readiness testing procedures can be created such that they measure driving performance directly, while they appear natural and reasonable to the driver. We presented such a novel testing procedure which also ensures a safe, effective, and smooth transition from automated to manual driving mode.
- The operator interface issues may be left to vehicle manufacturers and consumers to resolve within the context of competitive market forces. This process would also involve human factors experiments and experience.

Evolutionary Representative System Configuration Four (ERSC4)

At ERSC4, automated lane changing and lateral collision avoidance are introduced. In order to accomplish this, maneuver coordination is improved. Also, the vehicle can now perform route planning.

As previously discussed, there are four general system functions involved in a check-out operation. For ERSC4, we have the following specific functions:

1. The system may alert the driver that exit operations should be initiated. This could be prompted by a system detected malfunction for which the driver is part of the malfunction management strategy, or the vehicle may be approaching the intended exit previously declared by the driver.
2. The system puts the vehicle in an operational region, that is, within the capabilities of the human driver. This will involve increasing the headway and reducing the speed, such that the human driver is capable of resuming control.
3. The system performs a driver readiness test to assess readiness of the driver to resume control.
4. The control of the vehicle is transferred to the human driver.

In our approach, the last two steps will be combined into one. We will discuss the details of the driver readiness test later.

Designated Check-out with a Dedicated Ramp

In this scenario, the vehicle guides itself automatically onto the exit ramp. Figure 3 illustrates this scenario conceptually. The functions of the driver, roadway, and vehicle in this scenario are described as follows:

Driver Functions: The driver may initiate the check-out operations, and she/he takes over the control of the vehicle after the vehicle exits the automated lane.

Vehicle Functions: The vehicle may alert the driver that check-out operations should be initiated. This could be prompted by a system detected malfunction for which the driver is part of the malfunction management strategy, or the vehicle may be approaching the intended exit previously declared by the driver. Then the vehicle guides itself automatically onto the ramp, and supervises the driver readiness testing.

Roadway Functions: Apart from providing the dedicated lane with lane keeping reference aids, the roadway provides headway and speed recommendations, and traffic information to the vehicles. The roadway may also aid in gap synchronization via signs and communications.

Designated Check-out without a Dedicated Ramp

In this scenario, the vehicle guides itself automatically into the manual lane. Figure 4 illustrates this scenario conceptually. The functions of the driver, roadway, and vehicle in this scenario are described as follows:

Driver Functions: The driver may initiate the check-out operations and she/he takes over the control of the vehicle after the vehicle exits the automated lane.

Vehicle Functions: The vehicle may alert the driver that check-out operations should be initiated. This could be prompted by a system detected malfunction for which the driver is part of the malfunction management strategy, or the vehicle may be approaching the intended exit previously declared by the driver. Then the vehicle guides itself automatically into the manual lane, and supervises the driver readiness testing.

Roadway Functions: Apart from providing the dedicated lane with lane keeping reference aids, the roadway provides headway and speed recommendations, and traffic information to the vehicles. The roadway may also help in gap synchronization in the manual lane via roadway signs or communications.

Continuous Check-out

In this check-out scenario, the vehicle guides itself automatically into the manual lane. Figure 5 illustrates this scenario conceptually. The functions of the driver, roadway, and vehicle in this scenario are described as follows:

Driver Functions: The driver may initiate the check-out operations and she/he takes over the control of the vehicle after the vehicle exits the automated lane.

Vehicle Functions: The vehicle may alert the driver that check-out operations should be initiated. This could be prompted by a system detected malfunction for which the driver is part of the malfunction management strategy, or the vehicle may be approaching the intended exit previously declared by the driver. Then the vehicle guides itself automatically into the manual lane, and supervises the driver readiness testing.

Roadway Functions: Apart from providing the dedicated lane with lane keeping reference aids, the roadway provides headway and speed recommendations, and traffic information to the vehicles. The roadway may also help in gap synchronization in the manual lane via roadway signs or communications.

Functional Flow Block Diagrams

The functional flow block diagram shown in Figure 15 defines the various functions involved in the check-out process. The solid lines in this diagram correspond to nominal sequence of operations.

