Bus Rapid Transit Lane Assist Technology Systems
Volume 2
Bus Driver Stress While Operating in Narrow Dedicated Bus Shoulders: A Pilot Study

February 2003

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Bus Rapid Transit Lane Assist Technology Systems

Volume 2
Bus Driver Stress While Operating in Narrow Dedicated Bus Shoulders: A Pilot Study

Final Report
Submitted to
U.S. Department of Transportation
Federal Transit Administration

February 2003

Submitted by
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Volume 2

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# Table of Contents

EXECUTIVE SUMMARY ........................................................................................................................... 1

CHAPTER 1: INTRODUCTION - BUS RAPID TRANSIT (BRT) ........................................................................ 2

HUMAN FACTOR ISSUES .......................................................................................................................... 3
SUMMARY .................................................................................................................................................. 4

CHAPTER 2: MODELING DRIVER STRESS ................................................................................................. 7

STRESSORS ............................................................................................................................................... 7
- Bus Operation Stressors .......................................................................................................................... 8
DRIVER STRESS ........................................................................................................................................ 9
- Bus Driver Stress .................................................................................................................................... 11
IMPAIRMENT ........................................................................................................................................... 13
- Bus Driver Impairment ........................................................................................................................... 15
FRAMEWORK OF STRESS ....................................................................................................................... 15
- Stressors ................................................................................................................................................ 16
- Appraisal ............................................................................................................................................... 16
- Stress .................................................................................................................................................... 17
- Coping .................................................................................................................................................. 17
- Performance ........................................................................................................................................ 18
- Crash Risk ........................................................................................................................................... 18
SUMMARY ................................................................................................................................................ 18

CHAPTER 3: PILOT STUDY .......................................................................................................................... 20

METHOD .................................................................................................................................................. 22
- Subjects .................................................................................................................................................. 23
- Route .................................................................................................................................................... 24
- Bus ....................................................................................................................................................... 25
- Lane Support System (LSS) ................................................................................................................ 25
- Independent Variables ....................................................................................................................... 26
- Dependent Measures .......................................................................................................................... 27
- Procedure ............................................................................................................................................ 30

CHAPTER 4: RESULTS ............................................................................................................................... 32

STRESSORS .............................................................................................................................................. 32
- Appraisal ............................................................................................................................................... 34
- Environment ......................................................................................................................................... 34
- Lane Support System (LSS) ................................................................................................................ 34
DRIVER STRESS ....................................................................................................................................... 38
- Workload ............................................................................................................................................ 38
- Effort .................................................................................................................................................... 39
- Symptoms .......................................................................................................................................... 40
DRIVING PERFORMANCE ..................................................................................................................... 41
VEHICLE SPEED ........................................................................................................................................ 42
LANE POSITION ....................................................................................................................................... 44
SUBJECTIVE PERFORMANCE .................................................................................................................. 54
SUBJECTIVE SAFETY .............................................................................................................................. 54

CHAPTER 5: DISCUSSION ........................................................................................................................... 55

STRESSORS .............................................................................................................................................. 55
- Traffic ................................................................................................................................................... 56
- Width .................................................................................................................................................... 57
- System .................................................................................................................................................. 58
## Table Of Figures

<table>
<thead>
<tr>
<th>Figure</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Interaction between elements in BRT system</td>
<td>3</td>
</tr>
<tr>
<td>2</td>
<td>Relative duration of tasks during stages of driving, waiting and resting</td>
<td>9</td>
</tr>
<tr>
<td>3</td>
<td>Stress response coping strategies (Hockey, 1986)</td>
<td>10</td>
</tr>
<tr>
<td>4</td>
<td>Driving stress response to stressor of road geometry (derived from Richter et al., 1998)</td>
<td>11</td>
</tr>
<tr>
<td>5</td>
<td>Change in heart rate variability relative to baseline driving as an indication of increased workload imposed by secondary tasks (based on Gobel et al., 1998)</td>
<td>12</td>
</tr>
<tr>
<td>6</td>
<td>Relationship between demand and resources on task performance (Wickens &amp; Hollands, 2000)</td>
<td>14</td>
</tr>
<tr>
<td>7</td>
<td>Summary framework of stress process</td>
<td>16</td>
</tr>
<tr>
<td>8</td>
<td>Study design and planned comparisons for hypothesized effects of stressors</td>
<td>20</td>
</tr>
<tr>
<td>9</td>
<td>Alternative hypotheses for stress effect for LSS (relative to baseline)</td>
<td>22</td>
</tr>
<tr>
<td>10</td>
<td>Map of test route area (and comparison site to estimate traffic volume)</td>
<td>23</td>
</tr>
<tr>
<td>11</td>
<td>Picture of bus used for study</td>
<td>25</td>
</tr>
<tr>
<td>12</td>
<td>Summary of analyzed results based on framework of stress process (see Figure 7)</td>
<td>32</td>
</tr>
<tr>
<td>13</td>
<td>Mean usability rating scales for BRT operators and drivers (N = 10)</td>
<td>36</td>
</tr>
<tr>
<td>14</td>
<td>Usability scale for BRT samples</td>
<td>37</td>
</tr>
<tr>
<td>15</td>
<td>Mean workload score in driving conditions (N = 9)</td>
<td>39</td>
</tr>
<tr>
<td>16</td>
<td>Mean reported effort (RSME) in driving conditions</td>
<td>40</td>
</tr>
<tr>
<td>17</td>
<td>Median speed in driving conditions for both traffic volumes</td>
<td>42</td>
</tr>
<tr>
<td>18</td>
<td>Variability of speed in driving conditions for both traffic volumes</td>
<td>43</td>
</tr>
<tr>
<td>19</td>
<td>Median lane position in driving conditions for both traffic volumes</td>
<td>44</td>
</tr>
<tr>
<td>20</td>
<td>Variability of lane position in driving conditions for both traffic volumes</td>
<td>46</td>
</tr>
<tr>
<td>21</td>
<td>Median inverse of time-to-line crossing (1/TLC) in driving conditions for both traffic volumes</td>
<td>47</td>
</tr>
<tr>
<td>22</td>
<td>Maximum inverse of time-to-line crossing (1/TLC) in driving conditions for both traffic volumes</td>
<td>48</td>
</tr>
<tr>
<td>23</td>
<td>Median response time to recover boundary departure in driving conditions for both traffic volumes</td>
<td>49</td>
</tr>
<tr>
<td>24</td>
<td>Maximum response time to recover boundary departure in driving conditions for both traffic volumes</td>
<td>50</td>
</tr>
<tr>
<td>25</td>
<td>Median time duration of boundary departures in driving conditions for both traffic volumes</td>
<td>51</td>
</tr>
<tr>
<td>26</td>
<td>Maximum time duration of boundary departures in driving conditions for both traffic volumes</td>
<td>52</td>
</tr>
<tr>
<td>27</td>
<td>Total duration boundary departures in driving conditions for both traffic volumes</td>
<td>53</td>
</tr>
</tbody>
</table>
Table of Tables

Table 1. Matrix of System Interactions Impacting on BRT Objectives............................. 6
Table 2. Main stressors for urban bus driving (expanded from Gobel et al., 1998) ........ 8
Table 3. Percentage of Time Devoted to Tasks during Urban Bus Operations (Gobel et al., 1998)....................................................................................................................... 9
Table 4. Hypothetical Association of Coping Strategies with Stress and Performance. . 17
Table 5. Performance metrics and size of analyzed samples (N)......................................... 29
Table 6. Test Condition Assignment................................................................................ 31
Table 7. Reliability Coefficients for Mean Workload Score (R-TLX)............................... 38
Table 8. Correlation of RSME and Workload Factors on LSS (N = 8). .......................... 40
Table 9. Condition Assignment...................................................................................... E-4
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Executive Summary

Bus Rapid Transit (BRT) operations are a growing necessity for public transit. The use of dedicated bus shoulders is a key method for implementing BRT in areas that do not have the resources or space for the installation of additional infrastructure. However, the narrow width of the bus shoulder and the need to anticipate and interact with other traffic in the adjacent lane are both significant stressors for bus drivers. Driver stress in response to these conditions should be a significant concern for transit operators not only because the potential impairment of driving performance might jeopardize BRT objectives, but also because the long term effects of this occupational stress is a health risk factor for the bus drivers who staff the BRT services.

Technology may be harnessed to support the driving task in narrow shoulders and high traffic volumes associated with BRT services. This pilot study evaluated a prototype Lane Support System (LSS) that provides a coping function in support of vehicle control within the shoulder boundaries. The LSS did not reduce subjective stress for the drivers, perhaps because of the perceived unreliability and need to interpret system feedback. However, it did demonstrate significant improvements in the stability of vehicle control (position and speed) in the bus shoulder and shorter boundary departures that could represent a reduction in potential conflicts with other traffic. Jointly, these effects provide evidence in an operational context that (i) shoulders should be used in high traffic volume conditions, and (ii) devices such as the prototype LSS can support bus shoulder operations. Therefore, LSS can provide a reliable and safe public transit system that supports the objectives of BRT operations. As such, future research should support the deployment of such devices for bus operations on shoulders during high traffic volumes.
Chapter 1: Introduction - Bus Rapid Transit (BRT)

“Bus Rapid Transit (BRT) is a flexible, rubber tired form of rapid transit that combines stations, vehicles, services, running way, and Intelligent Transportation Systems (ITS) elements into an integrated system with a unique identity” (Zimmerman, 2001, p. 6). In order to achieve the objective of reducing travel time (or variability of travel time), such systems can provide several service types that require certain forms of operational roadway (Hardy, Stevens, & Roberts, 2001):

- Express BRT Service – high speed, large capacity, infrequent stop service connecting urban areas to outside areas along expressway routes using dedicated or semi-dedicated lane roadway operations.
- Urban Shuttle BRT Service – large capacity service in heavily congested (downtown) areas using semi-dedicated lane roadway operations (and dedicated lanes if right-of-way is available).
- Local Collector BRT Service – standard bus operations coupled to the other BRT services.

For the major BRT types of express and urban shuttle services, dedicated and semi-dedicated lanes are necessary forms of roadway operation. Such operations may include the use of dedicated narrow roadway shoulders.

The use of shoulders as a bus lane is a new alternative to improve the person carrying capacity of a roadway by altering the manner in which the roadway is operated. This change should improve the quality of the transit operation in terms of reliability of trip times and travel time savings. It is also hoped that these improvements will serve as an incentive to those currently not using transit to begin using it. (McCarthy & Davis, p. 3)

To support the use of these narrow roadways, there are a number of engineering and technological features that can be deployed (Hardy et al., 2001):

- Lateral control for narrow lanes
- Narrow vehicle design
- Lane assist
- Lateral warning system

ITS technologies such as lane assist and lateral warning systems are examples of Driver Assistance Technologies (DAT). The requirements to operate on narrow lanes and the inevitable deployment of ITS will fundamentally change the operating environment and driving task for the bus driver. The purpose of this chapter is to consider the human factors implications of BRT services using (semi-) dedicated lanes such as narrow roadway shoulders. A review of these implications will be used to support a pilot study
that will evaluate the use of a prototype DAT for an Express BRT Service in Minneapolis, MN.

Due to recurring congestion on segments of urban arterials, including freeways and expressways, in the Twin Cities Area [Minneapolis / St. Paul], the Minnesota Department of Transportation (MnDOT) and the Metropolitan Council Transit Authority (MCTO) have instituted the operation of transit buses on the outside shoulders of certain freeways and expresses. By using the shoulders, transit buses are able to bypass congestion, thus improving trip times and reliability. (McCarthy & Davis, p. 2)

Human Factor Issues
The objective of this report section is to describe the main human factors issues that may impact on the successful operation and deployment of BRT using lane assistance and lateral warnings. As a basis for this task, the schematic in Figure 1 was devised to identify the interactions between the key agents that interact in the operational context of a BRT service. This section of the report considers each interaction path and identifies the main issues that may impact the transit bus driver (and the operability of the BRT).

The use of the narrow lanes, HOV lanes, and bus shoulders affect the bus driver and other traffic (as well as the operation of the DAT). For example, the use of narrow lanes (bus shoulders) may increase the task demand and stress of the driver in terms of safely operating the vehicle within the narrower confines compared to the standard lane. Other traffic may use these environments opportunistically (or in protest should they perceive that the exclusive right to only increase mobility for a certain class of road user to be inequitable). In this case, the bus driver must also devote effort to anticipating unexpected hazards from encroaching vehicles into the bus lane. In order to support its assisting functions, the DAT itself must process the geometric parameters of the roadway.

1 Note that MCTO is now referred to as Metro Transit.
When operating in these environments, the bus driver must interact with other road users. For example, the bus driver must contend with the potential hazard of other traffic encroaching into these (restricted) roadway environments, particularly with large speed differentials between the bus in motion and stationary traffic under congested conditions. The other traffic must also interact with the operation of the bus in any (shared) environment.

There may be some vicarious effect on passengers resulting from the bus interacting with other road users and the perceived mobility of the bus relative to stationary traffic in congestion. Passengers may also feel “hemmed” in by the narrowness of the lane adjacent to stationary traffic cues, despite any positive response to improved travel time.

The passengers will also indirectly interface with the DAT functions and operating environment through an association with the actions of the driver and bus. That is, not only will the bus driver interact with passengers, but the bus driver will also be evaluated by the passengers in terms of the performance of the bus (e.g., smoothness of drive, stability in lane, travel time).

The interface between the DAT and the bus driver will be fundamental in terms of system compliance and operator performance. It is the interface design that communicates the system function to the bus driver and is the basis of the driver response. A good interface may engender trust in the system which will improve performance and acceptance. Attention should also be given to the possibility that excess trust may foster complacency toward the driving task, and a poor interface design may be both mentally and physically stressful for the driver.

Table 1 presents a matrix to summarize the speculative impact of each path of system interaction hypothesized in Figure 1. These impacts are considered with respect to the main objectives ascribed to BRT systems (Hardy et al., 2001); namely mobility (shorter and more reliable trip times) and safety. This matrix is then used to focus on the human factors that are likely to impact safety, which is implicit as the primary objective for all BRT strategies. Indeed, safety is an explicit concern for the BRT operation in Minnesota used as a test environment for the prototype DAT evaluated in this pilot study:

The change in freeway operations by transit buses operating on the right hand shoulder at speeds greater than mainline traffic was implemented on existing routes without a study of the negative effects on traffic operations or an evaluation of any like application of transit. The primary concern with this variation from standard traffic operation procedure, as with any such variation, is whether or not this change makes the roadway less safe. (McCarthy & Davis, p. 3)

**Summary**

It is apparent that the most germane human factors issues in relation to BRT safety objectives involve the interaction of the transit bus driver with the roadway and traffic environment as well as the system interface. Specifically, the operation of a wide bus on
a narrow lane (while anticipating and avoiding violators) is expected to increase driver workload such that bus drivers may become stressed. Moreover, whereas a proposed DAT may be expected to alleviate aspects of this workload related to the control of the vehicle in the narrow lane, the DAT interface may also increase other aspects of workload. For example, the application of other automated and assisting systems in other domains suggests that the introduction of these systems may change the primary task and impose additional monitoring demands on the operator to (i) interpret ambiguous system information; (ii) monitor system status; and (iii) diagnose system failures (Ward, 2000). It is therefore sensible to focus attention on the issue of driver stress in the operational BRT context with the hypotheses that driving on dedicated narrow lanes is intrinsically stressful, and DAT may reduce the overall stress depending on the workload required to operate the system as afforded by the system design.
Table 1. Matrix of Potential System Interactions Impacting Safety.

<table>
<thead>
<tr>
<th>Objective</th>
<th>Interaction Path (see Figure 1)</th>
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<tr>
<td></td>
<td><strong>A</strong></td>
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<tr>
<td>Safety</td>
<td>Driver stress from increased driving difficulty on narrow lanes (and boundary obstacles) may impair driving.</td>
</tr>
<tr>
<td></td>
<td>Driver stress and controllability during transition to and from dedicated and standard lanes.</td>
</tr>
<tr>
<td></td>
<td><strong>B</strong></td>
</tr>
<tr>
<td></td>
<td>Traffic encroaching in lane may be a hazard (side swipe, rear end crashes) and cause injury.</td>
</tr>
<tr>
<td></td>
<td><strong>C</strong></td>
</tr>
<tr>
<td></td>
<td>Incident due to driver impairment (stress) or emergency response to violator may cause injury.</td>
</tr>
<tr>
<td></td>
<td><strong>D</strong></td>
</tr>
<tr>
<td></td>
<td>Complacency resulting from trust of system. Delayed recovery from system errors. Excess workload to interact and interpret system. Fatigue from system feedback</td>
</tr>
<tr>
<td></td>
<td><strong>E</strong></td>
</tr>
<tr>
<td>Trip time/Speed</td>
<td>Impaired driving may increase variability of trip time, or reduce speed to compensate for increased stress.</td>
</tr>
<tr>
<td>(Mobility)</td>
<td><strong>A</strong></td>
</tr>
<tr>
<td></td>
<td>Traffic violation of dedicated lane will delay trip time.</td>
</tr>
<tr>
<td></td>
<td><strong>B</strong></td>
</tr>
<tr>
<td></td>
<td><strong>C</strong></td>
</tr>
<tr>
<td></td>
<td><strong>D</strong></td>
</tr>
<tr>
<td></td>
<td><strong>E</strong></td>
</tr>
<tr>
<td></td>
<td>Delay from traffic violation of dedicated lane may put pressure from passengers on the driver to make up lost time.</td>
</tr>
<tr>
<td></td>
<td>Time for set up of system may delay trip, especially if a failure occurs.</td>
</tr>
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Chapter 2: Modeling Driver Stress

This section provides an overview of driver stress with particular emphasis given to transit bus operations.

