Chapter 10. Operational Guidelines

In this chapter are operational guidelines for the automated highway system. They were derived from two main sources:

- Comparable system analysis (task C of the contract) done on three existing, mature systems that are functionally related to the visions of the automated highway system developed under this contract.[4,6] The objective of the analyses was to extract issues and design considerations from the existing systems and to apply them to the design of the AHS.
- Experimental analyses of several questions of importance to the design of the AHS. In all, 14 experiments were conducted.

A Cautionary Note

It is to be stressed that for all their rigor, the comparable systems analyses and the experiments necessarily provided only first looks at extremely complex human factors issues of relevance to the design of the automated highway system. The guidelines presented in this chapter are, therefore, to be considered as preliminary, being based on only relatively limited information. Further research, both analytical and experimental, is needed to verify the accuracy of these guidelines and to provide additional guidelines related to the large number of human factors questions that have yet to be investigated.

The Operational Guidelines

498. IF THE DRIVER DISREGARDS AN ALARM:

Stop a vehicle if an alarm to which the driver must respond is disregarded.(b)

Comment: Depending upon the nature of the alarm, it may be that the driver will be given more than one opportunity to respond. Failure to respond according to some criterion could mean that the driver is incapacitated; in any case, a controlled vehicle-stopping and shut-down in a safe area, with perhaps an automated call by the AHS to a central emergency number, seems a reasonable safety precaution.

499. IF THE DRIVER MUST ACCURATELY POSITION THE VEHICLE:

If drivers must accurately position their vehicles when entering the system or during check-in, use a guide line painted on the roadway or an in-vehicle display that graphically depicts vehicle position relative to a reference point.[6]

Comment: Providing visual support for desired vehicle control movements should make the driver's task easier and improve throughput.

500. DRIVER STEERING WHEN UNDER AUTOMATED CONTROL:

Don't let drivers steer when under automated control.[6]

Comment: Allowing such actions may confuse the driver concerning whether the driver or the automation is in control of the vehicle, and could be extremely dangerous. It is assumed that most people have not driven any vehicle at speeds they might encounter on the AHS (e.g., 144.8+ km/h [90+ mi/h]), and thus are not familiar with how their vehicles will react under those conditions. The possibility of an oversteering response by the driver seems very real, and thus allowing drivers to steer at high speeds is discouraged.

501. TRANSFERRING CONTROL TO THE AUTOMATION:

When a transition lane is used, transfer of control to the automation should not be attempted until the vehicle is stable in the transition lane and the driver is no longer preoccupied with entry tasks.[6]

Comment: The driver's workload should be kept to a minimum and the driver should be ready to concentrate on the control transfer before it is started.

502. PREVENTING UNWANTED TRANSFER OF CONTROL TO THE AUTOMATION:

Establish mechanical restrictions to guard against control transfer until the driver is prepared to initiate it.[6]

Comment: Although there does not appear to be a safety issue here, driver acceptance of the automation and satisfaction with the **AHS** in general may be better if the driver retains control until he/she indicates an explicit willingness to relinquish it. Note that with a segregated automated lane, entry into the check-in area may be seen as an expression of such willingness, so that the system can take control without further driver intervention if the vehicle passes the inspection.

503. MANUAL LANE CHANGES:

When the driver must change lanes manually, implement the lane change in one of the following ways:

a. Disengage the automated steering, manually change lanes, and manually re-engage the automated steering when the lane change has been completed and the vehicle is stable in the new lane.

b. Disengage the automated steering and manually change lanes; automatically re-engage the automated steering when the vehicle is stable in the new lane.[6]

Comment: One method specifically being avoided is where the system resumes automated control when the vehicle simply crosses into the new lane. The concern is that if the driver approaches the new lane at too high an angle (where 0° is straight ahead and 90° is directly to the left or right, depending upon the direction of the lane change), the torque exerted by the automation to straighten out the vehicle in the new lane could cause a driver injury.

Also, note that appropriate provision will have to be made for the driver who initiates a lane change and then decides to not complete it, returning to the lane from which he/she came.

504. CRITICAL SAFETY SYSTEMS AND FALSE ALARMS:

If critical vehicle safety systems are prone to false alarms under certain conditions, automatically inhibit the warnings under those conditions.[6]

Comment: The indication from other systems is that continued false alarms lead the users to disregard the alarm, even when it is real, or to disconnect the alarm. Both consequences are clearly to be avoided.

505. DISENGAGING THE AUTOMATION IN AN EMERGENCY:

In a free agent scenario, provide alternative means for quickly disengaging the automation during critical emergencies.[6]

Comment: In a free agent scenario, all automation is placed on the vehicle and there is mixed automated and manual traffic in all lanes.

Relying on the inexperienced driver to remember one specific action for taking control under emergency conditions may not be the best approach for the AHS.

506. ALERTING THE DRIVER THAT THE AHS ROADWAY IS ENDING:

Provide attention-getting displays (e.g., rumble strips) for areas where an AHS-equipped segment of roadway ends.[6]

Comment: These types of displays are already in use at the entrances to many toll booth areas and help to capture the attention of the inattentive driver. On the AHS, in-vehicle displays (e.g., auditory alarms) should also be used to ensure that the driver is alert to the situation.