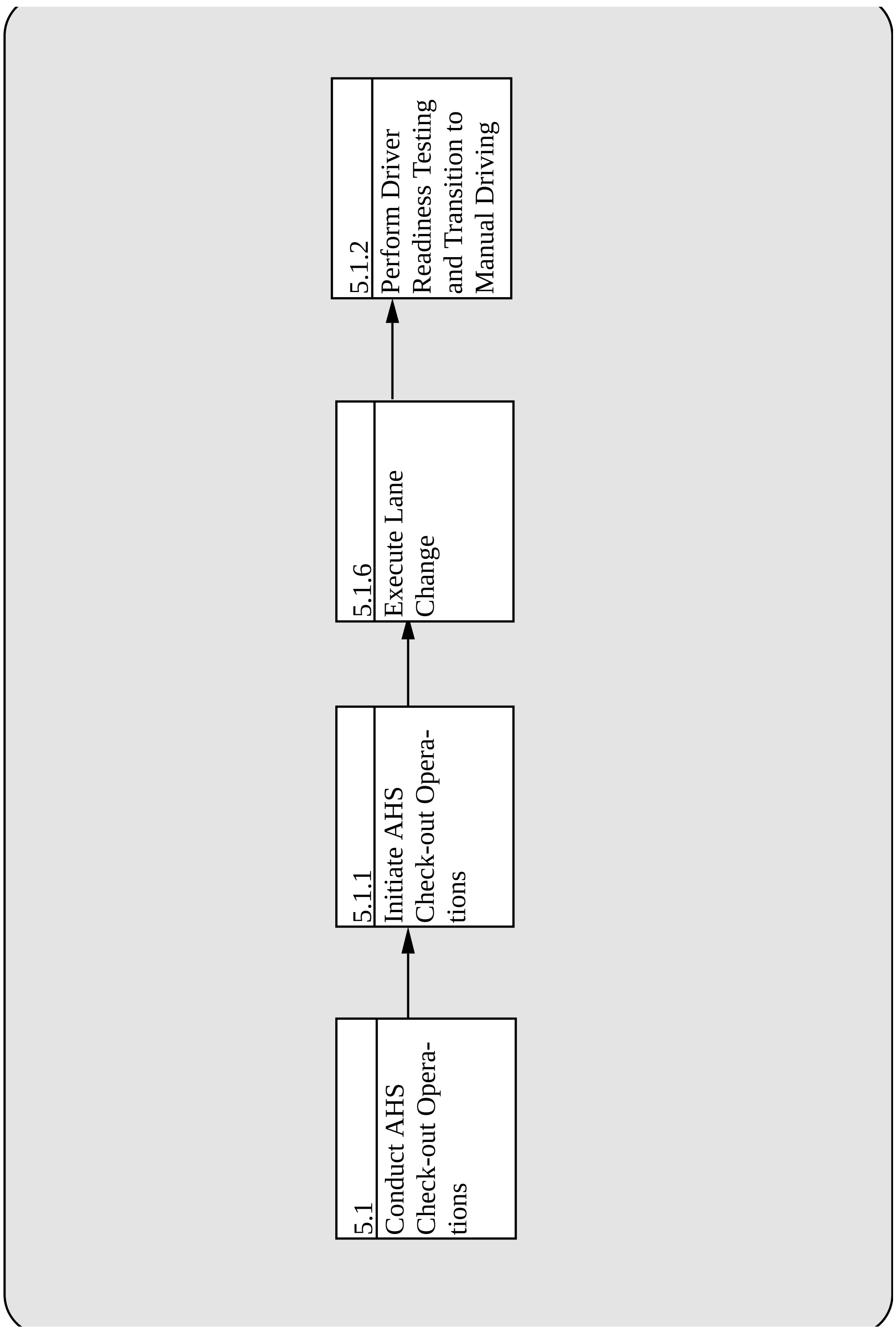

Figure 15: Top-level Check-out Flow Block Diagram for ERSC4 (The solid lines correspond to nominal sequence of operations).