Stressors
For a given task, a ‘stressor’ is any stimulus that imposes a demand to change the physiological, psychological or behavioral state of the driver. These changes arise from the application of compensatory effort to cope with the task demands. Such effort may be evident from increased (i) mental arousal, (ii) physiological and behavioral activation, or (iii) attention to the cognitive control processes assigned to manage the task (Mulder, 1986).

Stressors within the individual (state) or in the environment are appraised by the perceiver. According to Lazarus (1984) and other cognitive theorists (e.g. Frijda, 1987), emotions such as stress result from our interaction with the environment. Through our interaction with the environment, we develop cognitions about the significance of objects and events in the form of internalized goals, standards, beliefs and attitudes. We apply these cognitions to appraise stimuli and the impact of our actions upon the environment. The significance of the precepts derived from this appraisal determines the form of stress response to the stressor.

For the primary task of driving, the road environment may include stressors such as:

- road design (e.g., narrow lanes)
- road infrastructure (e.g., roadside hazards)
- traffic (e.g., encroaching/impeding traffic in lane)

Tasks secondary to driving that are engaged while operating a vehicle are also stressors. Examples of secondary tasks may include:

- use of car phone
- conversation with passengers
- operating vehicle controls (e.g. radio etc)
- interpreting feedback from ITS

Stressors may also exist as internalized stimuli such as mental representations that require attention (e.g., preoccupation about lane position or attention to unexpected hazards in lane), impaired states of mental function (e.g., intoxication, fatigue), or as emotional states (e.g., fear, frustration, anger, anxiety about driving performance, uncertainty about driving context).
Bus Operation Stressors

In addition to these general driving stressors, the driving environment of public transit includes additional “potent stressors” (Evans & Johanson, 1998).

Transit bus driving involves numerous job stressors inherent both in the driving task and in the public transit environment that are summarized in Table 2 (Gobel, Springer, & Scherff, 1998). These stressors can be described in terms of conflicting job demands given that a stress response to one stressor may limit resources to respond to other stressors. For example, pressure to adhere to time schedules will conflict with coping efforts to drive safely while contending with traffic congestion and the need for provision of passenger services (Rydstedt et al., 1998).

Table 2. Main stressors for urban bus driving (expanded from Gobel et al., 1998)

<table>
<thead>
<tr>
<th>Driving Task Stressor</th>
<th>Driving Environment Stressor</th>
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<tbody>
<tr>
<td>Drive bus</td>
<td>Constrained body pressure</td>
</tr>
<tr>
<td>Supervise passenger area</td>
<td>Vision and lighting</td>
</tr>
<tr>
<td>Supervise and control bus</td>
<td>Vibration</td>
</tr>
<tr>
<td>Comply with schedule</td>
<td>Varying climatic conditions</td>
</tr>
<tr>
<td>Bus stop services</td>
<td>Noise</td>
</tr>
<tr>
<td>Ticket selling and control</td>
<td>Traffic congestion</td>
</tr>
<tr>
<td>Passenger information services</td>
<td>Traffic hazards</td>
</tr>
<tr>
<td>Communication with depot</td>
<td>Road and lane geometry (conditions)</td>
</tr>
</tbody>
</table>

As noted by Evans and Johansson (1998), the characteristics of bus driving and the public transit environment “play a major role in elevating risk for stress and eventual morbidity” (p. 100). This stress can be attributed to the conflicting and high demands of the driving stressors in conjunction with the limited latitude granted bus drivers toward decisions about coping methods.

Gobel et al., (1998) completed an ergonomic analysis of tasks involved in transit bus services for a number of routes and bus types in different German cities. The main categories of bus operation and non-driving tasks are listed in Table 3. This shows that bus operations (100%) are comprised on three main activities: driving the bus, waiting at stations, and resting during work breaks. As expected, the majority of the operational time is occupied by driving. However, there are a large number of tasks not related to driving that are important to bus operations. It is estimated that approximately 20% of the time involved in bus operations is occupied with these non-driving tasks: servicing, administration, and vehicle control. These tasks may occur on average more than 200 times per hour, and are most frequent on approach and departure to the bus stops (Gobel et al., 1998).

The specific tasks involved in driving an urban bus are shown in Figure 2 as a percentage of the operational stages of driving, waiting, and resting. It can be seen from this task analysis that some tasks are naturally more common while the vehicle is in motion (e.g., steering control), while other tasks are exclusive to conditions when the bus is stopped (e.g., operating doors).
Table 3. Percentage of Time Devoted to Tasks during Urban Bus Operations (Gobel et al., 1998).

<table>
<thead>
<tr>
<th>Task</th>
<th>Time (SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Bus Operations</strong></td>
<td>100%</td>
</tr>
<tr>
<td>Driving</td>
<td>57% (7.6)</td>
</tr>
<tr>
<td>Waiting</td>
<td>29.1% (3.7)</td>
</tr>
<tr>
<td>Rest</td>
<td>13.9% (8.3)</td>
</tr>
<tr>
<td><strong>Non-driving tasks</strong></td>
<td>20.5%</td>
</tr>
<tr>
<td>Bus stop service tasks</td>
<td>9.5% (2.7)</td>
</tr>
<tr>
<td>Customer service tasks</td>
<td>4.1% (2.1)</td>
</tr>
<tr>
<td>Organizational/Administrative tasks</td>
<td>1.3% (1.1)</td>
</tr>
<tr>
<td>Specific vehicle control tasks</td>
<td>5.6% (1.5)</td>
</tr>
</tbody>
</table>

Figure 2. Relative duration of tasks during stages of driving, waiting and resting (Gobel et al., 1998).

Driver Stress

The term ‘state’ is used to refer to a profile of energy resources applied by the individual to process information and selecting, organizing and executing appropriate response behaviors (Mulder, 1986). For a given task, there will be a ‘target state’ in terms of a resource distribution consistent with the task demands to achieve optimal task performance goals. This is a hypothetical state based on ideal task performance conditions. In actuality, a person will exhibit a ‘cognitive state’ in response to stressors that are currently present in the task environment. The correspondence between the optimal and cognitive states will determine the extent to which the performance satisfies the task goals (Hockey, 1993).

The ‘stress response’ refers to the form and extent of compensatory effort applied in the presence of the stressor to satisfy performance goals. Hockey (1985) contends that the form of stress response will be motivated to reduce the discrepancy between the stress
states and the optimal state. The coping strategies that may be applied in a stress response are depicted in Figure 3.

These stress response strategies are applied in response to an error signal generated by the comparison of the optimal (target) state and the current cognitive state (1). These alternative strategies involve effort applied to (2) changing the current cognitive stress state; (3) modifying the optimal target state by reducing performance goals; (4) removing or modifying the stressor in the environment; and (5) enduring the stress state rather than taking direct action.

Thus, in relation to these coping strategies, a driver may exhibit any of the following responses to stressors in the driving task:

- **Change current state**: Driver can apply effort to summon necessary resources such as trying to stay alert and pay attention, thereby increasing workload to complete task goals.
- **Change target state**: Driver can reduce performance goals such as allowing more variation in speed or lane position, and extending planned travel time, thereby reducing the resources required for the task.
- **Change environment demands**: Driver may remove self from stressor, for example, by choosing a path that minimizes contact with the stressor, or chose another mode of travel entirely.
- **Inaction**: The driver may do nothing and endure the stress.

The mobilization of effort to compensate for the stress is an indication of an active coping strategy in response to the task demand. Evidence of a stress response can be observed in terms of changes in psychophysiology, behavior, or reported mental effort.

![Figure 3. Stress response coping strategies (Hockey, 1986).](Image)
As an example of a stress response, Figure 4 demonstrates driver effort (physiological stress) and performance (speed) in relation to the specific stressor of road curvature. The “Curvature Change Rate (CCR)” is calculated as the sum of all (absolute) directional changes along the roadway (Ritcher et al., 1998). Higher CCR values represent a larger magnitude stressor by imposing a greater task demand for vehicle control. Drivers were asked to drive sections of road that had different levels of CCR. The drivers reported significantly more subjective effort expended in the driving task as a function of increased CCR. This data supports the presumption that more curvy roads require more vigilance. This effortful response to the stressor is presented in Figure 4 by a reduction of heart rate variability (HRV) in the .10 Hz range which is an accepted psychophysiological measure of increased mental effort (De Waard, 1996). These drivers also reduced their driving performance level as a compensatory response to limit the amount of applied effort by reducing the target state with a lower goal for speed and travel time. From this data, it is apparent that “road layout has a critical influence on the structure of the driving task and therefore on the biological resources that the driver has to mobilize in order to cope with the demands of this driving task” (De Waard, 1996 p. 594).

![Driver Stress Response](image)

Figure 4. Driving stress response to stressor of road geometry (derived from Richter et al., 1998).

**Bus Driver Stress**

*Few other contemporary professions are as stressful as urban public bus operation. Bus drivers in urban areas all over the world are exposed to uniquely severe combinations of occupational stressors. Compared to employees in comparable professions, urban bus drives have elevated absenteeism rates, retire due to disability at earlier ages, and have higher rates of psychosomatic,*
Rydstedt et al., (1998) examined the effect of bus operation task demand on driver reported effort, fatigue, psychosomatic complaints, and drug use. Workload was defined in terms of a self-report index of perceived time pressure associated with the driving demands. Multiple regression models indicated that for both male and female drivers, increased workload in bus operations was associated with greater reported effort to sustain bus operations with increased fatigue and psychosomatic complaints involving cardiovascular and gastrointestinal disturbances.

In the case of bus operations, there are a number of specific tasks aside from driving that are associated with an imposed workload. Gobel et al., (1998) suggest that on average more than 200 tasks are involved in operating an urban bus aside from driving. As was shown in Table 3, approximately 20% of bus operation time may involve tasks not associated with driving.

In relation to baseline conditions of driving without any other imposed tasks, Gobel et al., (1998) measure the psychophysiological response of bus drivers as a measure of ‘work strain’. As shown in Figure 5, a number of the secondary tasks required for bus operations significantly increases driver stress (mental effort) in addition to normal driving demands, notably fare transactions and operating vehicle controls.

![Figure 5. Change in heart rate variability relative to baseline driving as an indication of increased workload imposed by secondary tasks (based on Gobel et al., 1998).](image)

---

2 Bus drivers gave a four-point rating of the frequency they recalled experiencing the following episodes in the preceding month: ‘time pressure’, ‘been forced to hurry during the work’, ‘strained myself to keep the driving schedule’, ‘not being able to give passenger service due to tight driving schedules’, ‘must drive too fast to keep up with time schedules, and ‘hazardous driving to keep the tight schedules’. This index yielded reliability (Alpha) of 0.90 and was scored such that larger scores meant greater workload.
In addition to stress related to primary and secondary task demands in operating buses, drivers must also contend with ‘job hassles’ originating from demanding circumstances imposed by other road users. For example, Evans, Johansson, and Rydstedt (1999) observed the rate of specific hassles per hour for a group of Swedish urban bus drivers. These hassles included such events such as traffic congestion, risky behavior of other road users, mechanical failures, and delays due to passengers. These hassles impose demands on drivers to maintain safety and time schedules. Comparisons were made between periods of driving with high and low hassle rates, and this analysis indicated that psychophysiological and subjective indications of coping effort were greater during conditions with more frequent hassle demands.

**Impairment**

As some of the preceding examples demonstrate, driver stress may result in impairment of driving performance. For this discussion, impairment is defined as a change in operator performance that is inconsistent with task goals and overall system objectives. For example, slower speeds on narrow lanes as a result of bus driver stress are considered a performance impairment because the likelihood of increased trip times is increased, thereby restricting mobility objectives. A change in performance, which increases the risk of a crash, is a special case of impairment that jeopardizes the overall objective of safety.

De Waard (1996, 2002) discusses several theoretical models that can account for changes in driver performance in response to environmental and state stressors. As has been discussed, humans have limited energetic resources for active control of task performance. To maintain effective task performance, the individual must engage active control to change either the target or cognitive state, or modify the relationship with the stressor directly (see Figure 3). These activities may require considerable (cognitive) effort. The amount of effort applied will be related to the amount of the discrepancy between the cognitive (stress) and target states, and the duration of exposure to the stressor. The availability of resources and the amount of effort applied determine the ‘workload’ imposed on the individual for the expenditure of (limited) resources.

Figure 6 demonstrates that if the amount of workload imposed exceeds the finite resource limit of the individual, then task performance will deteriorate. Performance may deteriorate because the resource demand for either ‘state-related effort’ or the ‘task-related effort’ exceeds the workload capacity of the individual (de Waard, 1996). For example, a driver may not have the capacity to exert sufficient effort to overcome a state of fatigue and stay awake on a very long drive after not sleeping. In the case of bus shoulders, the driver may not have the capacity to compensate for the increased task demand defined by the narrower control boundaries, must reduce speed to reduce workload of the driving task.
Control models can provide predictions about driver performance based on environmental constraints. For example, control output such as speed is constrained by the requirements for compensation of steering errors in relation to the optimal or desired path in the lane. The wider the lane, the greater the tolerance for steering errors with a lower rate of required correction input. A narrow lane would be expected to result in a reduction of speed to compensate for the greater effort to control lane position in terms of the increased rate of correction input.

Predictions about driver performance can also be made with respect to utility models. These models propose that drivers make an evaluation of the costs and benefits of behavioral choices. These models assume some computational activity, although the process may produce a satisfactory outcome rather than an optimal (rational) outcome. To the extent that the probability and cost of a crash is perceived to be high in a narrow lane, a reduction in speed can be expected if this cost is higher than the calculated benefit for reaching the destination on time (e.g., keeping on schedule).

Together, these models of the effect of driver stress on driver impairment suggest a number of patterns of stress outcome. First, despite increased effort to compensate for stress, performance can still be impaired. This is because humans have limited resources such that performance will deteriorate when the stressor demand exceeds the limit of available resources (see Figure 6). Second, there may be no indication of performance impairment despite the presence of apparent increased effort. In this case, spare resources are available to modify the current state to sustain (target) performance (see Figure 3). However, further increases in the stressor level may exceed the spare resources and result in impaired performance. Third, even with maintained or improved performance, stress may still be present in some form. The effort applied to sustain a state that can achieve target performance requires resources. Over time, the sustained
exertion of effort will produce psychosomatic symptoms and eventually decrease performance once resources are depleted. In any case, there may be long-term health effects of sustained effort to cope with stress. These health effects may then become internalized stressors that limit the capacity of the individual to cope. Fourth, there may be impairment of performance without other evidence of stress if a lower goal has been set for the task performance (see Figure 3), or if resource capacity has not been exceeded (see Figure 6).

**Bus Driver Impairment**

As discussed, it appears that the driving and secondary tasks involved in public transit operations, as well as hassles encountered on the job from other road users and passengers can induce stress responses from drivers. As a result of forced and prolonged exposure to these stressors, there may be short-term impairment of driving performance that increase crash risk, as well as long-term stress that may increase health risk. As already alluded, Evans and Johansson (1998) state that “epidemiological data from samples in several different countries consistently find urban bus drivers amongst the most unhealthy of occupational groups, particularly with respect to cardiovascular, gastrointestinal, and musculoskeletal disorders” (p. 100).

**Framework of Stress**

The framework of the relationship between stressors and crash risk adopted in this report can be summarized as shown in Figure 7. This framework presumes that internal (state) and external (environmental) stressors are appraised by the driver. The manner of appraisal and coping response is dependent on the attitudes and skill of the driver. Because of this appraisal, there will be a change in the physiological state of the driver as energetic resources are summoned to process the information about the stressor and prepare a response. Depending on the method of coping adopted (see Figure 3), the driver may act on the stressor to reduce the demand, change the appraisal (goal setting), and adjust the current cognitive state to reduce the discrepancy with the target state for task goals, or take no action. The resulting stress response may lead to no change in behavior or some degree of performance impairment. This stress response may have immediate consequences for crash risk (e.g., lane departure) or longer-term implications for driver health in relation to the form and degree of impairment. The stressor may also have a direct link to crash risk by virtue of physical constraints (e.g., lane too narrow for vehicle, to low friction due to ice). Similarly, the stress state may also have direct link to crash risk by virtue of functional limitations to the human system (e.g., so tired the driver falls asleep).
Stressors
There is ample evidence that certain stressors are related to increased crash risk. For example, numerous driver states such as distraction (Wang, Knipling, & Goodman, 1996) and intoxication (Evans, 1990) have been linked to increased crash risk from empirical research including epidemiological, field, test track, and driving simulator studies. Similarly, several studies have also related a number of environmental stressors such as road geometry and infrastructure to both crash incidents (Alexander, Barham, & Black, 2002) and crash outcome (Ghandi, 2002).

Appraisal
Our experience with the world generates cognitions that place value on the stimuli we perceive and the actions we engage in response to the environment. The appraisal of stressors in the environment determines the emotional response of the perceiver. The significance of the precepts derived from this appraisal determines the form of stress response to the stressor.

Research primarily based on self-report data has indicated that the style of interpretation and coping a perceiver may apply to a stressor in the driving environment are associated with higher rates of crashes and violations. For example, Matthews et al., (1997) compared the attitudes and beliefs of a group of crash involved and non-involved drivers with respect to common stressors in the driving environment. The data suggested that two appraisal styles were more typical of crash involved drivers, namely “aggression”

Figure 7. Summary framework of stress process.
and “thrill-seeking”. This suggests that the predisposition to interpret stressors as either a threat or a source of excitement may lead to a stress state that increases crash risk. These cognitive styles were also related to higher rates of speeding and traffic convictions as well as driving errors.