507. USE OF A BACKUP DISPLAY IN THE VEHICLE:

Provide a display in the vehicle that is at least partially redundant that can be used in case the primary visual display fails.[65]

Comment: If there are multiple display surfaces as part of the normal AHS in-vehicle interface, the backup display need not be an additional display surface. Rather, it could be one of the existing display surfaces tasked differently under failure conditions.

508. BETWEEN-VEHICLES GAPS IN STRINGS OF VEHICLES:

Based on driver preferences, if there are strings of vehicles in the automated lane, and the designated speed in that lane is $\geq$ 104.7 km/h ($\geq$ 65 mi/h), provide gaps between vehicles within a string of more than 0.0625 s. (Based on reference 66.)

Comment: In the experiment referenced, drivers indicated a preference for the longer gaps when gaps of 0.0625 s, 0.25 s, and 1.0 s were used. The result can be taken to indicate their dislike of the shortest gap, but cannot be used to determine what minimum gap drivers would find acceptable.

Note that the guideline is based on driver preferences. Other factors such as safety and system performance may lead to a different guideline.

509. SPEEDS OF VEHICLES ENTERING THE AUTOMATED LANE:

If the automated lane is reserved for vehicles traveling under automated control, vehicles entering that lane should be traveling at the same speed as vehicles already in the automated lane. (Based on references 67,68.)

Table 35 shows example acceleration-ramp lengths for three vehicles.[69]

Comment: Analyses indicated that when the automated-lane speed is 104.7 km/h through 153.0 km/h (65 mi/h through 95 mi/h) and the entering vehicle starts at 88.5 km/h (55 mi/h), throughput in the automated lane increases as the difference in speed between vehicles entering the lane and vehicles already in the lane decreases. Additional speeds were analyzed in determining ramp lengths because it is not clear at this time what the designated AHS speed is likely to be.

Table 35. Acceleration distances for three vehicle types.[1]

Automated-Lane Speed, km/h (mi/h)	Vehicle Type: A Vehicle That Accelerates from 0 km/h to 96.6 km/h (60 mi/h) in 10 s	A Vehicle That Accelerates from 0 km/h to 96.6 km/h (60 mi/h) in 15 s	A 12,712-kg (28,000-lb) Gross Weight Truck
48.3 (30)	34 (112)	48 (158)	121 (398)
64.4 (40)	59 (195)	85 (279)	222 (728)
80.5 (50)	92 (303)	135 (444)	360 (1180)
96.6 (60)	134 (440)	201 (659)	543 (1781)
112.7 (70)	185 (607)	290 (951)	783 (2568)
128.8 (80)	246 (807)	403 (1322)	1099 (3605)
144.9 (90)	318 (1043)	545 (1788)	1518 (4979)

[1] Shown are the distances required for the vehicles to accelerate from 0 km/h to the automated-lane speed. The analyses assumed no rolling resistance, no wind effects, and a level acceleration ramp. All lengths have been rounded to the nearest meter (foot).

510. SPEEDS OF VEHICLES LEAVING THE AUTOMATED LANE:

If the automated lane is reserved for vehicles traveling under automated control, when vehicles leave that lane they should be traveling at the same speed as vehicles in the automated lane. (Based on reference 66.)

Table 36 shows example deceleration-ramp lengths for the same three vehicles that were used for table 35.[(69)]

Comment: Analyses indicated that when the automated-lane speed is 104.7 km/h through 153.0 km/h (65 mi/h through 95 mi/h) and the leaving vehicle slows to 88.5 km/h (55 mi/h) before it leaves, throughput in the automated lane increases as the difference in speed between vehicles leaving the lane and vehicles already in the lane decreases. Additional speeds were analyzed in determining ramp lengths because it is not clear at this time what the designated AHS speed is likely to be.

511. METHOD OF TRANSFERRING CONTROL FROM THE DRIVER TO THE AHS:

A vehicle's speed and steering should both be under the control of the automation before the vehicle enters the automated lane. Exception: This will not be necessary in a free agent scenario. (Based on references 67,68.)

Comment: In a free agent scenario, all automation is placed on the vehicle and there is mixed automated and manual traffic in all lanes.

When the AHS has complete control of the vehicle before the vehicle enters the automated lane, traffic in that lane is disrupted less than with other transfer-of-control methods. This method can also best be used to ensure that guideline 509 is met.