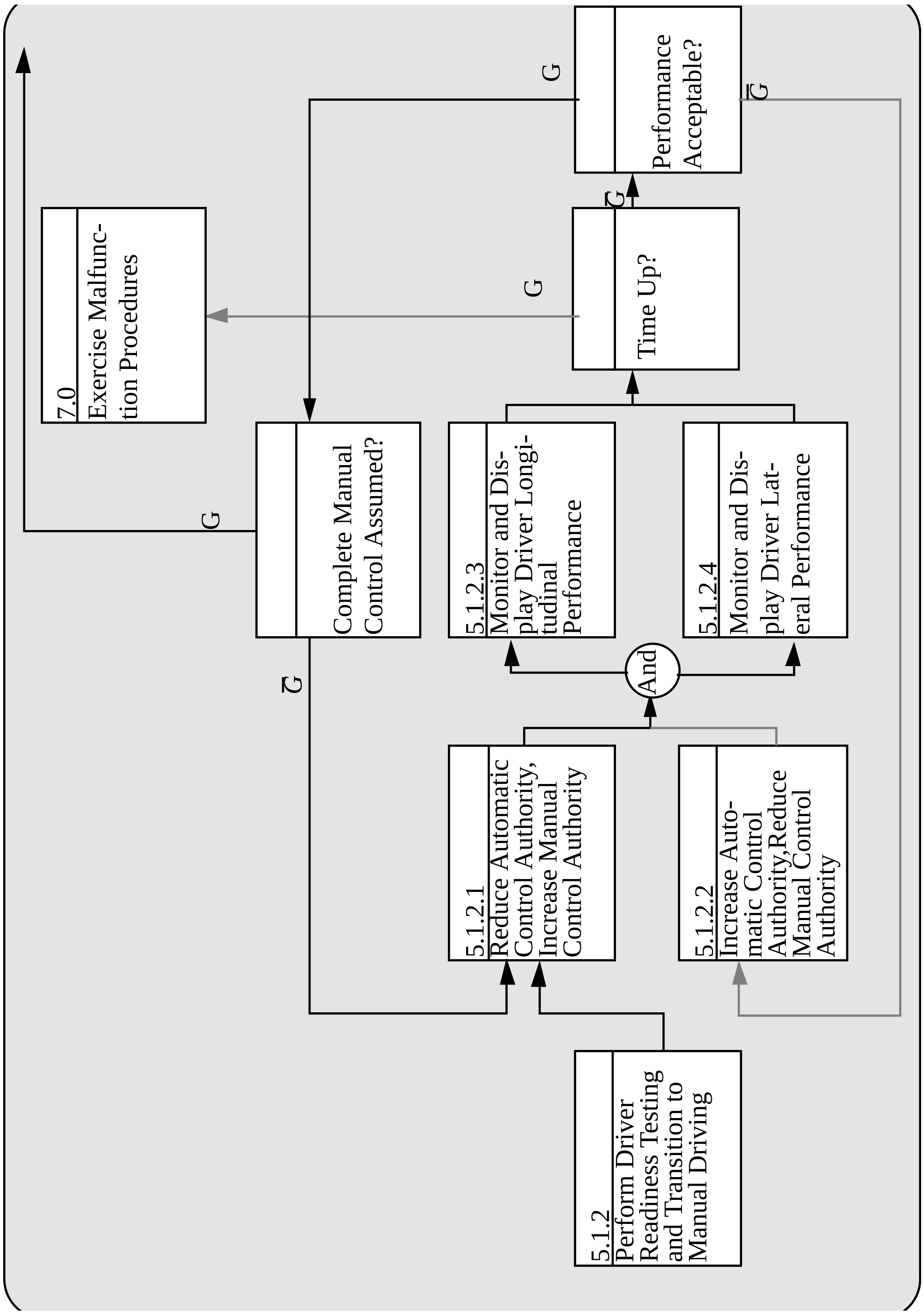

Figure 16: Detailed Flow Block Diagram of the Block 5.1.2 Perform Driver Readiness Testing and Transition to Manual Driving