**Stress**

Evidence exists that stress is directly related to crash risk. For example, Norris, Mathews, and Riad (2000) did a prospective survey of drivers to relate present stress factors to future crash rates. This data indicated that drivers with a subsequent motor vehicle crash reported higher preceding stress in the job, financial, and marital domains.

There is also evidence suggesting the opposite effect whereby a stress response can be triggered in driving contexts associated with high crash rates. For example, Wilde (1994) reports a study by Taylor who plotted the galvanic skin response (GSR) of drivers as a measure of stress in relation to the location on a roadway. The incidence of high stress responses tended to cluster in locations with a history of crashes. Specifically, the GSR response was correlated with the crash rate per vehicle-mile suggesting that stress increased during exposure to high risk driving contexts. Moreover, driving speed decreased as the crash rate increased suggesting some compensatory effort to cope with the prevailing stress state.

**Coping**

The effect of these stressors on the reported stress and observed performance on the drivers will depend on the adopted coping strategy. Tables 4 attempts to associate these primary coping strategies with expected changes in stress and performance. The appraisal of a stressor may result in a change of effort applied to the task workload that may change performance in relation to task goals.

However, this relationship between stress and performance may be mitigated by individual differences in terms of the baseline amount of resources committed to the driving task as defined by the goals set by the driver (see Figure 6). For example, a driver with low task aspirations may apply minimum resources such that any active coping strategy that increases effort and workload (X₁ – X₂) in response to a stressor may not impair performance because of a sufficient spare resource capacity. Conversely, a driver with high task aspirations may apply maximum resources such any additional effort and workload (X₂ – X₃) is not possible so that performance is impaired with all active coping strategies.

| Table 4. Hypothetical Association of Coping Strategies with Stress and Performance. |
|--------------------------------------|--------------------------------------|--------------------------------------|
| **Increase Stress**                  | **Performance Improvement**           | **Performance Decrease**             |
| Change Cognitive State               |                                       | No Action                            |
| **Decrease Stress**                  | **Change Environment**                | **Change Target State**              |

Note that changing the environment implies a different target state because the task demands have changed. In this case, less effort may be required if the current cognitive state is closer to the target state implied by the task demands of the new environment.
Performance
The specific form of performance will depend on the coping mechanism adopted in response to the stress as shown in Table 4. As discussed, the general effect of stress is to reduce driver capacity to react to unexpected additional demands and to maintain performance levels (see Figure 6). Performance may be impaired in terms of either reduced goal setting such as slower speeds when resource capacity is exceeded (Figure 4), or by increased variability as resources fluctuate at the capacity threshold. As attention resources are compromised, this may result in more frequent violation of safety margins as monitoring of the environment is reduced. For example, de Waard (1996) observed increases in variability of both steering input and lane position in response to increased environment stressors such as road design (e.g., roadside obstacles and complexity of merging lanes), as well as increased state stressors such as fatigue.

Crash Risk
Generally speaking, driving performance that is more variable or operates within short margins for error is related to an increased crash risk. Greater variability increases the opportunities for event perturbations that may represent a conflict between road users. In conjunction with short time margins, the probability that the conflict can be avoided is reduced given the diminished time within which to recognize and avoid the hazard (Ward & Buesmans, 1998).

Whereas these are logical assertions, there is some evidence to support them. For example, shorter headways have been related to increased crash risk (Knipling et al., 1993), and greater speed variation within traffic has been related to a greater crash risk (Cooper, 1997).

As noted by McCarthy and Davis (xxxx) in their extensive review of literature for High Occupancy Vehicles (HOV) operations, there is minimal crash data available for BRT operations because of limited experience with these services. However, there are several opportunities for conflicts between HOV and Single Occupancy Vehicles (SOV) that may precipitate a crash:

- Sideswipe crash between traffic in shoulder and adjacent lane.
- Rear end crash with SOV illegally using or stopped in HOV shoulder.
- Merging crash as SOV enters and crosses HOV shoulder to exit ramp.
- Merging crash as HOV enters congested traffic in lane after lane on shoulder is dropped.

In relation to the use of dedicated shoulders for BRT, it is also noteworthy that highway design research suggests that wider lanes and shoulder improve safety (Pfefer, Newman, & Raub, 1999). Conversely, to the extent that dedicated bus shoulder limit access to the shoulder and reduce path width, it may be expected that safety is reduced.

Summary
Decreased trip time is a primary goal of BRT operations, but this must be accomplished with the priority objective of safety. The preceding discussion has developed a
framework for the relationship between driver stress and driver performance that may increase crash risk (Figure 7). Applying this framework to BRT operations, a number of general hypotheses can be offered. First, both lane width and traffic density may be significant stressors for bus drivers (Table 2). Second, increased stress as a result of these stressors may impair driver performance, thereby jeopardizing both mobility and safety objectives for bus transit operations (Table 1). Third, Lane Support Systems (LSS) may reduce driver stress by assisting the driver to interact within these environmental stressors. Fourth, to the extent that the LSS itself is not perceived by the drivers to be a stressor, then the net effect of the LSS would be to improve driver performance in support of BRT objectives.
Chapter 3: Pilot Study

In order to consider these hypotheses, a study was conducted that would examine bus driver stress in an operational context. For this study, a method was proposed to provide preliminary data on driver stress and driving performance from the use of dedicated shoulders in traffic, and the operation of a prototype BRT Lane Support System (LSS). Because of the short duration and small sample size, this activity is termed a ‘pilot study’ to demonstrate the feasibility of this proposed method rather than providing definitive results. Thus, it is NOT possible to certify that this system is ‘safe’ for operational testing on the basis of this study alone. Rather, the objectives of the study are to (1) explore possible methods for future larger scale evaluations of BRT systems, and (2) provide data to suggest trends with respect to the following questions:

- Does driving on certified shoulders (in the presence of high volume traffic) increase driver stress?
- Does driving on certified shoulders (in the presence of high volume traffic) impair driver performance?
- Can the proposed lane support system reduce this stress response and improve driving performance?

Specifically, this study examined the driver stress response to the stressors inherent in BRT operations: (1) traffic volume in the traffic lane, and (2) narrow width of the dedicated bus shoulder. This study systematically examined driver stress and performance in response to these environment stressors with an experimental design as shown in Figure 8 with planned comparisons representing the effect of each stressor on stress and performance.

![Figure 8](image-url)  
*Figure 8. Study design and planned comparisons for hypothesized effects of stressors.*
The study also included an evaluation of a prototype LSS for a BRT service operating in a metropolitan corridor of Minneapolis, MN. It was expected that this system could be used as a surrogate coping mechanism in response to the effects of the other environment stressors (see Figure 8). With reference to the potential strategies for coping with stress, the LSS can be interpreted as technology that changes the cognitive state of the driver by providing information and support critical to task goals (see Table 4). This might increase stress if the state of the driver is changed, whereas stress may not be increased if the system acts independently as a separate agent whose own ‘state’ cooperates in addition to the driver to comply with task demands.

Similarly, if the LSS can act as in intermediary environment that imposes a lower task demand than existent in the operational environment such that fewer resources are applied with improved performance (see Table 4). In this case, the driver interacts with the system interface instead of the traffic environment. If the system interface is more simple and reliable than the traffic environment, then the target state for the driver is reduced because task demands are lowered and there will be less effort required to change the current driver state.

The various hypothesis for the effects of stress and performance in the BRT environment are shown in Figure 9. The bars in this figure show the hypothetical level of stress associated with the environment stressors including the presence of traffic (Traffic), the narrow shoulder (Width), and the feedback from the system (LSS). The effect of these stressors are presumed to be additive such that the sum is an estimate of the total stress in that context. The trend line shows the hypothetical effect of the stress on driving performance.

It was therefore expected that the LSS would improve performance by reducing the stress response to the stressors in the BRT environment: high traffic volume, narrow shoulder width. This hypothesis (A) is shown in Figure 9 relative to stress baseline of presumed stress of BRT operations without the LSS. However, it was also conceded that the LSS might itself be interpreted by drivers to be a stressor (B). Some increase in stress is acceptable if the feedback supports improved performance. It would not be acceptable if the reduction in stress associated with the traffic density and shoulder width were offset by the increase in stress associated with the operation of the system (C), particularly if the total stress level with the system exceeded the baseline conditions (D). To the extent that the increased stress resulting from the operation of the LSS may impose additional resource demands beyond the capacity threshold, then performance may deteriorate as illustrated in the trend between B, C and D in Figure 9.
Figure 9. Alternative hypotheses for stress effect for LSS (relative to baseline).

Method
The study was based on an experimental method using an operational bus route as shown in Figure 10. The study was conducted with Metro Transit bus drivers operating an instrumented bus during normal rush-hour conditions using standard lanes and dedicated bus shoulders along a metropolitan highway corridor in Brooklyn Park, MN. The locations of the bus shoulders are highlighted in this figure parallel to the lanes.
**Figure 10.** Map of test route area (and comparison site to estimate traffic volume)

**Subjects**

The experimental sample was comprised of 12 bus drivers who regularly drove on dedicated bus shoulders along this test route and were familiar with the type of bus used for the study. No recruitment criteria were specified for age and gender.
Data for two of the subjects were subsequently excluded because of a system failure and a mistake in following the instructed route. Thus, the analysis of data was applied to a final sample of 10 bus drivers.

**Route**

The Metro Transit Heywood Facility was used as a staging area for the study (see Figure 10). Drivers were met at the facility and then drove the bus with the research team North to a parking area adjacent to the start of the test route. A GPS map was digitized for the outside lane and adjacent bus shoulder between 66th Avenue and 85th Avenue. A circular route was driven between these avenues such that data was collected for these parallel sections in the North and South Direction.

The study was conducted along the operational bus route between late August and early September in 2002. The test sessions were completed between 3 and 6 pm during weekdays.

The weather during this period was predominately mild:

<table>
<thead>
<tr>
<th>Day</th>
<th>Date</th>
<th>High</th>
<th>Low</th>
<th>Weather of the day</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mon</td>
<td>Aug 5th</td>
<td>80</td>
<td>58</td>
<td>Bedoming partly cloudy and less humid</td>
</tr>
<tr>
<td>Tue</td>
<td>Aug 6th</td>
<td>78</td>
<td>60</td>
<td>Partly cloudy, pleasantly mild</td>
</tr>
<tr>
<td>Wed</td>
<td>Aug 7th</td>
<td>80</td>
<td>63</td>
<td>Plenty of sun, still comfortable</td>
</tr>
<tr>
<td>Thur</td>
<td>Aug 8th</td>
<td>82</td>
<td>64</td>
<td>Plenty of sunshine, still pleasant</td>
</tr>
<tr>
<td>Fri</td>
<td>Aug 9th</td>
<td>83</td>
<td>66</td>
<td>Hazy sticky sunshine, storms possible late</td>
</tr>
<tr>
<td>Mon</td>
<td>Aug 12th</td>
<td>80</td>
<td>60</td>
<td>Showers and thundersorms at times</td>
</tr>
<tr>
<td>Tue</td>
<td>Aug 13th</td>
<td>79</td>
<td>57</td>
<td>Plenty of sun, pleasant</td>
</tr>
<tr>
<td>Wed</td>
<td>Aug 14th</td>
<td>84</td>
<td>63</td>
<td>Warm sticky sun, breezy</td>
</tr>
<tr>
<td>Thur</td>
<td>Aug 15th</td>
<td>77</td>
<td>59</td>
<td>Shower and possible storms early, slow p.m. clearing</td>
</tr>
<tr>
<td>Fri</td>
<td>Aug 16th</td>
<td>79</td>
<td>64</td>
<td>Fading sun, a storm possible late</td>
</tr>
<tr>
<td>Tue</td>
<td>Aug 20th</td>
<td>81</td>
<td>66</td>
<td>Some sun, evening thundersorm possible</td>
</tr>
<tr>
<td>Wed</td>
<td>Aug 21th</td>
<td>76</td>
<td>65</td>
<td>Heavy shower and storms, some flooding possible</td>
</tr>
</tbody>
</table>

**Traffic Volume**

There were no loop detectors in the area of HWY252 used for the study to measure traffic volumes. To estimate traffic volumes on the test route, data was provided by the Traffic Management Center (MnDOT) for a comparison site that was parallel to the test site and also operated as a major metropolitan bus route (see Figure 10).4 Data from the comparison site indicate that the Northbound traffic at the test site was likely to be almost 1.9 times greater than the Southbound traffic. Thus, it is reasonable to use direction of travel as a surrogate for traffic volume. Accordingly, this study assumed that the North section of the test route represented a high traffic volume in contrast to the low traffic volume of the south section.

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4 This is the data for 35W from I-694 to Hwy 10 from the loop detectors.
**Lane Width**
Data for analysis was limited to the road section between the 66th and 85th Avenues in both directions (see Figure 10). This section had bus shoulders adjacent to the outside traffic lane. This route had a standard lane width of 12 feet and an adjacent dedicated bus shoulder approximately 10 feet wide. There was approximately 2.5 miles of lane and parallel shoulder in both directions of travel between 66th and 85th Avenues.

**Bus**
The bus is a 1990 Gillig Phantom conventional bus with an approximate length of 40 feet and a width of 9 feet. It was “wrapped” with a decorative green-yellow wrap as shown Figure 11.

![Figure 11. Picture of bus used for study.](image)

**Lane Support System (LSS)**
The lane support system is comprised of a DGPS based positioning system, on-board high accuracy geospatial database, on-board computers, forward looking radar, and a driver interface system which includes a Head Up Display (HUD), driver control panel display, a tactile seat, and steering wheel haptic feedback.

Although the HUD is primarily used for poor visibility conditions (e.g., fog, snow, night), it was included in this pilot study to provide an evaluation of the complete system. Also, the HUD overlay can provide important lane boundary information in the area of road intersections that may not have existing standard lane markings.

Real time GPS corrections are provided to the bus using the Trimble Virtual Reference station and a digital cell phone as the downlink. A pair of Trimble MS750 receivers are used to provide centimeter accurate position, roll, and heading information at 10 Hz.
A high accuracy geospatial database is used to provide guidance information to the bus and driver. Lane and shoulder boundaries are located in the database at an accuracy level of 5 cm or better. Queries to the database are based on vehicle position. The database query returns lane boundary positions of the bus shoulder and adjacent lane.

With the results of the database query, the lateral position of the bus can be compared to the location of the lane (or shoulder) boundaries. The lateral position of the bus with respect to the center of the lane, its width, speed, and heading are used to determine both lateral error and whether the bus is moving out of lane.

The haptic feedback system applies torque through the steering wheel. Steering wheel torque feedback is directly proportional to lateral position error. This “advisory” is provided continuously. The torque feedback on the steering system is limited to 3 ft-lbs, ensuring that any feedback can be overridden by a driver should they so choose. This feedback is continuous in the sense that it is proportional to the proximity to the lane or shoulder boundary. This feedback is at maximum when a lane boundary is detected and minimum when the bus is positioned in the center of the lane or shoulder.

Binary warnings are also provided by tactile and visual lane “warnings” when the bus has been determined to be departing the lane/shoulder. The tactile warning is a vibration of the driver’s seat, left side for left lane departure, and vice versa. Warnings are provided in the HUD as well, with the left lane boundary turning red for a left lane departure, and vice versa. It should be noted that the shoulder boundaries are continuously projected in the HUD as the bus travels along the shoulders, and the warnings are applied only when an imminent lane departure is detected.

**Independent Variables**

As illustrated in Figure 8, the study design included three independent variables that represent potential stressors in the operational bus context that may impact safety (see Table 1):

- **Traffic volume** – the direction of travel was used as a surrogate for traffic volume (North = high volume, South = low volume).
- **Lane width** – the use of the traffic lane or the bus shoulder defined two levels of width in which the bus must operate (Wide Lane = 12’, Narrow Shoulder = 10’).
- **LSS** – the system effect of the LSS (LSS = system on, No LSS = system off).

Test conditions were devised with these three independent variables (see Table 6). Because every driver experienced all test conditions, the study comprised a 2 (Traffic density) x 2 (Lane width) x 2 (LSS) repeated measure design. Within this design, a set of a priori comparisons between test conditions were defined to test specific stressor effects (see Figure 8):

- **Traffic stressor effect** = North versus South direction of travel on bus shoulder (with higher traffic volumes expected in the North direction).
• **Width stressor effect** = Lane versus bus shoulder in each direction of travel to consider the interaction of reduced width on the shoulder with increased traffic volume in the adjacent lane.

• **LSS stressor effect** = System on versus system off in the bus shoulder in each direction of travel to consider the interaction of the operating system on the shoulder with a high traffic volume in the adjacent lane.

**Dependent Measures**

The stress framework discussed earlier in this volume was used to identify relevant dependent measures with which to examine the environment stressors in the operational bus context, including the LSS (see Figure 7). These include measures of stressors, appraisal, stress, and resulting performance impairment relevant to safety.

**Usability Questionnaire**

A questionnaire was devised to measure several aspects of the stress framework for both the environment stressors and the LSS (see Appendix A). This was comprised of a series of response selection and open-ended questions that required subjects to rate their agreement with a number of statements and report their attitudes and opinions. Responses to this questionnaire identified stressors, described evaluations of those stressors, and reported levels of stress symptoms as well as self-reported changes in performance including expected impact on safety.