Table 36. Distances for three vehicle types to decelerate to 0 km/h and 48.3 km/h (30 mi/h).[1]

	Vehicle Type		
Designated AHS Speed, km/h (mi/h)	A Vehicle That Accelerates from 0 km/h to 96.6 km/h (60 mi/h) in 10 s	A Vehicle That Accelerates from 0 km/h to 96.6 km/h (60 mi/h) in 15 s	A 12,712-kg- (28,000-lb-) Gross-Weight Truck
DECELERATING TO 0, COEFFICIENT OF FRICTION = 0.5*			
48.3 (30)	18 (60)	18 (59)	18 (60)
64.4 (40)	32 (105)	31 (102)	32 (106)
80.5 (50)	49 (161)	47 (155)	50 (163)
96.6 (60)	70 (230)	66 (216)	71 (233)
112.7 (70)	93 (305)	87 (285)	95 (312)
128.8 (80)	118 (387)	109 (358)	122 (400)
144.9 (90)	146 (479)	131 (430)	152 (499)
DECELERATING TO 0; COEFFICIENT OF FRICTION = 0.2*			
48.3 (30)	45 (146)	43 (141)	45 (147)
64.4 (40)	77 (252)	73 (238)	78 (257)
80.5 (50)	116 (380)	106 (349)	119 (391)
96.6 (60)	160 (525)	143 (469)	167 (548)
112.7 (70)	208 (682)	180 (590)	219 (718)
128.8 (80)	258 (846)	216 (708)	276 (905)
144.9 (90)	308 (1010)	250 (820)	335 (1099)
DECELERATING TO 48.3 (30); COEFFICIENT OF FRICTION = 0.2*			
48.3 (30)	0 (0)	0 (0)	0 (0)
64.4 (40)	5 (16)	5 (15)	5 (16)
80.5 (50)	19 (61)	17 (56)	19 (63)
96.6 (60)	40 (131)	36 (118)	42 (138)
112.7 (70)	68 (223)	59 (194)	72 (236)
128.8 (80)	101 (331)	84 (276)	108 (354)
144.9 (90)	138 (453)	111 (364)	149 (489)

[1] Shown are the distances required for the vehicles to decelerate from the designated AHS speed to the speed indicated. The analyses assumed no rolling resistance, no wind effects, and a level deceleration ramp. All lengths have been rounded to the nearest meter (foot). In cases where conversions for two different (rounded) numbers led to the same (rounded) result, both results have been left in the table. For example, 15.7 ft rounds to 16 ft, and is then converted to 4.88 m, which is shown in the table as 5 m; 14.9 ft rounds to 15 ft, and is then converted to 4.58 m, which is also shown in the table as 5 m. This was believed preferable to showing decimal distances, which are of little practical value.

* The larger the coefficient of friction, the better the stopping performance. A coefficient of friction of 0.5 represents a nearly emergency stop; a coefficient of 0.2 represents a lower-g stop, which may be more realistic for normal exiting of the AHS.

512. AUTOMATED-LANE WIDTH:

If the designated speed in the automated lane is ≥ 128.8 km/h (≥ 80 mi/h) and the driver may have to take control of either steering alone or **both speed and steering, the automated lane should not be less than 3.7 m (12 ft) wide.** (Based on reference 70.)

Comment: In the referenced experiment, some drivers got back control of steering alone and others got back control of both steering and speed just before a curve to the left. At the end of the curve, the right edge of the driver's vehicle was very close to the right edge of the lane-about 0.4 m (1.3 ft) when the driver got control of steering alone, and about 0.1 m (0.3 ft) when the driver got control of both steering and speed.

513. USE OF SIMPLE BARRIERS TO SEGREGATE MANUAL AND AUTOMATED VEHICLES:

When vehicles must travel between manual and automated lanes, the use of a simple barrier-gap-barrier arrangement is not recommended for segregating manual and automated traffic. (Based on reference 71.)

Comment: Table 37 shows the minimum gaps between barriers that will allow vehicles traveling under automated control under ideal conditions to pass through. Of course, larger gaps would be used on an actual AHS to allow for worst case conditions.

In one of the experiments conducted for this contract, drivers in manual control of their vehicles and traveling at 104.7 km/h (65 mi/h) took an average of 1.25 s to complete a lane change.[67] This converts to 36.3 m (119 ft). Comparing this to the minimum best-case gap at that speed-l.5 times the value in table 37, or 114.5 m (375 ft)-it is apparent that a determined driver traveling under manual control could enter the automated lane without authorization by driving through a gap between barriers. If the driver were to slow down, he/she would have an even easier time getting through a gap. Thus, it is concluded that a simple arrangement of barrier-gap-barrier will not prevent unauthorized drivers from entering the automated lane.

Table 37. Between-barriers gap sizes to allow vehicles traveling under automated control under ideal conditions to pass through.[1,2]

Vehicle Speed When Passing Between Lanes	Minimum Gap Size
88.6 km/h (55 mi/h)	64m (211 ft)
104.7 km/h (65 mi/h)	76 m (250 ft)
120.8 km/h (75 mi/h)	87 m (286 ft)
153.0 km/h (95 mi/h)	110m (361 ft)

[1] A perfect car wheel angle and a dry, 3.7-m- (12-ft-) wide roadway were assumed.
[2] As a safety margin, the actual gaps used on a real automated highway system would be at least 1.5 times the minimum gaps determined.

514. METHOD OF TRANSFERRING CONTROL FROM THE AHS TO THE DRIVER:

When transferring control from the AHS to the driver, allow the driver to either take control of steering first followed by speed or of both speed and steering simultaneously. Do not transfer control of speed first followed by steering. (Based on reference 72.)

Comment: In the referenced experiment, three different transfer methods were used. Performance did not differ among the three methods, but drivers showed a preference against the speed-first-followed-by-steering method.