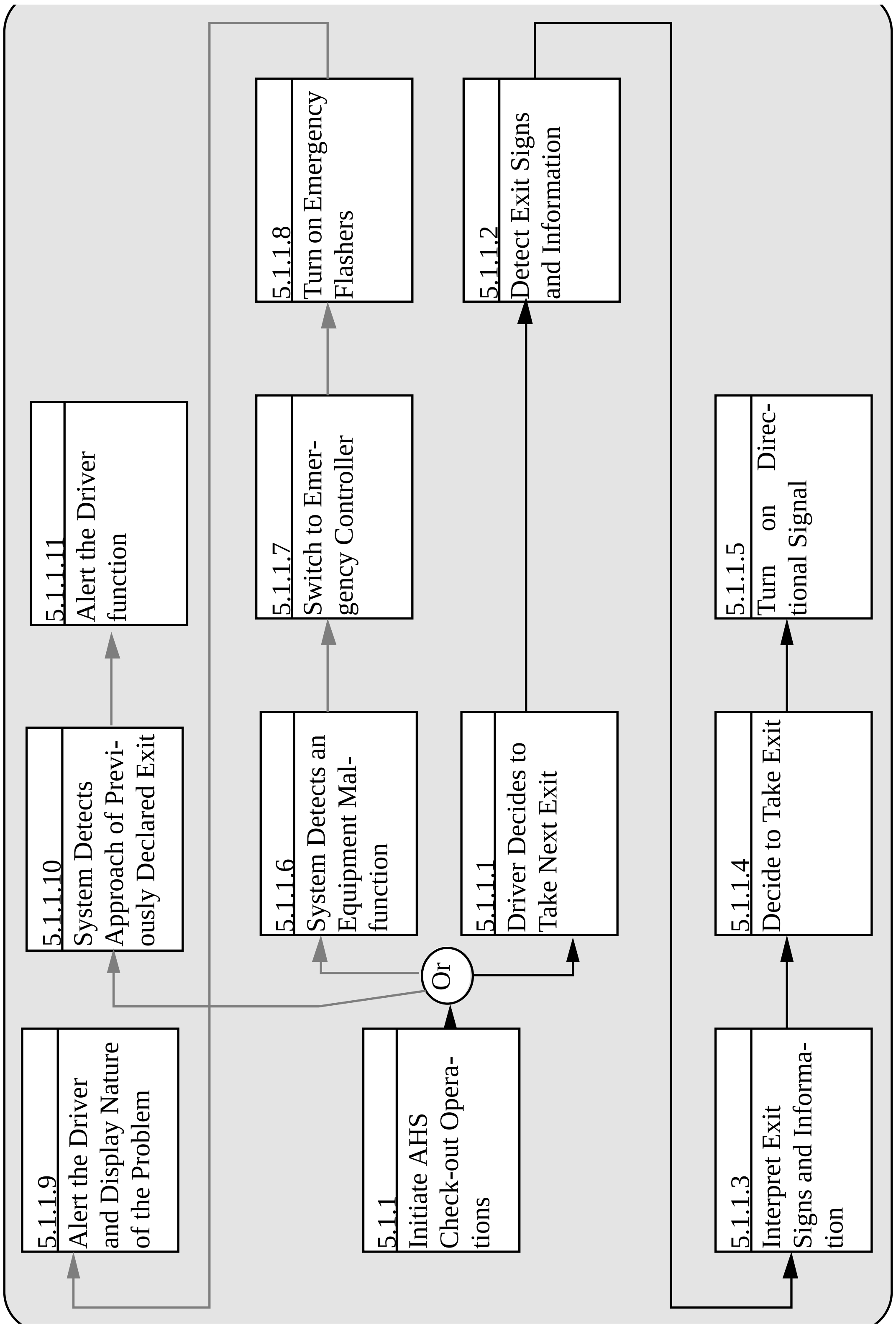

Figure 17: Detailed Flow Block Diagram of the Block 5.1.1 Initiate AHS Check-out Operations

Driver Readiness Testing

Driver readiness testing is a crucial part of the check-out procedures at ERSC4 since we have hands-off/feet-off operation. The driver's alertness and ability to resume lateral and longitudinal control of the vehicle needs to be verified before control is transferred from automatic to manual.

Recent research suggests that there are certain driver performance (e.g. erratic driver seat shifting and steering movements) and psychophysiological characteristics (heart and respiratory rates, blink rate, head nodding) that indicate the possibility of imminent unsafe driving behavior due to drowsiness and impairment [1,2,3,4] . These characteristics are, however, indirect measures of driving capabilities. The direct way to assess driver readiness is to test the driving capabilities of the driver, that is driving performance, which is what we are really interested in evaluating after all. An example of such a procedure is described in Figure 16. This apparently novel driver readiness testing procedure measures driving performance directly, while it appears natural and reasonable to the driver. In this procedure, the authority of the automatic controller is gradually decreased, while the manual control authority is gradually increased. This gradual transfer of control continues as long as the driver is capable of performing the manual control part of this hybrid, automatic/manual controller. The system monitors the driver's progress, and accelerates or slows down the transfer of control from automatic to manual. The system will not sacrifice safety at any point; hence, whenever the driver's performance is determined to be unsatisfactory, the automatic control authority may be increased to adequately control the vehicle. This could be achieved by letting the automatic controller provide an admissible envelope of trajectories for manual control. As an example, the lane keeping automatic controller would reduce the authority of the automated part of the control system such that lane keeping is accomplished to within ten inches as opposed to the nominal tolerance of couple of inches. If the driver is capable of keeping the vehicle centered in the lane within the threshold set by the automatic controller (i.e. ten inches in this example), the threshold is further increased. The speed of this procedure can also be adjusted as a function of the driver's performance, so that a skillful, alert, and fast responding driver could resume control within couple of seconds.

If the highway is essentially straight and level, there is only light traffic, and there are no disturbances, it is conceivable that little input is necessary from the driver in order to control the vehicle adequately, so that the driver's alertness and driving capabilities are not measured with such a procedure. This problem is easily overcome with a design modification that artificially introduces disturbances into the system so that active driver input is required in order to control the vehicle. Introducing such a "persistently exciting" signal is a standard procedure in system identification, and the related design issues are well understood [33] . In the example of lane keeping, this would amount to introducing small artificial forces in the steering that the driver would need to compensate for in order to keep the vehicle centered in the lane.