**Usability Scale**

To focus on the LSS as a potential stressor, an established usability scale (Appendix B) was used to quantify driver judgments about the usefulness and satisfaction of the LSS. This scale is based on a usability measure developed by the Traffic Research Centre at the University of Groningen in the Netherlands (van der Laan, Heino, & de Waard, 1997). The items in this scale are conceived from two dimensions of usability; namely, perceived “usefulness” in terms of the apparent utility of the system functions, and how “satisfying” the system is to use in terms of acceptability. These scales are scored such that larger numbers mean greater perceived usefulness and satisfaction.

This usability scale is an attempt to derive a standard scale that is simple to implement in assessing operator acceptance of telematic devices. Whereas its simple format may be limited in the quality of information that may be obtained, it does have the practical benefit of being easy to implement, and therefore, has been used in a range of telematic evaluation studies that may be used for baseline comparisons.

**Effort**

The potential effect of a stressor is the application of effort to increase task workload in the application of possible active coping mechanisms (see Figure 3). In such cases, subjective effort can be an indicator of a stress response. Thus, subjective stress was measured with the Rating Scale of Mental Effort (RSME) developed by Zijlstra, 1993 (see also de Waard, 1995). This is a unidimensional scale of reported mental effort anchored by a number of common reference points (Appendix C). This scale is scored such that higher values represent greater reported effort.
Workload
Similarly, the subjective level of workload applied to the task and application of active coping mechanisms was also considered a measure of the stress response. Subjective workload was measured by the NASA (reduced) Task Load Index (R-TLX) developed by Hart & Staveland, 1988 (see also Fairclough, 1991). This is as a multi-dimensional scale of subjective experience of task demands (Appendix D). The mean scale and each item are scored such that higher values represent greater reported workload.

Performance
Increased mobility and safety are primary objectives of BRT (see Table 1). Consistent with these objectives, performance measures were derived for speed: high speeds result in increased mobility by reducing trip time. Measures were also devised for lane position because this can be indirectly related to safety to the extent that lane departures impose a crash risk. Indeed, several variants of lane position performance were included that incorporated speed (Time-to-line-crossing) and time-based responses to actual lane departures (time to recover lane departure, distance traveled outside lane, and percentage of time outside lane).

As shown in Table 5, all performance measures included a metric to quantify the central tendency of driving performance (median) and also a metric to represent the variability of the distribution that might represent a safety issue (maximum, 85th percentile, Sd). Note that the precision of all data based on position is limited to accuracy of GPS (2 cm).
Table 5. Performance metrics and size of analyzed samples (N).

<table>
<thead>
<tr>
<th>Measure</th>
<th>Sample (N) North Traffic Width LSS</th>
<th>Sample (N) South Traffic Width LSS</th>
<th>Definition</th>
<th>Tendency</th>
<th>Variability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Speed</td>
<td>7</td>
<td>7</td>
<td>Velocity of travel.</td>
<td>Median (m/s)</td>
<td>SD (m/s)</td>
</tr>
<tr>
<td>Lane position</td>
<td>7</td>
<td>7</td>
<td>Distance of bus center from right boundary.</td>
<td>Median (m)</td>
<td>SD (m)</td>
</tr>
<tr>
<td>1/TLC</td>
<td>7</td>
<td>7</td>
<td>Distance from outside or tire to nearest boundary for lane or shoulder divided by lateral speed. Calculated based on vectors comprising direction and speed. Vectors indicating a lane departure (TLC = 0) are excluded.</td>
<td>Median (s)</td>
<td>85th Percentile&lt;sup&gt;5&lt;/sup&gt; (s)</td>
</tr>
<tr>
<td>Response</td>
<td>7</td>
<td>7</td>
<td>Lane departures defined by duration from exit of bus edge departure relative to either boundary in lane or shoulder until maximum departure position indicating start of return path.</td>
<td>Median (s)</td>
<td>Max (s)</td>
</tr>
<tr>
<td>Departure</td>
<td>7</td>
<td>7</td>
<td>Lane departures defined by duration from exit and return point of bus edge departure relative to either boundary in lane or shoulder.</td>
<td>Median (s)</td>
<td>Max (s)</td>
</tr>
<tr>
<td>%Time boundary violation</td>
<td>7</td>
<td>7</td>
<td>Lane departures defined by percentage of total data sample with position of bus edge recorded outside either boundary in lane or shoulder.</td>
<td>Total %</td>
<td>-</td>
</tr>
</tbody>
</table>

Note:  N is the number of subjects analyzed in a test condition.

Because most data was defined relative to GPS based measures of bus position, data was excluded without a ‘good’ GPS measurement. This resulted in a loss of 16% of the data due to occasional poor GPS signals. The data set was then filtered to exclude lane changes and speeds below 5 mph. This eliminated a further 14% of the reduced dataset. Overall, the final data set represented 72% of the original data.

---

<sup>5</sup> Note that the maximum value was defined by the 85<sup>th</sup> percentile during the drive to represent a more typical extreme value rather than the absolute maximum. This percentile was calculated for each subject for the data variable based on the entire direction of travel. The analysis of the maximum is then graphed as the mean percentile value for the group of drivers.
**Procedure**

Drivers attended a training session and a test session. These sessions were scheduled separately in previous weeks so that all drivers were trained for the study before the test session.

*Practice Session*

The purpose of the training session was to train the drivers to operate the Lane Support System (LSS) and familiarize them with the operation of the bus along the test route. Each driver received three hours of training, with the majority of the training in-vehicle. Driver training began with an explanation of the purpose of the lane assist system, a description of its operation, and a walk-around to point out sensors located on the outside of the bus. Once the walk-around was completed, drivers were invited into the bus, where the computers, GPS receivers, and radar processors were shown to the driver.

Once questions were answered, the driver sat behind the steering wheel. While behind the wheel, the functionality of the system and the individual driver interfaces were explained. The driver was then instructed on the use of driver information (touch) panel. Once the driver was comfortable with the purpose and operation of the system, the driver and trainer rode the bus to the test staging area.

At the driver staging area, questions regarding the system were answered. When the driver was comfortable in his/her understanding of the bus, the driver moved onto the test corridor, where the test route was driven repeatedly in the presence of a trainer. The trainer was there to answer any questions raised by the driver.

When training was complete, the driver drove the bus back to the Heywood facility, where it was parked until the next driver was trained.

*Test Session*

The procedure for the test session was formulated as a check list with scripts for specific instructions to ensure standardized administration of procedures administered to all drivers (Appendix E).

The test session was comprised of four stages. All stages began and finished in the parking area adjacent to the test route (see Figure 10).

In stage one, drivers were met at the Metro Transit Heywood Facility to be briefed on the purpose of the study and be given a review of the system (see Figure 10). Drivers then read and signed a consent form approved by the University of Minnesota (Appendix F) and drove the bus to the test area with the HUD in the down position, but with the system deactivated.

In stage two, drivers were given a review of the general procedures that would govern the test session and a final review of the system. The drivers were also given specific instructions to provide verbal reports and complete the subjective questionnaires used in the study. Drivers were then directed along the test route on the dedicated shoulder with
the LSS for a practice drive so that they were familiar with the test procedures, system operations, and the directions for each test.

In stage three, drivers completed three test drives. Each test drive comprised a different test condition:

- Lane – driving on the right traffic lane adjacent to the shoulder without the LSS.
- Shoulder – driving on the dedicated bus shoulder adjacent to the normal lane without LSS.
- LSS – driving on the dedicated bus shoulder adjacent to the normal lane with LSS.

Each driver was assigned to a specific sequence of test conditions. As shown in Table 6, the order of these test conditions was counterbalanced with a Latin square design. During each test drive, the drives were encouraged to comment about any stressful events. These comments were recorded by the experimenter. The drivers completed the set of stress questionnaires at the end of each test drive.

In the final stage, subjects completed the set of usability questionnaires and were then debriefed before returning to the Metro Transit Heywood Facility.

Table 6. Test Condition Assignment

<table>
<thead>
<tr>
<th>Subject</th>
<th>Test Drive 1</th>
<th>Test Drive 2</th>
<th>Test Drive 3</th>
<th>Test Drive 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Practice-LSS</td>
<td>Lane-No LSS</td>
<td>Shoulder-No LSS</td>
<td>Shoulder-LSS</td>
</tr>
<tr>
<td>2.</td>
<td>Practice-LSS</td>
<td>Lane-No LSS</td>
<td>Shoulder-LSS</td>
<td>Shoulder-No LSS</td>
</tr>
<tr>
<td>3.</td>
<td>Practice-LSS</td>
<td>Shoulder-No LSS</td>
<td>Lane-No LSS</td>
<td>Shoulder-LSS</td>
</tr>
<tr>
<td>4.</td>
<td>Practice-LSS</td>
<td>Shoulder-No LSS</td>
<td>Shoulder-LSS</td>
<td>Lane-No LSS</td>
</tr>
<tr>
<td>5.</td>
<td>Practice-LSS</td>
<td>Shoulder-LSS</td>
<td>Lane-No LSS</td>
<td>Shoulder-No LSS</td>
</tr>
<tr>
<td>6.</td>
<td>Practice-LSS</td>
<td>Shoulder-LSS</td>
<td>Shoulder-No LSS</td>
<td>Lane-No LSS</td>
</tr>
<tr>
<td>7.</td>
<td>Practice-LSS</td>
<td>Lane-No LSS</td>
<td>Shoulder-No LSS</td>
<td>Shoulder-LSS</td>
</tr>
<tr>
<td>8.</td>
<td>Practice-LSS</td>
<td>Lane-No LSS</td>
<td>Shoulder-LSS</td>
<td>Shoulder-No LSS</td>
</tr>
<tr>
<td>9.</td>
<td>Practice-LSS</td>
<td>Shoulder-No LSS</td>
<td>Lane-No LSS</td>
<td>Shoulder-LSS</td>
</tr>
<tr>
<td>10.</td>
<td>Practice-LSS</td>
<td>Shoulder-No LSS</td>
<td>Shoulder-LSS</td>
<td>Lane-No LSS</td>
</tr>
<tr>
<td>11.</td>
<td>Practice-LSS</td>
<td>Shoulder-LSS</td>
<td>Lane-No LSS</td>
<td>Shoulder-No LSS</td>
</tr>
<tr>
<td>12.</td>
<td>Practice-LSS</td>
<td>Shoulder-LSS</td>
<td>Shoulder-No LSS</td>
<td>Lane-No LSS</td>
</tr>
</tbody>
</table>
Chapter 4: Results

The results section is organized by headings corresponding to the stages depicted in the framework adopted in this volume to depict the process of stress in relation to performance and crash risk (see Figure 7). As shown in Figure 12, the results are presented for these topics:

- Stressors – elements of the driving environment and LSS that attract driver attention
- Appraisal – attitudes and valuation of stressors
- Stress – response to appraisal of stressor in terms of effort, workload, and stress.
- Performance – impact of stress (and coping) on driving performance
- Safety – expectations about crash risk based on driving performance.

Figure 12. Summary of analyzed results based on framework of stress process (see Figure 7).

Stressors

Particular stressors were identified by the drivers in this study with the usability questionnaire and driver commentaries.

Usability Questionnaire

Appendix A contains the consolidated survey of responses from drivers who used the system (N =10). This questionnaire required drivers to list the elements of the driving environment to which they attended while driving in order of priority (Q7). The questionnaire also asked drivers to report difficult aspects of driving a bus on a dedicated shoulder (Q10, Q11).
The following stressors were reported to attract the most attention while driving without LSS (Q7):

- Stay close to curb;
- mirrors;
- constantly thinking and watching lines and curbs;
- cars position in adjacent lane;
- views down road;
- the ‘big picture’;
- traffic conditions;
- staying in the shoulder.

The following task demands were reported to be most difficult while driving without LSS (Q10):

- Insufficient space for buses on bus shoulder; other vehicles must stay off the bus shoulder.
- Traffic not seeing bus and cutting into shoulder.
- Unpredictability of traffic in adjacent lane.
- Traffic entering or stopping in shoulder.
- Traffic passing through shoulder (e.g., to exit) or passing too close and forcing bus toward curb.

With the LSS, the drivers reported the following stressors requiring most attention (Q7):

- Steering,
- Heads Up Display;
- left white line;
- whether the LSS was going to give misinformation;
- cars on my left;
- lane boundaries;
- losing the GPS signal.

The following issues with LSS were reported to be most difficult while driving (Q11):

- Calibration of steering.
- Restricted view of HUD.
- Loss of GPS signal.
- Inaccurate front detection and lane positioning feedback (e.g., during intersections).
- Distraction of HUD information and combiner.

It is apparent that attention to stressors shifted with the use of the system such that drivers attended less to lane width and road geometry and instead focused on the function and
components of the LSS. Attention was given to traffic as a major stressor both with and without the system.

*Driver Comments - Driving*

The following are example of the appraised stressors relating to traffic and lane width while driving the test route:

**Traffic Stressors**
- Other vehicles stopped in the shoulder lane in emergency.
- Other bus in front of the bus.
- Heavy vehicles in the lane next to the shoulder lane.
- Other vehicles violating the shoulder lane.
- Vehicle and pedestrians trying to pass across in intersections.

**Width Stressors**
- The bus bouncing in the shoulder lane due to rough road surface.
- The bus hitting on the curb.

**Appraisal**

The drivers reported attitudes and opinions in relation to the evaluation of the identified stressors. Drivers were asked to appraise the environment stressors (traffic, width) and the Lane Support System (LSS).

**Environment**

The appraisal of the environmental stressors was measured with the usability questionnaire (Appendix A).

*Usability Questionnaire*

The usability questionnaire contained one question that required drivers to report their attitudes and opinion about driving on the shoulder as a stressor requiring attention from them (Q4):

- (Q4) Most drivers described their attitude toward driving on dedicated bus shoulders as positive.

**Lane Support System (LSS)**

The appraisal of the LSS was made with the usability questionnaire (Appendix A), driver commentary, and the usability scale (Appendix B).

*Usability Questionnaire*

The usability questionnaire contained several questions that required drivers to rate the level of agreement with a number of evaluative statements about the LSS (QA – F). The drivers were also asked to report their attitudes and opinion about the LSS as a stressor requiring attention from the driver (Q3, 8, 9).
The summary for each question from the usability questionnaire relevant to the appraisal of the system is presented below:

- (QB) Most drivers moderately agreed that the system would be most beneficial to bus operations in rural areas.
- (QC) Most drivers moderately agreed that the system would be most beneficial to bus operations on highways.
- (QE) Most drivers moderately agreed that the system would require specialized training for safe and effective use.
- (Q3) Half of the drivers described their attitude toward the system as positive.
- (Q8) Most drivers had the opinion that the LSS was beneficial, especially during poor visibility conditions such as night or inclement weather.
- (Q9) Most drivers had the opinion that the LSS had some problems, specifically in relation to (i) unreliable GPS, (ii) calibration of steering, and (iii) complexity of information from the range of displays in the current system configuration (e.g., HUD, seat vibration, LCD monitors).  

**Driver Comments - Driving**
The following are examples of the appraisals that the drivers appraised made while using the system:

- Disturbance in steering feedback
- Losing GPS signal

**Driver Comments – Debriefing**
The following are examples of both positive and negative appraisals made by drivers of the system while reflecting on their experience during the debriefing period after the study:

**Positive Appraisal**
- It’s interesting that the more I use the system, the more I like it! The system is great - just take some time to get used to it. Once I get used to it, I can just kind of let it go. (2 drivers)
- The bus is nice! And easy to handle! (if GPS is working) (1 driver)
- I think this [the LSS technology] is the way to go! (1 driver)

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6 Trimble’s Virtual Reference Station (VRS) system was used to provide GPS corrections for the testing conducted as part of this study. During the driver testing, which occurred in the July and August 2002 timeframe, some drivers noted reliability problems with GPS.

The VRS system in use during this timeframe was provided by Mn/DOT. To our knowledge, it is Trimble’s first VRS installation in the US. The VRS system worked reasonably well, but some reliability issues were noted. In October 2002, Trimble upgraded the VRS system at Mn/DOT, and provided to the University of Minnesota a mirror site which provides redundant correction service. The U of MN site has been used since it was made available to the U of MN. Since the upgrade, GPS performance has been significantly improved. Problems cited by drivers have been addressed and corrected.
Negative Appraisal

- The “HUD” is getting into my way. I would like to put it up when driving in lane. The HUD is not for use in normal weather conditions - plus it does not provide detailed information about the traffic. I think it’ll only be helpful in darkness, snow and rain. (5 drivers)
- The side [virtual] mirror is a distraction rather than helpful; it only shows redundant information that I can see myself. (4 drivers)
- I am not sure the steering is working; sometime it’s pulling me to traffic. I don’t know why it’s doing it. Sometime I have to try hard to fight against the steering. (3 drivers)
- GPS is not reliable. It’ll be great if we got a warning sign when it’s about to go off, like an alarm, that’ll be very helpful. We can’t trust the system if we constantly lose GPS. (7 drivers)

Usability Scale

The mean scales for usefulness and satisfying were computed such that higher scores represent greater perceived usability. An acceptable reliability coefficient of .96 for the usability scale was obtained for all drivers that completed this measure with the system (N = 8). The usability scale scores for the drivers using the system in this study are included in Figure 13.

Figure 13. Mean usability rating scales for BRT operators and drivers (N = 10).

---

7 The system, as tested, was designed to keep the bus in the center of the shoulder. Through this testing, we found that some drivers like to keep the bus in the center of the shoulder, others like to “hug” the fog line, and other still prefer to keep the bus near the curb. To accommodate these different preferences, a means to allow the driver to adjust the desired lateral position from dead center was added to the driver interface. This allows a driver to set a desired offset in increments of two inches either left or right of center.

8 The reliability coefficient is a measure of the consistency of the scale to measure the concept it is intended to represent (Kaplan & Saccuzzo, 1982, p. 103).
In addition, Figure 13 also includes scale values for (i) a group of drivers at the Metro Transit facility (N = 17) that did not participate in the evaluation pilot study; and (ii) a group of BRT operators that made ratings in a survey conducted by UMN (N = 16). Both of these additional groups did not experience the system, but instead only imagined the features of a LSS and its impact on BRT operations.

The usability scale data was analyzed with a 2 (usability scale) x 3 (respondent group) mixed-factor design (ANOVA). The Metro Transit facility drivers rated the (imagined system) to be more useful [F(38) = 3.83, p .05] and satisfying [F(38) = 5.61, p .01] than both the BRT operators and the drivers that actually drove the system. Generally, all respondents rated the system to be more useful than desirable (satisfying) to operate. That is, the raters recognized the potential utility and benefits of such systems for BRT operations, but do not necessarily consider them to be as desirable at this stage.

This analysis suggests that the perceived usability of the LSS is primarily based on the apparent level of performance it can support. Indeed, this is a sizeable relationship given that approximately 80% of the shared variance of these usability scales are accounted for by reported quality of performance. However, whereas attained performance may determine perceived usefulness and satisfaction with the LSS, the effort applied to operate the system also determines the level of satisfaction. That is, operators can be satisfied with a system they perceive to be useful, but they must also find it easy to use in order to be satisfied.

Figure 14. Usability scale for LSS based on reported data from BRT samples.

Figure 14 presents the usability scales reported by the three BRT samples for the LSS in the context of historical data from evaluations of ‘other’ telematic systems in Europe.
(based on data reported from drivers experiencing these systems). This figure includes several examples of different categories of system that have been evaluated with this measure:

- Speed regulation systems (S) that warn or control driving speed (e.g., Intelligent Speed Adaptation, Adaptive Cruise Control),
- Information systems (I) that advise or provide tutorial information about safe driving,
- Collision avoidance systems (C) that warn or control the vehicle,
- Automated highway systems (A) that control both the speed and headway of platooning vehicles.

From these types of systems, the LSS is most comparable to speed regulation systems and information systems. For example, the LSS provides feedback to assist the driver in maintaining vehicle control within lateral boundaries while the speed regulation systems also assist drivers in maintaining vehicle control, but with respect to longitudinal boundaries. Similarly, the LSS can provide information without classifying hazards or automating vehicle control as do other forms of information system. In this respect, the LSS tended to be perceived as useful and more satisfying than some of the collision avoidance systems.

This historical data suggests that drivers who have not experienced LSS expect it to be highly useful and satisfying with respect to these comparable telematic systems. However, with the current technical functioning and design of the LSS, drivers who have experienced the system rate lower usefulness and satisfaction. For these drivers, the LSS is appraised as being less useful than most information and speed regulation systems, but more satisfying than all collision avoidance and automated highway systems that impose hazard classifications and automate the driving task. This would be expected given that professional drivers may typically prefer to retain authority for hazard decisions and vehicle control.

**Driver Stress**

The stress response resulting from the negative appraisal of the stressors in operational environment and the LSS were measured in terms of task workload (Appendix D) and driver effort (Appendix C). In addition, the drivers also reported symptoms of stress in the usability questionnaire (Appendix B).

**Workload**

Table 7 present the reliability coefficients for the NASA R-TLX based on all subjects (Hart & Staveland, 1988) in each driving condition (N = 10). It is apparent that the reliability of the mean workload score based on all items is acceptable for all of the driving conditions (> 0.70, Kaplan & Saccuzzo, 1982, p. 106).

<table>
<thead>
<tr>
<th>Lane</th>
<th>Shoulder</th>
<th>Shoulder (LSS)</th>
</tr>
</thead>
<tbody>
<tr>
<td>.76</td>
<td>.89</td>
<td>.90</td>
</tr>
</tbody>
</table>
Figure 15 presents the mean workload score reported by drivers in each driving condition. This data was analyzed with appropriate non-parametric methods to test for the effect of driving condition (Freidman test). The trend of greater workload reported for driving on the shoulder and with the LSS was not statistically significant.

![Bar chart showing mean workload score in driving conditions](image)

**Figure 15. Mean workload score in driving conditions (N = 9).**

**Effort**

Table 8 specifies the correlations between reported effort using the RSME (Zijlstra, 1993) and workload based on the R-TLX items and mean score for each driving condition. Most of these correlations are significant and practical. This implies that the RSME is a valid measure of general effort toward driving tasks.

Generally, the reported effort was related to task demand (mental and physical) as well as stress (effort and frustration). These relationships were strongest for the LSS condition, presumably because of greater subject variation in terms of demand and frustration in response to the system.

Notably, reported effort did not appear to be based on subjective ratings of performance in any condition. This implies that effort was related more to experienced cognitive states involving applied effort rather than to observed behavior in relation to task goals (performance).

---

9 One subject was removed from this data set because the workload measure was not completed correctly.
Table 8. Correlation Coefficients of RSME and Workload Factors on LSS (N = 8).

<table>
<thead>
<tr>
<th></th>
<th>Mental Demand</th>
<th>Physical Demand</th>
<th>Time Pressure</th>
<th>Performance</th>
<th>Effort</th>
<th>Frustration</th>
<th>MEAN SCORE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lane</td>
<td>.77***</td>
<td>.58</td>
<td>.15</td>
<td>.45</td>
<td>.70**</td>
<td>.34</td>
<td>.78**</td>
</tr>
<tr>
<td>Shoulder</td>
<td>.79**</td>
<td>.65*</td>
<td>.18</td>
<td>.15</td>
<td>.67*</td>
<td>.66*</td>
<td>.66*</td>
</tr>
<tr>
<td>LSS</td>
<td>.90***</td>
<td>.65*</td>
<td>.64*</td>
<td>.10</td>
<td>.65*</td>
<td>.79**</td>
<td>.87***</td>
</tr>
</tbody>
</table>

Note: * p < .10, ** p < .05; *** p < .01

Figure 16 presents the mean effort level reported by drivers in each driving condition. The trend of greater effort reported for driving on the shoulder and with the LSS was not statistically significant.

![Mean Effort Chart](chart.png)

**Figure 16. Mean reported effort (RSME) in driving conditions.**

**Symptoms**

The usability questionnaire contained several questions that required drivers to rate the level of agreement with a number of evaluative statements about stress symptoms experienced with the LSS (QG – L). The drivers were also asked to report their attitudes and opinion about the stress experienced with LSS as a stressor requiring attention from the driver (Q2, 5, 6).

The summary for each question from the usability questionnaire relevant to the appraisal of the system is presented below:

- (QI) Most drivers moderately disagreed that the system would reduce driver vigilance.
- (QJ) Most drivers moderately disagreed that the system would reduce driver stress.

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10 One subject was removed from this data set as an outlier, and another for not completing the workload measure correctly.
• (Q2) Most drivers felt that driving with the LSS would be more stressful, primarily because the complexity of information was considered distracting (especially on curves and intersections).

• (Q5) Drivers were split evenly into groups representing those that felt either more confident/comfortable with the LSS (“LSS added a little more confidence, hence less stress”), and those feeling less confident/comfortable with the LSS (“I noticed things that I missed around the bus that I should have noticed, but I was paying too much attention to the system displays”).

• (Q5) Most drivers reported that they paid more attention to the driving task with the LSS, for example:

“When using the system you had to keep in mind that this is new tech and that something might go wrong, but when the bugs get worked out, the trust will rise and stress will go down, and maybe paying a little less attention will be the result, but right now I have to pay much more attention.”

**Driving Performance**

The driving performance measures used in this study to assess the effect of stress on driver behavior and vehicle control are listed in Table 5. Each measure was analyzed for the effects of traffic volume, lane width, and system support as illustrated in the study design depicted in Figure 8. Non-parametric tests were used for the planned comparisons that defined these effects (Wilcoxon test).

Subjective impressions of performance were also reported in the usability.
Vehicle Speed

Figure 17. Median speed in driving conditions for both traffic volumes.

Figure 17 presents the median speed for the driving conditions in both direction of travel that represent differences in traffic volume:

Traffic: There was a significant effect of traffic volume in the adjacent lane resulting in a slower average speed in the shoulder (without the system) for the North direction of travel corresponding to a higher traffic volume [Wilcoxon Z = 2.34, p < .018].

Width: In the North direction of travel with a higher traffic volume, average speed was significantly faster in the bus shoulder (without the system) compared to unassisted driving in the traffic lane [Wilcoxon Z = 2.43, p < .015]. However, average speed was marginally slower on the bus shoulder than in the lane with a lower traffic volume in the South direction [Wilcoxon Z = 1.78, p < .075].

System: There was no significant effect of the system on average speed (travel time) for either level of traffic volume (direction of travel).
Figure 18. Variability of speed in driving conditions for both traffic volumes.

Figure 18 presents the standard deviation (Sd) of speed. The data is displayed for each driving condition in both direction of travel that represent differences in traffic volume:

**Traffic:** There was no significant effect of traffic volume in the adjacent lane for the variability of speed on the bus shoulder.

**Width:** In the North direction of travel with a higher traffic volume, speed variability was significantly lower in the bus shoulder (without the system) compared to unassisted driving in the traffic lane [Wilcoxon Z = 2.67, p < .008]. However, this effect was not significant with a lower traffic volume in the South direction.

**System** In the North direction of travel with a higher traffic volume, speed variability on the shoulder was marginally lower with LSS than without the system [Wilcoxon Z = 1.84, p < .066]. However, this effect was not significant with a lower traffic volume in the South direction.
Figure 19. Median lane position in driving conditions for both traffic volumes.

Figure 19 presents the **median position** within the lane and shoulder relative to the bus center point. The position data is relative to the right side of the lane and shoulder in the direction of travel. This figure also identifies the corresponding center of the lane and shoulder with an arrow line. These lines assume standard 12’ (3.658 m) and 10’ (3.048 m) lane and shoulder widths. If the data showed the median position in line with these references, then the bus would be driven in the center of the lane or shoulder. Deviations from these references indicate that the bus was driven away from the center position.

In comparison to the marked references for the lane and shoulder center line demonstrate that drivers favor a lane position toward the shoulder where there is open space compared to the adjacent lanes occupied by traffic. In contrast, drivers target the center position of the narrower shoulder because there is no space on the side of the verge and the adjacent lane is occupied by traffic. However, when there is less traffic (South direction), drivers on the shoulder appear to shift to the relative open space of the adjacent lane where there may be gaps in the traffic stream.

The data is displayed for each driving condition in both direction of travel that represent differences in traffic volume:

**Traffic:** The absolute value of the average position was significantly different on the shoulder without the system between the North and South direction of travel [Wilcoxon Z = 2.34, p < .018]. As commented above, the average position within the boundary of the bus shoulder was significantly closer to the adjacent lane when there was less traffic volume in the South direction.
**Width:** There was no significant effect of lane width on average (absolute) position. However, in terms of position relative to the center point, there was a marginally significant offset for average position in the traffic lane relative to the center point in both the high \(Z = 1.42, p < .077\) and marginally in the low traffic conditions \(Z = 1.45, p < .073\). On the shoulder in the South direction, the average position was significantly offset from the center in the direction of the traffic lane \(Z = 2.15, p < .016\). In the North direction on the shoulder, the average position was not significantly different from the center point.

**System:** There was no significant system effect for average lane position.
Figure 20. Variability of lane position in driving conditions for both traffic volumes.

Figure 20 presents the standard deviation (Sd) of position within the lane and shoulder relative to the bus center point. The data is displayed for each driving condition in both directions of travel that represent differences in traffic volume:

**Traffic:** There was a marginal significant effect of traffic volume in the adjacent lane resulting in less variability of position in the shoulder (without the system) for the North direction of travel corresponding to a higher traffic volume [Wilcoxon Z = 1.69, p < .091].

**Width:** In the North direction of travel with a higher traffic volume, position variability was significantly lower in the bus shoulder (without the system) compared to unassisted driving in the traffic lane [Wilcoxon Z = 2.55, p < .011]. However, this effect was not significant with a lower traffic volume in the South direction.

**System:** In the North direction of travel with a higher traffic volume, position variability on the shoulder was significantly lower with LSS than without the system [Wilcoxon Z = 2.67, p < .008]. However, this effect was not significant with a lower traffic volume in the South direction.
**Figure 21.** Median inverse of time-to-line crossing (1/TLC) in driving conditions for both traffic volumes (excluding lane boundary departures).

Figure 21 presents **median of the inverse of time-to-line crossing (1/TLC)**. All TLC data excludes boundary departure events from either the lane or shoulder (TLC = 0 s). Based on the inverse of TLC, larger values represent a shorter time-based safety margin. The results are then inverted and described in more conventional terms by the implied effect on (median) TLC.

The data is displayed for each driving condition in both direction of travel that represent differences in traffic volume:

**Traffic:** There was a significant effect of traffic volume in the adjacent lane resulting in a larger average time-based safety margin (TLC) in the shoulder (without the system) for the North direction of travel corresponding to a higher traffic volume [Wilcoxon Z = 2.20, p < .028].

**Width:** In the North direction of travel with a higher traffic volume, the average safety margin was significantly shorter in the bus shoulder (without the system) compared to unassisted driving in the traffic lane [Wilcoxon Z = 2.67, p < .008]. This effect was also significant in the South direction with a lower traffic volume [Wilcoxon Z = 2.20, p < .028].

**System:** There was no significant effect of the system on average safety margin for either level of traffic volume (direction of travel).
Figure 22. Maximum inverse of time-to-line crossing (1/TLC) in driving conditions for both traffic volumes (excluding lane boundary departures)

Figure 22 presents the maximum (85th percentile) of the inverse of time-to-line crossing (1/TLC). All TLC data excludes boundary departure events from either the lane or shoulder (TLC = 0 s). Based on the inverse of TLC, larger values represent a shorter time-based safety margin. The results are then inverted and described in more conventional terms by the implied effect on the minimum (15th Percentile) TLC.

The data is displayed for each driving condition in both direction of travel that represent differences in traffic volume:

**Traffic:** There was a marginal effect of traffic volume in the adjacent lane resulting in a larger minimum time-based safety margin (TLC) in the shoulder (without the system) for the North direction of travel corresponding to a higher traffic volume \( \text{Wilcoxon Z} = 1.86, \ p < .063 \).

**Width:** In the North direction of travel with a higher traffic volume, the minimum safety margin was significantly shorter in the bus shoulder (without the system) compared to unassisted driving in the traffic lane \( \text{Wilcoxon Z} = 2.67, \ p < .008 \). This effect was also significant in the South direction with a lower traffic volume \( \text{Wilcoxon Z} = 2.20, \ p < .028 \).

**System:** There was no significant system effect for the minimum time-based safety margin for either level of traffic volume (direction of travel).
Figure 23. Median response time to recover boundary departure in driving conditions for both traffic volumes.

Figure 23 presents the **median response time** to recover the bus from boundary departures. This is defined as the time from the start of a departure and the maximum point of departure (signifying the beginning of the return path).

The data is displayed for each driving condition in both direction of travel that represent differences in traffic volume:

**Traffic:** There was no significant effect of traffic volume in the adjacent lane for the average response time to boundary departures in the bus shoulder.

**Width:** In the North direction of travel with a higher traffic volume, the average response time to recover the boundary departures was marginally faster in the bus shoulder (without the system) compared to unassisted driving in the traffic lane [Wilcoxon Z = 1.72, p < .087]. This effect was also statistically significant in the South direction with a lower traffic volume [Wilcoxon Z = 2.02, p < .043].

**System:** In the North direction of travel with a higher traffic volume, the average response time to recover a boundary departure in the shoulder was significantly faster with LSS than without the system [Wilcoxon Z = 2.03, p < .043]. However, this effect was not significant in the South direction with a lower traffic volume.
Figure 24. Maximum response time to recover boundary departure in driving conditions for both traffic volumes.

Figure 24 presents the **maximum response time** to recover the vehicle from a boundary departure. This is defined as the time from the start of a departure and the maximum point of departure (signifying the beginning of the return path).

The data is displayed for each driving condition in both directions of travel that represent differences in traffic volume:

**Traffic:** The apparent trend for slower maximum response times in the lane was not statistically significant for either level of traffic volume (Direction of travel). The absence of statistical significance may be due to high inter-subject variation and a small sample size.

**Width:** The apparent trend for slower maximum response times with high volume traffic in the adjacent lane was not statistically significant for either level of traffic volume (Direction of travel). The absence of statistical significance may be due to high inter-subject variation and a small sample size.

**System:** In the North direction of travel with a higher traffic volume, the maximum (slowest) response time to recover a boundary departure in the shoulder was significantly faster with LSS than without the system [Wilcoxon Z = 2.20, p < .028]. This effect was not significant in the South direction with a lower traffic volume.
Figure 25. Median time duration of boundary departures in driving conditions for both traffic volumes.

Figure 25 presents the **median time occupied during boundary departures**. This is defined as the elapsed time between the start of a departure and the return point to the lane or shoulder.

The data is displayed for the driving conditions in both directions of travel that represents differences in traffic volume:

**Traffic:** There was no significant effect of traffic volume in the adjacent lane for the average duration of boundary departures in the bus shoulder.

**Width:** In the North direction of travel with a higher traffic volume, the average time duration of boundary departures was significantly *less* in the bus shoulder (without the system) compared to unassisted driving in the traffic lane [Wilcoxon Z = 2.31, p < .021]. This effect was also significant in the South direction with a lower traffic volume [Wilcoxon Z = 1.99, p < .046].