This driver readiness testing procedure could also be designed to account for individual driver characteristics. The driving behavior (speed of response, maneuver preferences, etc.) of the operator can be identified in manual driving conditions before the vehicle gets on the automated lane using the sensors. A neural network with a standard learning algorithm could be used for this purpose [34] . During the driver readiness testing, this identified model of the driver can be used to establish driver readiness.

The driver readiness procedure example presented above also ensures a safe, effective, and smooth transition from automated to manual driving mode, minimizing the transient errors due to transfer of control. It appears natural to the driver, and the driver dictates the speed of transfer.

Driver Task Analysis

In order to produce information that is relevant to the design of a human/machine system, a task analysis is typically performed. Although there is little agreement over how a task analysis should be performed, partly because of heavy problem dependence, task analysis is an established and frequently used tool [7,8,9] . It enables the designer to systematically analyze various human factors issues involved in the system. Our approach will be to pick certain operator tasks in the functional flow block diagrams, and perform task analysis on them. The selection of the tasks to be subjected to task analysis will be based on their relevance to check-out operations, and on their criticality. A task will be labeled as “very critical” if a failure in performing that task has a high potential of causing a serious accident. If a task is labeled as “critical”, the system performance will deteriorate in case of failure, but the potential for serious accident is fairly low. A failed task that is designated as “non-critical” will only cause slight performance degradation, and usually will not be subjected to a task analysis. It should be noted that our task analysis will focus on key issues and risks, rather than trying to be exhaustive and detail oriented.

The task analysis is performed in the form of tables (Table 12, Table 13). The task numbers in these tables correspond to the numbers used in the functional flow block diagrams presented above. In these tables, first general information about the task is provided. Then, the stimulus or circumstance that prompts action is discussed under “Initiating Cue”. Operator interface issues are discussed under “Feedback” (providing information to the operator about the system operations) and “Control Functions” (receiving commands from the operator). Criteria for success of the task, speed of response, etc. are discussed under “Task Standards”, and factors that may affect the success of the task such as noise levels, illumination, poor equipment design, weather, etc. are discussed under “Task Conditions”. The next row, “Skills Required”, describes the operator skills (psychomotor, cognitive, memory) necessary to complete the task. Potential errors that might cause safety problems, their causes (inattention, memory lapse, time pressure, lack of feedback, poor equipment design, etc.), consequences of these errors on people or the system, and recovery points for these errors where they can be identified and recovered (e.g. alarm, second chance, etc.) are all discussed next. Finally, individual differences such as age, disability, and experience as they relate to the task are described. Each task is then assigned a criticality level as described above.

Table 12: Task Analysis for Task 5.1.1 Initiate AHS Check-out Operations

General	Task is similar to that of manual driving.
Initiating Cue	Signs, recognized surrounding, warning from system may prompt the task.
Feedback	Roadway exit warning, directional signal light indicator.
Control Functions	Directional signal
Task Standards	Nominal durations for the task are in general the same as in manual driving.
Task Conditions	Desirable to have consistent (standardized, e.g., location and style) and visible highway information. Task conditions e.g., weather and night, provide a highly variable task environment.
Skills Required	Cognitive, psychomotor (compatible with manual driving task)
Potential Errors	Failure to recognize signs and information, inability to read signs and receive information, deciding too late, forgetting to turn on signal (hierarchical task analysis, error analysis, workload analysis and human reliability assessment needed to determine full range and impact of human error and methods of error reduction for this and other tasks in check-out).
Causes of Errors	Non-alertness, poor eyesight and/or hearing disability, disorientation, memory problems, time pressure
Consequences of Errors	Too much delay prevents the vehicle from exiting
Recovery Points	Driver may get repeated warnings and be given the chance to exit as long as it is not too late
Individual Differences	Certain drivers, the older, disabled, visually impaired and foreign for example, may need considerably more time in this phase of check out to reduce stress and confusion. Transitional errors may be especially important for these groups. Under low illumination conditions older drivers visibility distances for viewing text signs may be problematic [10] .
Criticality	Critical

Table 13: Task Analysis for Task 5.1.2 Perform Driver Readiness Testing and Transition to Manual Driving