**System:** In the North direction of travel with a higher traffic volume, the average time duration of boundary departures in the shoulder was significantly *less* with LSS than without the system [Wilcoxon Z = 2.31, p < .021]. However, this effect was only marginally significant in the South direction with a lower traffic volume [Wilcoxon Z = 1.69, p < .091].
Figure 26. Maximum time duration of boundary departures in driving conditions for both traffic volumes.

Figure 26 presents the **maximum time occupied during a boundary departure**. This is defined as the elapsed time between the start of a departure and the return point to the lane or shoulder.

The data is displayed for the driving conditions in both directions of travel that represents differences in traffic volume:

**Traffic:** The apparent trend for longer departure duration in the north bound lane was not statistically significant. The absence of statistical significance may be due to high inter-subject variation and a small sample size.

**Width:** In the North direction of travel with a higher traffic volume, the maximum time duration of a boundary departure was significantly *less* in the bus shoulder (without the system) compared to unassisted driving in the traffic lane [Wilcoxon Z = 2.55, p < .011]. However, this effect was not significant in the South direction with a lower traffic volume.

**System:** In the North direction of travel with a higher traffic volume, the maximum time duration of a boundary departure in the shoulder was significantly *less* with LSS than without the system [Wilcoxon Z = 2.31, p < .021]. However, this effect was not significant in the South direction with a lower traffic volume.
Figure 27. Total duration boundary departures in driving conditions for both traffic volumes.

Figure 27 presents the total duration occupied by boundary departures. This is defined as the percentage of time (data samples) in each condition with a calculated boundary departure with respect to a boundary line and the edge of the bus.

The data is displayed for the driving conditions in both directions of travel that represents differences in traffic volume:

**Traffic:** There was a significant effect of traffic volume in the adjacent lane resulting in a shorter total duration of boundary departures in the shoulder (without the system) for the North direction of travel corresponding to a higher traffic volume \(\text{Wilcoxon } Z = 2.03, p < .043\).

**Width:** In the North direction of travel with a higher traffic volume, the total duration of boundary departures was significantly less in the bus shoulder (without the system) compared to unassisted driving in the traffic lane \(\text{Wilcoxon } Z = 2.67, p < .008\). This effect was also significant in the South direction with a lower traffic volume \(\text{Wilcoxon } Z = 2.00, p < .046\).

**System:** In the North direction of travel with a higher traffic volume, the total duration of boundary departures in the shoulder was significantly less with LSS than without the system \(\text{Wilcoxon } Z = 2.31, p < .021\). However, this effect was not significant in the South direction with a lower traffic volume.
Subjective Performance
The usability questionnaire contained several questions that required drivers to rate the level of agreement with a number of evaluative statements about their performance with the LSS (QM – O).

The summary for each question from the usability questionnaire relevant to the appraisal of the system is presented below:

- (QM – O) Most drivers reported neutral agreement about the impact of the system on driving performance.

Subjective Safety
In the usability questionnaire, the drivers were asked to rate their level of agreement about a statement that the LSS will improve safety (QP). Subjects also reported their opinion about the extent to which the LSS could improve safety (Q1).

The summary for each question from the usability questionnaire relevant to the appraisal of the system is presented below:

- (QP) Most drivers reported moderate agreement that the system would improve safety.
- (Q1) One group of drivers (n = 4) thought the system would improve safety to some degree (“It kept me totally aware at all times of the roadway boundary”), and a second group (n = 5) that thought the system may potentially reduce safety (“I felt not quite as safe with the system because at times the GPS signal was lost and I began to drive up on the curb of the shoulder”).
Chapter 5: Discussion

This study comprised a preliminary evaluation of a prototype Lane Support System (LSS) in a Bus Rapid Transit (BRT) operational context. With BRT operations on narrow bus shoulders, the bus driver may be expected to have more stress from the increased demands on controlling the bus in a narrow bounded space and avoiding conflict with other traffic (see Table 1). In addition, the LSS may also be perceived as a stressor and introduce new task demands in spite of its function to support the driver in coping with the stress of BRT operations on dedicated bus lanes (see Figure 9).

The study used a framework for the effect of stressors on driver performance that may relate to transit safety and the occupational health of transit bus drivers (see Figure 7). In this framework, elements of the task environment that require driver attention are identified as stressors (including the LSS). If the driver has a negative attitude about a stressor, then it might be appraised adversely resulting in stress as the driver exerts effort to actively cope with the situation (see Figure 3). Depending on the coping strategy adopted in response to this stress, there may be a change in performance that might ultimately reduce safety.

Stressors

The bus drivers were normally assigned to the scheduled bus route that included the test section used in this study. Thus, the results from these drivers in response to the traffic and narrow shoulder can be considered typical and not subject to novelty effects. Despite the familiarity of these drivers with bus operations on the test section, the narrow shoulder and requirement to interact with other traffic were reported to be primary stressors. The drivers reported that their attention was focused on the task demand of controlling the vehicle within the narrow confines of the bus shoulder while monitoring and anticipating hazards from other road users. These are in addition to the other main stressors that are typical for regular transit operations (Table 2).

The bus drivers also had substantial training on the operability of the LSS on the test route. This training provided specific experience with the LSS and general instruction on the methodology used in the study to collect data. Thus, novelty effects with the system and confusion about procedures were minimized by this prolonged training regime. Even with this exposure to the system prior to the study, the interaction with the LSS was identified as potential (new) stressors. The drivers reported that the interpretation of the information provided and assessment of its reliability imposed additional task demands that required attention.

The intended function of the LSS is to support the driver in coping with the stressors inherent in BRT operations including interactions with traffic and bus control in the narrow shoulder. However, it is necessary to demonstrate that the LSS function can produce benefits that can offset the stress that may potentially result from the interpretation of the LSS as an additional stressor in the environment (see Figure 9).
This issue will be considered by examining the effect of the different stressors on driver stress and performance. The changes in performance will be interpreted in terms of coping mechanisms that may be applied by the drivers in response to environment demands and required target states for optimal performance (see Figure 3).

**Traffic**

Despite identifying traffic and the narrow shoulder as stressors, most drivers generally had a positive attitude toward driving on dedicated bus shoulders. This positive attitude may reflect acceptance by drivers that these stressors are inextricably linked to their working environment. Indeed, the positive attitude may result from a sense of pride for transit bus drivers in their job and capacity to cope with these prevailing task demands.

Traffic volume in the lane had three primary effects on bus driver performance. First, the higher traffic volume reduced average speed on the lane. Notably, the presence of traffic in the lane also produced slower average speeds in the adjacent bus shoulder (Figure 17). This suggests that drivers cope with the increased stress of monitoring and anticipating hazardous interactions with adjacent traffic by lower performance goals (and the associated target state) and assuming a lower target speed (see Figure 3).

Second, the presence of traffic in the adjacent lane also influenced the position of the bus within the shoulder. Specifically, the high volume of traffic in the lane prompted the drivers on the shoulder to position the bus near the center between the shoulder boundaries. This produced a larger average safety margin both in terms of distance (Figure 19) and time (Figure 21, 22). In contrast, the bus was positioned closer to the lane boundary when traffic volume was lower in the adjacent lane. This suggests that drivers coped with the stress of the traffic hazards during high volume conditions by increasing their safety margin, thereby changing the environment demands (see Figure 3). By accepting a greater safety margin with respect to the lane boundary when the traffic volume was high, fewer adjustments were required in response to encroaching traffic. As a result, the control of position on the bus shoulder was more stable (Figure 20) with less time outside the shoulder boundary (Figure 21) when the traffic volume was high.

Third, many of the effects of the shoulder width and operation of the LSS were only significant under conditions of high traffic volume. This interaction effect suggests that the resources applied by drivers to the task demand may have been low enough not to reveal performance decrements with the additional demands of driving in the narrow shoulder and interacting with the LSS (see Figure 6). Only with the additional increase in task demand provided by the high traffic volume is the resource capacity reached with the other stressors resulting in an observable change in performance.

11 Admittedly, there is only a presumption that the traffic volume was higher in the North direction than in the South direction based on traffic data from a comparable site. It is possible that other characteristics of North and South roadways on this route may have influenced driving performance. For example, there were more roadside barriers on the verge along the side of the shoulder in the South direction. As such, the drivers may have positioned the bus nearer the lane when driving on the shoulder not only because of greater opportunity with less traffic, but also in an attempt to increase the safety margin with respect to the barriers.
Alternatively, the limited number of significant effects with the low traffic volume may also be the result of reduced power in the analyses resulting from smaller samplers in the South direction of travel (see Table 5).

**Width**

Given that the width of the shoulder was identified by drivers to be a significant stressor for BRT operations, it was expected that higher stress would be reported by drivers on the bus shoulder in comparison to the traffic lane. However, despite the use of reliable and related measures of workload and effort, no significant increase in subject stress was reported by bus drivers on the narrow shoulder. Given that the trend in both workload (Figure 3) and effort (Figure 4) were in the expected direction of increased stress on the shoulder, then the absence of a statistically significant effect may be due to insufficient power from the study sample size or insensitive measures. This suggests that the observed trends might be significant with a larger sample, alternative measures, or alternative administration procedures.12

Without a significant increase in reported stress, there were several significant changes in driving performance in response to the narrow bus shoulder. This implies a general coping strategy of adjusting performance goals to lower the target state whereby performance is reduced, but not necessarily with an increase in stress (see Figure 3).

First, with high traffic volume, average speed was significantly faster in the bus shoulder than in traffic in the lane (Figure 17). This would be expected given that a higher volume produces less space within the traffic stream to move at higher speeds. This confirms the purported objective of BRT to increase trip times. Speed was also less variable compared to the adjacent lane – but only for higher traffic volume conditions (Figure 18) – supporting another BRT objective of reliable trip times.

However, note that the average speed was slower on the shoulder when there was low traffic volume on the adjacent lane. This suggests that the advantage of driving on an open shoulder in comparison to a congested lane is lost when the congestion is reduced. In this case, the width of the shoulder as a stressor limited performance (speed) as the driver coped to the maximum level of resources (see Figure 6). This limited speed was less than could be accommodated in the lane once the traffic volume was reduced.

Second, width also had a significant effect on lateral positioning of the bus. On the wider traffic lane, the average bus position was offset toward the additional area provided by the adjacent bus shoulder (Figure 19). In the narrow confines of the bus shoulder without adjacent protected areas (i.e., access to an escape path), the bus was positioned more centrally.13 Thus, whereas bus drivers in the lane could cope with stress by positioning the bus toward the open space of the adjacent shoulder to reduce the environment

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12 For example, the wording of the measures could be made more specific to particular stressors or aspects of performance (e.g., lane position).
13 The absolute position with respect to the right boundary line was very similar for the lane and shoulder suggesting that drivers had a preferred offset from the right side. The fact that the lane is wider results in the apparent larger offset from the lane center compared to the shoulder (that has a similar distance offset from the right boundary line, but a narrow width).
demand, the drivers on the bus shoulder had to invest greater effort to change their cognitive state to control position within narrower confines (see Figure 3). This greater control effort is also evident from the lower variability of position in the shoulder compared to the lane with the high traffic volume only (Figure 20). This improved stability in lateral control is beneficial to ride comfort and safety in BRT operations.

Third, the average safety margin (TLC) to the boundaries (excluding actual departures) was less in the shoulder compared to the traffic lane (Figure 21). This would be expected given the reduced physical confines of the shoulder, but this effect was only significant with the high traffic volume. The same trend was also evident only with the high traffic volume for minimum safety margins (Figure 22). In this case, there are limited actions that can be taken by drivers in the shoulder to overcome the physical limits of the narrow width and safety margins are necessarily reduced (see Figure 3).

Fourth, with respect to safety margins, one possible action that can be invested by a driver is the speed of recovering a boundary departure. Accordingly, the average response time to recover the path of travel for a boundary departure was significantly faster in the narrow shoulder compared to the lane, regardless of traffic volume (Figure 23). This demonstrates the effort by drivers to heighten their cognitive state and increase response readiness to recover a boundary departure (see Figure 3). Indeed, this coping mechanism was effective in reducing both the average (Figure 25) and maximum (Figure 26) duration of boundary departures in the bus shoulder. The net result of this increased response was a significant reduction in the total amount of driving outside the boundaries of the shoulder compared to the lane (Figure 27).

**System**

The amount of information provided by the LSS and the perceived need to evaluate the veracity of that information were reported by drivers to be additional stressors with the system. In spite of this, drivers were generally positive toward the LSS and recognized that this type of system could be beneficial for BRT operations, especially for poor visibility conditions. Specifically, the LSS was appraised as having a useful support function, whereas the current interface and reliability were not as satisfying. Overall, the system was rated more favorably than typical collision avoidance systems, although perhaps not as highly as other purely informative system or systems directly supporting speed control. In comparison to expectations, actual exposure to the LSS seemed to reduce satisfaction more than the recognized utility of the provided support function of this system for BRT operations.

There were no significant changes in reported effort (Figure 15) or workload (Figure 16) in response to the use of the LSS compared to unassisted driving on the bus shoulder. Notably, the trends were consistent with the alternative hypotheses that this prototype LSS imposes an additional level of stress. However, these trends were not significant and could not differentiate between the alternative hypothesis that interaction with the LSS resulted in an amount of stress that offset (C) or exceeded (D) the reduction in stress provided by the system in coping with the lane width and traffic stressors (see Figure 9). Indeed, most drivers did not believe that this prototype would reduce stress. Without exploring this trend with more sensitive and relevant measures with a more powerful
study design, this observations and explanations are only speculative. It is expected that refinement of the interface design would reduce stress experienced from the interaction with the LSS such that this system may reduce the overall level of stress operating a bus within narrow shoulders.

Furthermore, an examination of individual driver responses suggests that there might be reliable individual differences that may relate to the stress response generated by the LSS. For example, separate groups of drivers could be identified that were distinguished by low or high confidence levels in driving with the system. Thus, stress reduction may be predictable for definable types of driver or operating condition. Such individual differences may be related to the predisposition to trust such technology.

Regardless of the question about subjective stress in response to interactions with the LSS, this system did result in changes in driving performance that support BRT objectives. First, whereas average speed on the bus shoulder was not increased with the LSS, the variability of speed with the LSS was significantly lower with a high traffic volume on the adjacent lane (Figure 18). The lateral support function of the LSS served as a coping mechanism by reducing the demand on the driver with respect to the width stressor (see Figure 3). This reduced the amount of resources expended by the driver below the capacity threshold such that there was an available resource buffer to accommodate performance fluctuations (see Figure 6). In so doing, the BRT objective of improved reliability of travel time is supported by the LSS.

Second, the coping function of the LSS for the width stressor similarly reduced variability of lane position (Figure 20). It is reasonable to conclude that the resources made available by the reduced task demand on the narrow shoulder with the support of the LSS were redirected to change the cognitive state of the driver to a condition of heightened response readiness. Alternatively, this may be explained by the augmented control of lane position provided by the steering feedback instigated by the system. These benefits are evident from faster response times to boundary departures in the bus shoulder with the LSS under conditions of high traffic volume in the adjacent lane (Figure 23, 24). As a result, departures from the shoulder boundaries were shorter in duration with the LSS for high traffic volume conditions (Figure 25, 26). This redirection of resources to response readiness rather than monitoring vehicle position is consistent with the BRT objective to facilitate safe bus operations. Indeed, the LSS operating on the shoulder with a high traffic volume in the adjacent lane reduces the total exposure time to departures from the dedicated bus shoulder (Figure 27). This may be the basis of the general consensus of the driver that the LSS could improve safety for BRT operations on dedicated bus shoulders.

Together these results suggest that performance improved with the system, although the effect of driver stress was not clear. With reference to the possible forms of coping strategy (see Table 4), the support from the system involved either the changing of the environment or the state of the driver. In this sense, the system separated the driver from direct interaction with the stressors of the shoulder width and traffic hazards. Instead, the driver interacted with the system feedback and was supported by the provided information. Moreover, the system acted as an independent resource applied to the
demands of the driving task. This improved the overall state of the combined effort of the driver and system toward the demands of the driving task. The allocations of lateral control and hazard functions to the system may also have released driver resources for other objectives such as longitudinal speed control. As a result of the driver increased spare capacity resulting from the reduced task demand could simultaneously be applied to changing the cognitive state to further improve performance (see Table 4) and manage the interaction with the LSS to minimize any additional stress (see Figure 9).

Summary

Returning to the main questions posited for this study, the following general answers can be offered based on the results discussed in this report:

• Does driving on certified shoulders (in the presence of high volume traffic) increase driver stress?

The narrow dimension of the bus shoulder and potential conflicts with other road users are commonly identified by bus drivers to be stressors. The subjective data also suggests a trend for increased stressed under these conditions.

• Does driving on certified shoulders (in the presence of high volume traffic impair driver performance?

By virtue of the narrower width of the bus shoulder, it is reasonable that the time based safety margin with respect to the boundaries would be shorter within the shoulder. This means that drivers on average have a shorter time margin with respect to the boundaries of the shoulder than when they are in the lane. In other words, bus drivers get closer in time to departing the shoulder than they do the lane. However, it is also the case that driver performance in other respects is improved in the bus shoulder, perhaps because drivers apply more effort to increase response readiness to operate the bus. For example, the response time to recover a departure and the duration of departures is actually improved in the bus shoulder in comparison to driving in the traffic lane.

• Can the proposed lane support system reduce this stress response and improve driving performance?