General	Procedure to assess driver readiness and to transition from automatic to manual control
Initiating Cue	Warning from system
Feedback	Start testing display, performance of the driver display, percent completed display, steering wheel and accelerator/brake pedal movements
Control Functions	Steering wheel and accelerator/brake pedal action
Task Standards	Nominal durations depend on driver alertness and skill
Task Conditions	Weather, type of warnings, physical characteristics of roadway (curves, grade)
Skills Required	Cognitive, motor
Potential Errors	Failure to start testing, poor test performance, quitting test early
Causes of Errors	Non-alertness, poor eye sight and/or hearing disability, disorientation, time pressure, poor motor skills, poor perceptional skills, slow reaction time
Consequences of Errors	Too much delay prevents the vehicle from exiting
Recovery Points	Driver may get repeated warnings and be given the chance to complete the test as long as it is not too late
Individual Differences	Certain drivers, the older, disabled, and visually impaired, for example, may need considerably more time in this phase of check out. Transitional errors may be especially important for these groups.
Criticality	Critical

Issues, Risks, and Recommendations

Design Issues:

The major design issue is the design of the driver readiness testing procedure. We have shown that, by appropriate design considerations, driver readiness testing procedures can be created such that they measure driving performance directly, while they appear natural and reasonable to the driver. We presented such a novel testing procedure which also ensures a safe, effective, and smooth transition from automated to manual driving mode.

Since the driver readiness testing is performed on the exit ramps or in the manual lanes, the issue of modification of ramps or manual lanes to allow lane keeping arises. For designated exit configurations, this is easily accomplished, but for continuous exit, portions of the manual lane need to be modified to allow lane keeping. In addition, there is the issue of what to do with the vehicles whose drivers fail the readiness tests. One solution may be to guide these vehicles to special areas where they can be brought to a stop. If these kinds of areas are not available, the vehicle would still be stopped, but this would cause disturbance to traffic on the ramp or in the manual lanes.

Driver Issues:

The major driver issue emerging at ERSC4 check-out that distinguish it from the traditional manual driving situation is how the driver readiness is going to be perceived by the driver. The specific readiness testing design characteristics and the kinds and extent of support information (signs, in vehicle displays, warnings) that would enhance acceptance, efficiency and safety will determine user friendliness. There are a wide variety of studies and guidelines for operator interface that are applicable at ERSC4. (See references 19,20,7,21,22,8,23,24,25,26,27.) There are alternative display technologies, e.g. Head-up displays (HUD), Liquid Crystal Displays (LCD), Light-Emitting Diode (LEDO), computer generated voice message, sudden vehicle acceleration/deceleration (jerk), and tactile feedback. The interface can be continuous, or perhaps more appropriately activated when a driver action is needed or at the driver's request. The concept of generating progressively stronger warnings may be applied to devise an operationally acceptable interface. How to design the best user interface for AHS operations is still an open issue, and involves selecting a display technology, type and duration of warnings, user controls type and location, etc. Ultimately, experiments on simulators and actual vehicles will need to be carried out to determine the system characteristics that make the system appear natural to the driver, the best way to present the data to the driver, and the most convenient way for the driver to input commands.

User acceptance is the second important issue [28,29] . Since many functions at this ERSC are expected to be developed independent of AHS, user friendliness to ensure public acceptance should be integrated into the design process by the manufacturer for each function The Daimler-Benz study is a good example for this kind of effort [6] .

The possibility that the ERSC4 level of automation will pose special acceptance and user problems for the elderly, disabled and inexperienced drivers is a third issue. These sub-populations should be routinely incorporated in simulator and vehicle studies done for check-out at this level of automation and special studies conducted on acceptance and usability under a variety of anticipated highway conditions.

Institutional Issues:

Legal and liability issues are very important for the deployment of AHS[30] . Therefore, designing a fail-safe system is a basic requirement.

Another major issue for implementation of AHS is dedicating a lane to AHS operations. Construction of a new lane will be costly, and taking away an existing lane from manual traffic may provoke major political turbulence [31,32] . It may therefore be necessary to consider scenarios in which various ERSC level vehicles coexist in the early phases of the deployment.

Program Issues:
Many functions at ERSC4 are expected to be developed independent of AHS. Working out details of dedicating lanes will be the major activity required. The deployment schedule will depend on the availability of independently developed components.
User Type Issues:
There are no specific user type issues at ERSC4.

Key Findings

- By appropriate design considerations, driver readiness testing procedures can be created such that they measure driving performance directly, while they appear natural and reasonable to the driver. We presented such a novel testing procedure which also ensures a safe, effective, and smooth transition from automated to manual driving mode.
- The exit ramp or portions of the manual lane need to be modified to allow lane keeping operations, since the transition from automated to manual control now takes place on the ramp or in the manual lanes.
- The vehicles whose drivers fail the driver readiness test will be brought to a stop. A designated area for this purpose is desirable.
- The operator interface issues may be left to vehicle manufacturers and consumers to resolve within the context of competitive market forces. This process would also involve human factors experiments and experience.