Whereas reliability and the design of the prototype of the LSS used in this study did not reduce subjective stress while driving on the dedicated bus shoulder (effort, workload, symptoms), it did significantly improve driving performance consistent with BRT objectives for reliable and safe public transit services. For example, speed (travel time) and position was more stable in the bus shoulder with the LSS, with additional improvements in the recovery of boundary departures such that the total duration of travel within the confines of the shoulder boundaries is increased. These benefits may result from the application of augmented feedback by the system to assist the driver avoid and correct departures from the shoulder. This functionality was perceived to be useful and
satisfying to the drivers. However, to further improve satisfaction with the system, it is necessary to reduce the effort required to operate and interpret the system.
Chapter 6: Conclusion

BRT operations are a growing necessity for public transit. The use of dedicated bus shoulders is a key method for implementing BRT in areas that do not have the resources or space for the installation of additional infrastructure. However, the narrow width of the bus shoulder and the need to anticipate and interact with other traffic in the adjacent lane are both significant stressors for bus drivers. Driver stress in response to these conditions should be a significant concern for transit operators not only because the potential impairment of driving performance might jeopardize BRT objectives, but also because the long term effects of this occupational stress is a health risk factor for the bus drivers that staff the BRT services.

Technology may be harnessed to support the driving task in narrow shoulders and high traffic volumes within BRT services. This pilot study evaluated a prototype Lane Support System (LSS) that provides a coping function in support of vehicle control within the shoulder boundaries. Whereas this LSS did not reduce subjective stress for the drivers, it did demonstrate significant improvements in the stability of vehicle control (position and speed) in the bus shoulder and shorter boundary departures that could represent a reduction in potential conflicts with other traffic. Jointly, these effects provide strong evidence in an operational context that devices such as the prototype LSS used in this study can support the objectives of BRT operations to provide a reliable and safety public transit system.

Several areas of future research should be advanced to further develop Driver Assistance Technologies in support of BRT operations:

1. Whereas the LSS in this study did produce performance improvements, it did not reduce subjective stress. This may be because of the complexity of the various forms of information feedback used in this system, and the tendency for occasional unreliable system performance. In this regard, it is recommended that future phases of research:

   A. Prescribe methods for improving and ‘hardening’ the Driver Assistance Technology (DAT) such that it can be certified as robust prior to an operational test;

   B. Consider alternative feedback systems based on intuitive information formats that do not require the active generation of cognitive resources to process (this includes withdrawing the HUD in good viewing conditions for which the presented information is redundant or distracting);

   C. Evaluate each feedback system individually to isolate the minimum information that can achieve optimal performance. This would then produce a system that supported performance consistent with BRT operations, and reduces subjective stress for the driver by presenting only necessary and reliable information.
2. Generally, most of the effects observed in this study accompanied high traffic volumes. This interaction with traffic volume suggests that the benefit of a DAT may be most relevant and demonstrable under higher workload conditions when applied resources approach the threshold limit of the cognitive system (see Figure 6). Indeed, the benefit of the LSS in this study was generally expected to be manifest during low visibility conditions with the highest driving task demand. In this regard, it is recommended that future studies:

   A. Evaluate driver stress and performance, as well as system benefits, under high workload conditions such as inclement weather in combination with high traffic volumes;
   B. Include larger sample sizes to improve power and evaluate alternative measures that might be more sensitive and relevant to changes in subjective stress.

3. There was some indication in the self-report data that drivers with certain characteristics might ‘cluster’ to form homogenous groups with shared experiences and attitudes toward DAT. These groups may be diverse with respect to each other, with each group demonstrating a defining stress response and change in driving performance. In this regard, it is recommended that future studies:

   A. Evaluate measures to characterize and quantify reliable individual differences that define group membership categories (e.g., trust);
   B. Relate these group categories to reliable and coherent patterns of stress and performance;
   C. Use these relationships between group membership and stress outcome to support methods for selecting and training drivers for BRT operations based on buses integrated with DAT.
References


Appendix A – Usability Questionnaire
Note - The usability questions relate to the following elements of the above model that depicts the presumed stress model:

Stressors (width, traffic) = 7, 10, 11 (The first page focus on the LSS as a potential stressor and asks specific questions about appraisal, stress performance, and safety).

Appraisal = 3, 4, 8, 9
Stress = 2, 5, 6
Performance/Safety = 1
**USABILITY QUESTIONNAIRE**

You have driven a bus that is fitted with a Lane Support System (LSS) that provides feedback to assist you in maintaining proper lane position. The system highlights the roadway boundary provide feedback to help control lane position. Based on your driving experience with this Lane Support System (LSS) in comparison to unassisted driving, please indicate how much you agree with the following statements:

“*I view a system that supports lane keeping as*” (please circle your response)

<table>
<thead>
<tr>
<th>Statement</th>
<th>Disagree</th>
<th>Agree</th>
</tr>
</thead>
<tbody>
<tr>
<td>“I view a system that supports lane keeping as”</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Appraisal</td>
<td></td>
<td></td>
</tr>
<tr>
<td>A. Useful in urban areas</td>
<td>1 2 3 4 5</td>
<td></td>
</tr>
<tr>
<td>B. Useful in rural areas</td>
<td>1 2 3 4 5</td>
<td></td>
</tr>
<tr>
<td>C. Useful on highways</td>
<td>1 2 3 4 5</td>
<td></td>
</tr>
<tr>
<td>D. Unreliable in its operations</td>
<td>1 2 3 4 5</td>
<td></td>
</tr>
<tr>
<td>E. Requires specialized training</td>
<td>1 2 3 4 5</td>
<td></td>
</tr>
<tr>
<td>F. A source of confusion or distraction</td>
<td>1 2 3 4 5</td>
<td></td>
</tr>
<tr>
<td>Stress</td>
<td></td>
<td></td>
</tr>
<tr>
<td>G. Increasing mental (and visual) effort</td>
<td>1 2 3 4 5</td>
<td></td>
</tr>
<tr>
<td>H. Increasing driver comfort</td>
<td>1 2 3 4 5</td>
<td></td>
</tr>
<tr>
<td>I. Making the driver less vigilant</td>
<td>1 2 3 4 5</td>
<td></td>
</tr>
<tr>
<td>J. Making the driver less stressed</td>
<td>1 2 3 4 5</td>
<td></td>
</tr>
<tr>
<td>K. Making the passengers less stressed</td>
<td>1 2 3 4 5</td>
<td></td>
</tr>
<tr>
<td>L. Encouraging over confidence in drivers.</td>
<td>1 2 3 4 5</td>
<td></td>
</tr>
<tr>
<td>Performance</td>
<td></td>
<td></td>
</tr>
<tr>
<td>M. A system to enhance performance</td>
<td>1 2 3 4 5</td>
<td></td>
</tr>
<tr>
<td>N. Creating difficulties on curves</td>
<td>1 2 3 4 5</td>
<td></td>
</tr>
<tr>
<td>O. Encouraging faster than normal speeds</td>
<td>1 2 3 4 5</td>
<td></td>
</tr>
<tr>
<td>Safety</td>
<td></td>
<td></td>
</tr>
<tr>
<td>P. A system to improve safety</td>
<td>1 2 3 4 5</td>
<td></td>
</tr>
</tbody>
</table>
For the remaining questions, place an ‘X’ in the box for the response that best you feel best represents your opinion of the Lane Support System (LSS). When completing these questions, try to compare your experience using the LSS to how you felt with driving unassisted without the system:

1. Do you think that LSS made your driving more or less **safe** for you as a driver, in comparison to how you felt when driving without the system?

<table>
<thead>
<tr>
<th>Much less safe</th>
<th>A little less safe</th>
<th>No change</th>
<th>A little more safe</th>
<th>Much more safe</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>4</td>
<td>1</td>
<td>3</td>
<td>1</td>
</tr>
</tbody>
</table>

Please explain the reason(s) for your answer.

- Calibrated steering not 100% reliable – vacillates frequently.
- It gave me more things to watch then I use to (i.e. the boxes flashing on the display).
- I always put the highest emphasis on safe operation of a bus – whether LSS assisted or not. (no change)
- It made driving more safe, feel more safe with the system.
- On certain curves and at intersections, the systems reassured me that my judgment was correct.
- It kept me totally aware at all times of the roadway boundaries. There was no chance of daydreaming or boredom.
- Key to system is original mapping – if it is inaccurate in spots, safety suffers.
- A little more safe – the reason for this is due to the fact that I had to pay more time watching the position of the bus in the lane
- I felt not quite as safe with the system, at times the GPS signal was lost, and I began to drive up on the curb of the shoulder.

2. Do you think that LSS made you feel more or less **stressful** as a driver, in comparison to how you felt when driving without the system?

<table>
<thead>
<tr>
<th>Much less stressful</th>
<th>A little less stressful</th>
<th>No change</th>
<th>A little more stressful</th>
<th>Much more stressful</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>1</td>
<td>6</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Please explain the reason(s) for your answer.

- Driver’s side wheels wandered over white line frequently.
- The watching of the displays makes it a little more stressful.
• Personally I am not easily flustered but the LSS seemed to just add a little more confidence, hence less stress.
• I felt less stressful – easier on curves and corners when system is on.
• Perhaps one can get used to the system, but it did add more input for driver to attend to.
• At times the systems could be distracting because of too much information.
• Don’t believe I allowed LSS to override personal brain function/response – always in control and therefore no change, in bad weather however, these would clearly diminish stress.
• When the system is on straight areas stress came down but when on curves or going on turn lanes/ intersections it became more unreliable and need more monitoring
• I did not need to concentrate as much as I did with the system off.

3. How would you describe your attitude towards driving on bus shoulder with LSS?

<table>
<thead>
<tr>
<th>Very Negative</th>
<th>Slightly Negative</th>
<th>Neutral</th>
<th>Slightly Positive</th>
<th>Very Positive</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>1</td>
<td>2</td>
<td>4</td>
<td>1</td>
</tr>
</tbody>
</table>

4. How would you describe your attitude towards driving on bus shoulder without LSS?

<table>
<thead>
<tr>
<th>Very Negative</th>
<th>Slightly Negative</th>
<th>Neutral</th>
<th>Slightly Positive</th>
<th>Very Positive</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2</td>
<td>2</td>
<td>3</td>
<td>3</td>
</tr>
</tbody>
</table>

5. Did using LSS make driving more or less confident for you as a driver, in comparison to how you felt when driving without the system?

<table>
<thead>
<tr>
<th>Much more uncomfortable</th>
<th>A little more uncomfortable</th>
<th>No change</th>
<th>A little more comfortable</th>
<th>Much more comfortable</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>3</td>
<td>2</td>
<td>3</td>
<td>1</td>
</tr>
</tbody>
</table>

Please explain the reason(s) for your answer.

• It’s difficult to place confidence in calibrated steering.
• I noticed things that I was missing around the bus, stuff that I should have seen but paying too much attention to displays.
• LSS added a little more confidence, hence less stress.
• I felt more confident – easy to handle, when LSS off I made all the decisions.
• Though it is somewhat stressful to drive on shoulder under any conditions, the LSS helped to make sure I was “on track” (tracks would be ideal, I suppose).
• I am confident in my abilities, but it (the system) could be used to compliment them.
• I can only see the LSS as a positive tool driving very poor visibility conditions only.
• A little more comfortable – again the difference is going straight verses intersection.
• At times the system had problems calibrating the steering at one point, I had to reset the steering motor.

6. Do you think that you paid more or less attention to the driving task while using the LSS, in comparison to how you felt when driving without the system?

<table>
<thead>
<tr>
<th>Much less attention</th>
<th>A little less attention</th>
<th>No change</th>
<th>A little more attention</th>
<th>Much more attention</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>2</td>
<td>2</td>
<td>4</td>
<td></td>
</tr>
</tbody>
</table>

Please explain the reason(s) for your answer.
• I had to focus more on left side to avoid close proximity with vehicles.
• While the LSS was on, the systems allowed me to concentrate on all aspects of the task equally.
• Always pay full attention – take nothing for granted used also while raining.
• I continue to concentrate on the driving task despite presence of LSS. Sometimes the seat system did help me to keep on course, although I doubted its correctness at times.
• The roadway boundary lines helped keep your concentration peaked.
• Only a fool would ever pay less attention, probably paid a little more because it was a new experience.
• When using the system you had to keep in mind that this is new tech and that something might go wrong, but when the bugs get worked our, the trust in will rise and stress will go down, and maybe paying a little less attention will be the result, but right now I have to pay much more attention.
• I did not have to worry as much about leaving the shoulder.

7. List the things you paid most attention to when driving with and without the LSS:

<table>
<thead>
<tr>
<th>Lane Support System (LSS)</th>
<th>No assistance</th>
</tr>
</thead>
<tbody>
<tr>
<td>1&lt;sup&gt;st&lt;/sup&gt; Steering(2), Heads Up Display (2); left white line; whether the LSS was going to give misinformation; cars on my left; lane boundaries; losing the GPS signal</td>
<td>1&lt;sup&gt;st&lt;/sup&gt; Stay close to curb; mirrors; constantly thinking and watching lines and curbs; cars position in adjacent lane; views down road; the big picture; traffic conditions (2); staying in the shoulder.</td>
</tr>
<tr>
<td>2&lt;sup&gt;nd&lt;/sup&gt; Staying away from line; right curb; view down the road ahead; passing cars; lane adjustments; side mirrors; steering calibration</td>
<td>2&lt;sup&gt;nd&lt;/sup&gt; Focus on vehicles with tires on line; lane-speed; slow down curves; cars on left; total surroundings; forward and peripheral vision; mirrors</td>
</tr>
<tr>
<td>3&lt;sup&gt;rd&lt;/sup&gt; Cars too close to bus; intersections; speed of bus; object detection; lidar</td>
<td>3&lt;sup&gt;rd&lt;/sup&gt; Vehicles with wide mirrors, steering corrections; slow down intersections; speed of bus; potential “snifters” (vehicle and pedestrians go across in front of the bus)</td>
</tr>
<tr>
<td>4&lt;sup&gt;th&lt;/sup&gt; Vehicles with wide mirror; turn lanes; seat movement; system screen</td>
<td>4&lt;sup&gt;th&lt;/sup&gt; Wide vehicles; following distances; speed; curves and intersection and</td>
</tr>
<tr>
<td>5&lt;sup&gt;th&lt;/sup&gt; Vehicles that are too wide; straight-always speed traffic; white lines projected ahead;</td>
<td>5&lt;sup&gt;th&lt;/sup&gt; traffic; my time</td>
</tr>
</tbody>
</table>

8. Having tried it, do you think that LSS had any benefits for you as a bus driver?

<table>
<thead>
<tr>
<th>No benefits</th>
<th>Minor benefits</th>
<th>Major benefits</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>4</td>
<td>3</td>
</tr>
</tbody>
</table>

Please explain the reason(s) for your answer.

• It isn’t necessary. I would rather rely on my own skills.
• At this time (after the study) I feel I can do a better job of using the lane (without the LSS).
• More noticeable benefits during poor-visibility driving events, or on marginally unfamiliar routes

• Need training to drive, very comfortable – less stress.

• We still have to follow rules of safety, speed, etc. Despite presence of LSS, LSS could help in “white-cuts” and fog, also as an assist in judgment and keeping driving attentive.

• Could be of great value at night or inclement weather while in unfamiliar surroundings.

• As previously stated – only in very poor visibility – absolutely none in conditions such as those when tested.

• I like the help it gives me to stay within the shoulder lanes, the Lidar helps especially if you can get rear and right side views.

• On very foggy days it may be more beneficial to use the LSS system for assistance with visibility problems.

9. Having tried it, are there any problems with LSS (e.g., that may reduce safety)?

<table>
<thead>
<tr>
<th>No problems</th>
<th>Minor problems</th>
<th>Major problems</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>5</td>
<td>3</td>
</tr>
</tbody>
</table>

Please explain the reason(s) for your answer.

• Calibrated steering! Display unit!

• HUD doesn’t give you the big picture.

• Everything works fine.

• It’s unreliable.

• Looking though a glass, seat and keeping within the lines would be distracting, although one probably would get used to this (earlier practice seems helped me) also hear of letting go human control of bus/steering wheel.

• The auto steer system seemed unreliable at times, also could foster a sense of false security.

• The significance of highly accurate mapping because of the narrow width we deal with, numerous occasional where mapping on test runs “corrected” in wrong direction.

• Right now almost too much information, if everything was on the HUD, it would help.

• When the GPS signal is lost, there may be a problem with road visibility.
10. Please briefly describe the most difficult aspects of driving on bus shoulders:

- Insufficient space for buses, we need an additional 12’ added to lane by painting to left-solid line. Cars and other vehicles must then stay off that line.
- Traffic to your left not knowing I am there and cutting me off at times.
- Inability of bus drivers to predict what traffic – lane motorists will do.
- The hardest is when the traffic come over their right line happens often.
- Cars that don’t stay in their lane, shoulder lane itself is too narrow.
- Cars, trucks, etc; edging is on “our lane”; staying off the curb; vehicle in the way when stopped for emergency; including weather that impedes the view ahead.
- Passing cars trying to press you over and cars you are passing not giving you enough room.
- The traffic crossing into lane
- Some lanes are very narrow – not giving you room for error. When on shoulder and traffic starts to stop – people drift to the right blocking you, entrance ramps, sewer grates.
- The most difficult aspect of driving on the shoulder is observing other vehicles as they may veer into the shoulder lane.