Evolutionary Representative System Configuration Five (ERSC5)

At ERSC5, the roadway coordinates vehicle maneuvers, sends lateral/longitudinal control commands to each vehicle, and receives speed, acceleration, headway, and destination information from each vehicle. Route planning is also performed by the roadway.

As previously discussed, there are four general system functions involved in a check-out operation. For ERSC5, we have the following specific functions:

1. The system may alert the driver that exit operations should be initiated. This could be prompted by a system detected malfunction for which the driver is part of the malfunction management strategy, or the vehicle may be approaching the intended exit previously declared by the driver.
2. The system puts the vehicle in an operational region that is within the capabilities of the human driver. This will involve increasing the headway and reducing the speed, such that the human driver is capable of resuming control.
3. The system performs a driver readiness test to assess readiness of the driver to resume control.
4. The control of the vehicle is transferred to the human driver.

In our approach, the last two steps will be combined into one.

Designated Check-out with a Dedicated Ramp

In this scenario, the roadway guides the vehicle automatically onto the exit ramp. Figure 3 illustrates this scenario conceptually. The functions of the driver, roadway, and vehicle in this scenario are described as follows:

Driver Functions: The driver may initiate the check-out operations and she/he takes over the control of the vehicle after the vehicle exits the automated lane.

Vehicle Functions: The vehicle may alert the driver that check-out operations should be initiated. This could be prompted by a system detected malfunction for which the driver is part of the malfunction management strategy, or the vehicle may be approaching the intended exit previously declared by the driver. The vehicle also provides lateral detection sensor output to the roadway so that the roadway can issue control commands. When the vehicle is on the exit ramp, the vehicle supervises the driver readiness testing.

Roadway Functions: Apart from providing the dedicated lane with lane keeping reference aids, the roadway provides control commands to the vehicles to guide the vehicles to the exit ramp.

Designated Check-out without a Dedicated Ramp

In this scenario, the roadway guides the vehicle automatically into the manual lane. Figure 4 illustrates this scenario conceptually. The functions of the driver, roadway, and vehicle in this scenario are described as follows:

Driver Functions: The driver may initiate the check-out operations and she/he takes over the control of the vehicle after the vehicle exits the automated lane.

Vehicle Functions: The vehicle may alert the driver that check-out operations should be initiated. This could be prompted by a system detected malfunction for which the driver is part of the malfunction management strategy, or the vehicle may be approaching the intended exit previously declared by the driver. The vehicle also provides lateral detection sensor output to the roadway so that the roadway can issue control commands. When the vehicle is in the manual lane, the vehicle supervises the driver readiness testing.

Roadway Functions: Apart from providing the dedicated lane with lane keeping reference aids, the roadway provides control commands to the vehicles to guide the vehicles to the manual lane.

Continuous Check-out

In this check-out scenario, the roadway guides the vehicle automatically into the manual lane. Figure 5 illustrates this scenario conceptually. The functions of the driver, roadway, and vehicle in this scenario are described as follows:

Driver Functions: The driver may initiate the check-out operations and she/he takes over the control of the vehicle after the vehicle exits the automated lane.

Vehicle Functions: The vehicle may alert the driver that check-out operations should be initiated. This could be prompted by a system detected malfunction for which the driver is part of the malfunction management strategy, or the vehicle may be approaching the intended exit previously declared by the driver. The vehicle also provides lateral detection sensor output to the roadway so that the roadway can issue control commands. When the vehicle is in the manual lane, the vehicle supervises the driver readiness testing.

Roadway Functions: Apart from providing the dedicated lane with lane keeping reference aids, the roadway provides control commands to the vehicles to guide the vehicles to the manual lane.

Functional Flow Block Diagrams

The functional flow block diagram for ERSC5 is the same as the one presented for ERSC4.

Driver Readiness Testing

Driver readiness testing for ERSC5 is the same as the one presented for ERSC4.

Driver Task Analysis

Driver task analysis for ERSC5 is the same as the one presented for ERSC4.

Issues, Risks, and Recommendations

Issues, risks, and recommendations for ERSC5 are the same as the ones presented for ERSC4.

Key Findings

Key findings for ERSC5 is the same as the one presented for ERSC4.

Conclusions

Key Findings

We have analyzed situations in AHS where transition from automated to manual control takes place. In particular, driver readiness testing to ensure safe and smooth transition from automated to manual control has been emphasized.

For each Evolutionary Representative System Configuration (ERSC), alternative scenarios describing the sequence of events in nominal operations are described. This clarifies the role of the driver, vehicle, and roadway in check-out operations and enables us to perform a functional analysis by constructing functional flow block diagrams, and performing a task analysis for critical functions of the driver. This task analysis focuses on key issues and risks related to check-out, rather than trying to be exhaustive and detail oriented.

We have shown that, by appropriate design considerations, driver readiness testing procedures can be created such that they measure driving performance directly, while they appear natural and reasonable to the driver. We presented such a novel testing procedure which also ensures a safe, effective, and smooth transition from automated to manual driving mode.

Below is a summary of key findings:

- Many functions at ERSC1 and ERSC2 are identical or very similar to the manual driving situation. In particular, no specific driver readiness test should be necessary at these levels.
- The operator interface issues may be left to vehicle manufacturers and consumers to resolve within the context of competitive market forces. This process would also involve human factors experiments and experience.
- The vehicle should create a large enough gap before transferring the control of the vehicle, so that the driver resumes control in a driving situation that is compatible with the relative slowness and imprecision of human response.
- By appropriate design considerations, driver readiness testing procedures can be created such that they measure driving performance directly, while they appear natural and reasonable to the driver. We presented such a novel testing procedure which also ensures a safe, effective, and smooth transition from automated to manual driving mode.
- At ERSC4 and ERSC5, the exit ramp or portions of the manual lane need to be modified to allow lane keeping operations, since the transition from automated to manual control takes place on the ramp or in the manual lanes.
- The vehicles whose drivers fail the driver readiness test will be brought to a stop. A designated area for this purpose is desirable.

Issues, Risks, and Recommendations

Design Issues:

The major design issue is the design of the driver readiness testing procedure. We have shown that, by appropriate design considerations, driver readiness testing procedures can be created such that they measure driving performance directly, while they appear natural and reasonable to the driver. We presented such a novel testing procedure which also ensures a safe, effective, and smooth transition from automated to manual driving mode.

Since the driver readiness testing may be performed on the exit ramps or in the manual lanes, the issue of modification of ramps or manual lanes to allow lane keeping arises. For designated exit configurations, this is easily accomplished, but for continuous exit, portions of the manual lane need to be modified to allow lane keeping. In addition, there is the issue of what to do with the vehicles whose drivers fail the readiness tests. One solution may be to guide these vehicles to special areas where they can be brought to a stop. If these kinds of areas are not available, the vehicle would still be stopped, but this would cause disturbance to traffic on the ramp or in the manual lanes.

Driver Issues:
The major driver issue is how the driver readiness test is going to be perceived by the driver. The specific readiness testing design characteristics and the kinds and extent of support information (signs, in vehicle displays, warnings) that would enhance acceptance, efficiency and safety will determine user friendliness. There are a wide variety of studies and guidelines for operator interface that are applicable. (See references 19,20,7,21,22,8,23,24,25,26,27.) There are alternative display technologies, e.g. Head-up displays (HUD), Liquid Crystal Displays (LCD), Light-Emitting Diode (LEDO), computer generated voice message, sudden vehicle acceleration/deceleration (jerk), and tactile feedback. The interface can be continuous, or perhaps more appropriately activated when a driver action is needed or at the driver's request. The concept of generating progressively stronger warnings may be applied to devise an operationally acceptable interface. How to design the best user interface for AHS operations is still an open issue, and involves selecting a display technology, type and duration of warnings, user controls type and location, etc. Ultimately, experiments on simulators and actual vehicles will need to be carried out to determine the system characteristics that make the system appear natural to the driver, the best way to present the data to the driver, and the most convenient way for the driver to input commands.
User acceptance is the second important issue [28,29] . Since many functions are expected to be developed independent of AHS, user friendliness to ensure public acceptance should be integrated into the design process by the manufacturer for each function The Daimler-Benz study is a good example for this kind of effort [6] .
The possibility that automation will pose special acceptance and user problems for the elderly, disabled and inexperienced drivers is a third issue. These sub-populations should be routinely incorporated in simulator and vehicle studies done for check-out and special studies conducted on acceptance and usability under a variety of anticipated highway conditions.
Institutional Issues:
Legal and liability issues are very important for the deployment of AHS[30] . Therefore, designing a fail-safe system is a basic requirement.
Another major issue for implementation of AHS is dedicating a lane to AHS operations. Construction of a new lane will be costly, and taking away an existing lane from manual traffic may provoke major political turbulence [31,32] . It may therefore be necessary to consider scenarios in which various ERSC level vehicles coexist in the early phases of the deployment.
Program Issues:
Many functions are expected to be developed independent of AHS. Working out details of dedicating lanes will be the major activity required. The deployment schedule will depend on the availability of independently developed components.
User Type Issues:
There are no specific user type issues for check-out.

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