11. Please briefly describe the problems(if any) when using LSS:

- Calibrated steering primarily. I don’t like looking into the display unit – feel restricted
- Loss of satellites when going under bridge
- May possibly make some drivers too complacent because of the benefits of the system.
- LSS is OK.
- For whatever constellation of inadequate mechanical and technological variable at play in this study, the LSS is not ready for testing. It imposes extra demands on the bus operator who is placed in the pouter of having to compensate and correct for the error introduced by the inadequacy of the LSS to lead to the lane.
- Distracting caused by glass in front of driver (HUD), keeping within lines; probably can be over come with time and practice, as prepared. System may need to be refined and corrected at certain stop along the line.
• Can be stressful on the eyes; at times, too much information; needs more reliability, wouldn’t want to lose the satellite signal when you really need it.
• Potential inaccuracies with front object detection or misdetection.
• Loses track going then intersection seems slow some times to correct itself, menu setting screens haul to go back and forth on.
• As stated before, the loss of GPS can be a problem.
Appendix B – Usability Scale
Technology Assistance for Narrow Bus Lanes

In order to increase timeliness and reduce travel time for bus travel, some service routes are using dedicated narrow shoulders for buses. There are a number of technologies that could be fitted to buses to assist the bus driver stay within these narrow lanes. These systems may use auditory warnings or feedback in the steering wheel and seat pan to help you guide the bus within the narrow shoulder lane. In this questionnaire, we would like you to report your expectations and opinions about this proposed technology to support bus driving in narrow lanes.

What is your opinion about these technology systems that could assist you driving a bus in narrow lanes (e.g., bus shoulder)? Please rate your opinion for each descriptive item below (please tick one box for each item):

<table>
<thead>
<tr>
<th>Easy</th>
<th>Simple</th>
<th>Difficult</th>
<th>Confusing</th>
</tr>
</thead>
</table>

**Please continue to rate your opinion of the system for each descriptive term below:**

- Useful
- Comfortable
- Good
- Nice
- Beneficial
- Irritating
- Assisting
- Undesirable
- Raising Alertness
- Pleasant
- Friendly
- Effective

- Useless
- Stressful
- Bad
- Annoying
- Irrelevant
- Likeable
- Worthless
- Desirable
- Sleep-inducing
- Unpleasant
- Antagonistic
- Superfluous

*Thank you for completing this questionnaire.*
Appendix C – Effort Scale (RSME)
Rating Scale Mental Effort

Please indicate, by marking the vertical axis below, how much effort it took for you to complete the task you've just finished.

EXTREME EFFORT

VERY GREAT EFFORT

GREAT EFFORT

CONSIDERABLE EFFORT

RATHER MUCH EFFORT

SOME EFFORT

A LITTLE EFFORT

ALMOST NO EFFORT

ABSOLUTELY NO EFFORT
THE WORKLOAD QUESTIONNAIRE

Driving requires both mental and physical resources to complete the task. ‘Workload’ refers to the mental and physical strain experienced in the driving task as these resources are applied.

This questionnaire is designed to measure your feelings and perceptions about the mental and physical workload you may experience within the driving task that you have completed.

This questionnaire is based on a definition of workload that considers several characteristics of the driving experience. As described below, please read the definitions for each of these characteristics carefully. While you are driving, reflect on these definitions and consider your experience of driving in terms of these characteristics:

MENTAL DEMAND
This refers to the ‘thinking’ component of the driving task. For example, consciously making decisions about the road environment or deciding how to respond to traffic or other hazards. How much of this type of thinking, deciding, calculating, remembering, looking, searching, etc. did you need to do? Was the task easy or demanding, simple or complex in this respect?

PHYSICAL DEMAND
How much physical activity was required (e.g. operating brake, clutch and accelerator, steering the vehicle, using the indicator, etc.)? Was the task easy or demanding, slow or brisk, slack or strenuous in this respect?

TIME PRESSURE
Did you feel you had enough time to adequately perform the driving task? Did you feel under pressure to complete the driving task in the time available?

PERFORMANCE
How satisfied were you with your performance in achieving the instructed goals of the driving task (e.g., driving at a safe speed, achieving targets speeds, maintaining good lane position)?

EFFORT
How hard did you have to work (mentally and physically) to achieve your level of performance? Did you feel stretched or comfortable during the task?

FRUSTRATION LEVEL
How insecure, discouraged, irritated, stressed and annoyed versus secure, gratified, content, relaxed did you feel during the driving task?
MENTAL WORKLOAD

Please place a vertical line through each scale to indicate your level of workload on each of the six characteristic based on your experience of the entire lap you just completed:

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Scale Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mental Demand</td>
<td>LOW</td>
</tr>
<tr>
<td>How much thinking, deciding, calculating, remembering, looking, searching, did you need to do?</td>
<td></td>
</tr>
<tr>
<td>Physical Demand</td>
<td>LOW</td>
</tr>
<tr>
<td>How much physical activity was required?</td>
<td></td>
</tr>
<tr>
<td>Time Pressure</td>
<td>LOW</td>
</tr>
<tr>
<td>Did you feel under pressure to complete the driving task in the time available?</td>
<td></td>
</tr>
<tr>
<td>Performance</td>
<td>POOR</td>
</tr>
<tr>
<td>How satisfied were you with your level of performance?</td>
<td></td>
</tr>
<tr>
<td>Effort</td>
<td>LOW</td>
</tr>
<tr>
<td>How hard did you have to work?</td>
<td></td>
</tr>
<tr>
<td>Frustration Level</td>
<td>LOW</td>
</tr>
<tr>
<td>How insecure, discouraged, irritated, stressed and annoyed during the drive?</td>
<td></td>
</tr>
</tbody>
</table>
Appendix E – Test Session Procedure Check List
Check List

- Laptop
- Copy of Shoulder Bus Lane Operating Rules
- Consent form
- Clip board
- Pen
- Note book
- Digital video tape (Insert)
- Wet ones™
- RSME questionnaires (5)
- Workload questionnaires (5)
- Usability questionnaire (2)
- Envelope for completed subject material

↔↔↔↔
At Facility

Stage 1: Introduction

Review system features (CO)
Put HUD down (CO)
System off (CO)

"You are invited to be in this study to investigate how bus drivers respond to driving on bus only shoulders. This study will explore the potential role of specially equipped buses with a Lane Support System (LSS) to assist bus drivers when operating in shoulder lanes. This Lane Support System (LSS) is designed to give the bus driver feedback about the position of the vehicle in the lane to support safe and stable lane positioning within the confines of the shoulder lane boundaries.

You will be asked to make several laps of a shortened route on HWY252 using standard lanes and the bus-only shoulder. Sometimes you will drive this route manually without assistance, and other times you will drive with the LSS active to assist you."

"For this study, we will be collecting some data from you. There are several types of data that we will collect:

We will record your driving data such as lane position and speed;
We will ask you to verbally indicate when you experience high stress events while driving;
We will ask you to complete some questionnaires about your opinion of the LSS and the effort it took to drive the bus."

"Do you have any questions at this time?" Answer questions

"Please review and sign this consent form indicating your willingness to participate. Of course, you are free to stop this study at anytime without any need to give a reason."

Administer consent form and file
Verify all equipment (CO)
System off (CO)

"Please follow my instructions to drive to the HWY252 area where you received your training. You will be given more instructions there about today’s study."

"We can take off when you feel ready ...take a left turn at 66th Ave and park the bus with the engine running back at the cinema parking lot."

(CO)
(ZM)
<table>
<thead>
<tr>
<th>↔ At Cinema</th>
<th>Stage 2: Instruction</th>
</tr>
</thead>
<tbody>
<tr>
<td>“This is the staging area for the study. This is the area that you should return to after each lap of the route. Please bring the bus to this spot after each lap. You will be given more instructions for your next lap once we have stopped here.”</td>
<td></td>
</tr>
<tr>
<td>“Before we start, I want to again review with you what you will be asked to do”</td>
<td></td>
</tr>
<tr>
<td>“Basically, we will ask you to make several laps of the route. The first lap is a practice session and will be used to tune and adjust the system. For the other laps, we will give you specific instructions. In these instructions we will tell you to either turn the Lane Support System on or turn the system off. We will then tell you to either drive in the normal traffic lane, or to drive on the dedicated bus-only shoulder.”</td>
<td></td>
</tr>
<tr>
<td>“At all times, you are ultimately responsible for the safety of the bus and traffic, so you should drive safely and ignore any instructions that prevent you from being safe.”</td>
<td></td>
</tr>
</tbody>
</table>

| Confirm that they are aware of Operating Rules. If they ask, indicate that they can use it when instructed even if traffic is traveling faster than 35 mph (i.e., Rule #4). |
| “Let us review the data that we are collecting with you on each lap” |
| “First, driving data is automatically collected by the bus.” |
| “Second, if anything happens that you feel is stressful or risky (e.g., traffic, system functioning), you should give a short but clear statement of this incident in the microphone when it is safe to do so.” |
| “Third, after each lap of the route, we will ask you to complete a simple questionnaire about how much effort it took to drive the bus.” |
| “Finally, at the end of the study, we will give you a set of questionnaires that will ask you to express your opinion about the system we are evaluating today.” |
| “Do you have any questions at this time?” Answer questions |
| “Now, so that you can get some final practice with the bus and the system, we will ask you to turn on the system and drive the evaluation route so that the system can be adjusted” |

| On Bus Shoulder |
| “Remember to verbalize any high effort or risky episodes in relation to traffic or how the system functions” |

<table>
<thead>
<tr>
<th>↔ At Cinema</th>
<th>Stage 3: Evaluation</th>
</tr>
</thead>
<tbody>
<tr>
<td>“Park the bus with the engine running back at the cinema parking lot as before” Record start and end mileage AND time for each lap.</td>
<td></td>
</tr>
<tr>
<td>“Thank you – we would like you to complete this questionnaire based on how much effort you used to drive the bus on that last route” Administer RSME and Workload questionnaire</td>
<td></td>
</tr>
<tr>
<td>“When you are ready, we will now begin the (next) evaluation drive”</td>
<td></td>
</tr>
<tr>
<td>“For this drive, we want you to ….. (see Table 9) Give instructions”</td>
<td></td>
</tr>
</tbody>
</table>
“Any questions – please proceed”

“Remember to verbalize any high effort or risky episodes in relation to traffic or how the system functions”

Record start and end mileage AND time for each lap.

Table 9. Condition Assignment

<table>
<thead>
<tr>
<th>Subject</th>
<th>Run 1</th>
<th>Run 2</th>
<th>Run 3</th>
<th>Final Run 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Practice</td>
<td>Lane-No LSS</td>
<td>Shoulder-No LSS</td>
<td>Shoulder-LSS</td>
</tr>
<tr>
<td>2.</td>
<td>Practice</td>
<td>Lane-No LSS</td>
<td>Shoulder-LSS</td>
<td>Shoulder-No LSS</td>
</tr>
<tr>
<td>3.</td>
<td>Practice</td>
<td>Shoulder-No LSS</td>
<td>Lane-No LSS</td>
<td>Shoulder-LSS</td>
</tr>
<tr>
<td>4.</td>
<td>Practice</td>
<td>Shoulder-No LSS</td>
<td>Shoulder-LSS</td>
<td>Lane-No LSS</td>
</tr>
<tr>
<td>5.</td>
<td>Practice</td>
<td>Shoulder-LSS</td>
<td>Lane-No LSS</td>
<td>Shoulder-No LSS</td>
</tr>
<tr>
<td>6.</td>
<td>Practice</td>
<td>Shoulder-LSS</td>
<td>Shoulder-No LSS</td>
<td>Lane-No LSS</td>
</tr>
<tr>
<td>7.</td>
<td>Practice</td>
<td>Lane-No LSS</td>
<td>Shoulder-No LSS</td>
<td>Shoulder-LSS</td>
</tr>
<tr>
<td>8.</td>
<td>Practice</td>
<td>Lane-No LSS</td>
<td>Shoulder-LSS</td>
<td>Shoulder-No LSS</td>
</tr>
<tr>
<td>9.</td>
<td>Practice</td>
<td>Shoulder-No LSS</td>
<td>Lane-No LSS</td>
<td>Shoulder-LSS</td>
</tr>
<tr>
<td>10.</td>
<td>Practice</td>
<td>Shoulder-No LSS</td>
<td>Shoulder-LSS</td>
<td>Lane-No LSS</td>
</tr>
<tr>
<td>11.</td>
<td>Practice</td>
<td>Shoulder-LSS</td>
<td>Lane-No LSS</td>
<td>Shoulder-No LSS</td>
</tr>
<tr>
<td>12.</td>
<td>Practice</td>
<td>Shoulder-LSS</td>
<td>Shoulder-No LSS</td>
<td>Lane-No LSS</td>
</tr>
<tr>
<td>13.</td>
<td>Practice</td>
<td>Lane-No LSS</td>
<td>Shoulder-No LSS</td>
<td>Shoulder-LSS</td>
</tr>
<tr>
<td>14.</td>
<td>Practice</td>
<td>Lane-No LSS</td>
<td>Shoulder-No LSS</td>
<td>Shoulder-LSS</td>
</tr>
</tbody>
</table>

Note: If subjects are excluded, then replace next subject with lost number.

Lane-No LSS = “Please turn OFF the system and drive the route in the standard traffic lane next to the shoulder”

Shoulder-No LSS = “Please turn OFF the system and drive the route in the dedicated bus shoulder (in compliance with bus lane operating rules)”

Shoulder- LSS = “Please turn ON the system and drive the route in the dedicated bus shoulder (in compliance with bus lane operating rules)”

↔ ↔ ↔ ↔

At Cinema (after final RSME)

Stage 4: Debriefing

“Thank you – the driving section of this study is now finished”

Video/audio OFF

“We would now like you to take some time to tell us about your opinion of the LSS that we are evaluating. Please carefully consider all the questions here and provide complete answers.”

Demonstrate and administer usability questionnaires.

“Thank you again for your time. Do you have any further questions or comments”

Answer questions/Note comments.

“Please return to the Transit Facility”

Give return directions (CO)

File all questionnaires & video (recording correct subject ID)

“Thank you for participating in the study. Steve Mclaird will have more information about the results of the study once it is completed. We do ask that you do NOT discuss any aspect of this study with any of your colleagues so that they do not know what to expect if they participate in the study later.”

Dismiss driver

Close down

* Note that we are exempt from Operating Rule #4 in that drivers can use the shoulder when instructed even if traffic in other lanes is moving faster than 35 mph.
Appendix F - University of Minnesota Consent Form
University of Minnesota Bus Shoulder Pilot Study

This study is being conducted by the University of Minnesota Center for Transportation Studies. As a bus driver, you were selected as a possible participant because the proposed system may be used in the category of vehicle you drive professionally. We ask that you read this form and ask any questions you may have before agreeing to participate in this study.

You are invited to be in a pilot study to investigate how bus drivers respond to driving on bus only shoulders. This study will explore the potential role of specially equipped buses with a Lane Support System (LSS) to assist bus drivers when operating in shoulder lanes. This Lane Support System (LSS) is designed to give the bus driver feedback about the position of the vehicle in the lane to support safe and stable lane positioning within the confines of the shoulder lane boundaries.

Background Information:
The purpose of this study is to investigate your response to the conditions of driving in the shoulder lane and your opinion about how the proposed Lane Support System (LSS) may assist you in driving safely.

Procedures:
If you agree to be in this study, we would ask you to drive under a number of different conditions along the HWY 252 bus corridor at a safe and comfortable speed within the guidelines set by Metro Transit and Mn/DOT for bus only shoulder operations. Even though you will be driving without any public passengers, you should drive as you would normally as if on active service along the actual bus route. The total time for to complete this study is estimated to be 3-4 hours, depending on traffic conditions.

You will be asked to drive in different lanes, including the bus only shoulder lane. For some trips, you will be asked to drive with the assistance of the Lane Support System (LSS). We will be measuring your control of the bus. In addition, we will record your voice so that we can identify any high stress episodes that you identify to us while driving. Finally, will be asked to complete some simple questionnaires about your experience driving the bus under these conditions. For example, you may be asked to respond to this question:

1. How would you describe your attitude towards LSS?

<table>
<thead>
<tr>
<th>Very Negative</th>
<th>Slightly Negative</th>
<th>Neutral</th>
<th>Slightly Positive</th>
<th>Very Positive</th>
</tr>
</thead>
</table>

Risks and Benefits of Being in the Study:
The main risk of this study is that you may have an accident if you do not drive at a speed that is safe and comfortable for the driving conditions. But the risk should be no more than normal for driving this route under regular bus service conditions.

The benefit to you for participation in this study is that your responses may be incorporated into subsequent design and policy considerations for implementing the Lane Support System (LSS) into an operational context that could include you or your colleagues in the future.

Confidentiality:
The records of this study will be kept private. In any sort of report we might publish, we will not include any information that will make it possible to identify a subject. All data records will be kept in a locked area; and only University of Minnesota researchers will have access to the records.

Voluntary Nature of the Study:
Your decision whether or not to participate will not affect your current or future relations with the University or your Employer. If you decide to participate, you are free to withdraw at any time without affecting those relationships.

Contacts and Questions:
This is a University of Minnesota project managed by Craig Shankwitz of the Center for Transportation Studies, University of Minnesota. You may ask any questions you have now to the researcher who is hosting you. If you have questions later, you may contact either project manager at the Center for Transportation Studies: (612) 626-1077.

If you have any questions or concerns regarding this study and would like to talk to someone other than the researcher(s), contact Research Subjects’ Advocate line, D528 Mayo, 420 Delaware Street Southeast, Minneapolis, Minnesota 55455; telephone (612) 625-1650. If you request it, you can receive a copy of this form to keep for your own records.

Statement of Consent:
I have read the above information. I have asked questions and have received answers. I consent to participate in the study.

Signature ______________________________________________________ Date ________________

Signature of Investigator __________________________________________ Date ________________