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## **Safety Analysis of Concept Systems for Guidance and Control of Transit Buses**

**James Bret Michael**

**California PATH Research Report  
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# **Safety Analysis of Concept Systems for Guidance and Control of Transit Buses**

## **Final Report for MOU 327**

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### **Abstract**

Automated guidance of transit buses in urban areas will introduce challenges in terms of maintaining acceptable levels of service to patrons while not compromising system safety. In this report, we present the findings from conducting both an extensive literature review and field observations of the operations of transit buses in an urban setting. The scope of the research conducted under MOU 327 is limited to reporting on the automated docking of buses, although many other safety-related services involving automation exist or have been proposed.

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## **Executive Summary**

Automated guidance of transit buses in urban areas will introduce challenges in terms of maintaining acceptable levels of service to patrons while not compromising system safety. In this report, we present the findings from conducting both a review of the literature and field observations of the operations of transit buses in an urban setting. The scope of the research conducted under MOU 327 is limited to reporting on the automated docking of buses, although many other safety-related services involving automation exist or have been proposed.

The literature on automated guidance of buses covers both mechanical and electronic systems. Research has been conducted on the safety of both types of systems. A large body of data about the safety of operational mechanical systems, such as the O-Bahn, is available. The safety of such systems has been good, but the acceptance of these systems by transit operators comes and goes, depending on institutional factors. The body of knowledge and experience with electronic bus guidance systems is growing, although the majority of the safety data has been gathered from operational testing of research prototypes, such as the systems developed by Cegelec and Renault. There appears to be interest within the transit industry to develop dual mode buses: those for which the driver can assume responsibility for performing the tasks associated with vehicle guidance, or delegate one or more of the tasks to the automated portion of the guidance system.

Conclusions about the safety of systems that assist or relieve the driver of guidance-related tasks are inconclusive at this time. We conducted field observations in the downtown business district of San Francisco to determine what types of hazards could evolve that are due to automation of tasks performed by drivers to dock a bus. We found many hazards that bus drivers face on a regular basis, such as avoiding pedestrians who jaywalk and maneuvering around vehicles illegally parked in a bus loading zone.

The report concludes with a recommendation that formal protocols be used to study the hazards associated with bus docking in urban areas. The results of these studies would be used as a basis for modifying existing standards and guidelines for the placement of bus stops, with explicit consideration of the safety-related requirements for partial and full automation of bus guidance tasks. Public officials and their constituents also need to have access to safety cases based on these studies in order to make informed decisions about whether the deployment of bus docking systems presents an acceptable level of risk.

## 1. Introduction

The technology needed to build automated buses has matured and been demonstrated, but transit operators still need to determine specific ways in which automating buses can improve service. Improved service should result in increased ridership, especially from people who ride buses by choice rather than out of necessity. For instance, service can be improved by increasing accessibility and by integrating bus operation with other modes of transportation, such as subways and light-rail transit.

Low-floor buses were a major advance in improving bus accessibility. These buses, pioneered by the German manufacturer NEOPLAN, permit passengers to board and alight on the level, without stepping up or down from the sidewalk at the bus stop docking platform. Level boarding also reduces dwell time—the time a bus spends at a stop. However, if the bus pulls up too far from the curb, and the horizontal gap between bus door and curb is too wide, passengers must first step down to the pavement, rather than across to the bus. Even a small gap could lead to a passenger's falling between the bus and platform, or tripping on the edge of the bus or curb. For some transit users, such as the vision impaired, children, the elderly, or people in wheelchairs, any gap could be a hazard, as documented by studies such as the one conducted in Caen, France in the early 1990s [14].

By automating the docking process whereby a bus pulls up to a bus stop, buses can be made to dock consistently at precisely the desired distance to the curb. This report contains a description of two types of automated docking systems, along with a summary of the safety research on this topic conducted by the California PATH Program.

## 2. Automated Docking Systems

Two types of systems have been introduced to eliminate the horizontal gap between bus and docking platform. One, a docking assistance system, tells the driver where the bus is with respect to the docking point. For example, the French National Institute for Transportation and Safety Research (Institut National de Recherche sur les Transports et leur Sécurité—INRETS) has evaluated, as part of the GIBUS (Guidage des autobus en station) project, an electronic horizontal display mounted on the dashboard of the bus [4, 5, 6, 8, 21, 23, 24]. This display indicates the lateral distance from bus to docking point, and has been field tested in Grenoble—a large city located in the southeast corner of France.

The other type of docking system provides for full or partial-authority automatic control of the bus during docking: the bus driver lets the automated system drive, or at least steer, the bus. The VISEE system developed by Renault, for example, uses a partial-authority, vision-based control system to steer the bus into the desired docking position. While the system steers, the driver controls the throttle and brakes. Renault, in cooperation with MATRA, is also working on a full-authority electronic-vision based system known as Civis, with testing underway in Paris and other French cities. Cegelec AEG has adapted the fully automated vehicle technology it developed for Channel Tunnel service vehicles for use by full-size transit buses [15]. The bus follows two electronic guide wires embedded in the roadway. Speed is controlled either by the system (using a pre-programmed profile) or the driver. The Cegelec system has been field tested in Newcastle, England, on a Mercedes-Benz bus.

PATH is experimenting with a precision docking system, in which the vehicle follows magnets buried in the pavement. PATH researchers have demonstrated the ability to maneuver a passenger car (Buick LeSabre) very accurately at low speeds, as a kind of simulation of a docking maneuver. The car follows an S-shaped trajectory, analogous to that of a bus approaching a curbside bus stop, with a consistency of better than 1 cm. Researchers expect to be able to repeat this precision docking with a bus as soon as one becomes available. PATH is also investigating design alternatives for fully automated busways (automated highway system lanes dedicated to carrying bus traffic).

The systems mentioned above are based on the concept of electronic guidance, but mechanically based bus guidance systems are still being refined [13]. In the 1980s, the O-Bahn automated bus system, which uses guide wheels with mechanical arms for lateral control, drew the attention of the transit community and was put into service in Essen, Germany, and Adelaide, Australia [25]. The system was not widely deployed, primarily for nontechnical reasons [3]. In 1997, Bombardier introduced a light transit vehicle guided by a single central rail, instead of costly, loadbearing double tracks [19]. The Bombardier GLT, like the Civis system, can be operated under manual steering control. Both systems compete with light-rail systems (or trams). Scott McIntosh of London Transport Planning has pointed out that although trams have many appealing characteristics, such as predictable paths of travel, electronically guided rubber-tired buses can provide the same service at less cost.

The Urban Mass Transportation Administration sponsored a thorough study of bus guidance technology [17]. A more up-to-date report on developments in the bus-guidance arena can be found in a report published by London Transport Planning in 1997 [18]. Both of these reports provide technical information about how the various types of systems have been or could be implemented.

### **3. Safety Concerns**

The systems mentioned above are not considered to be mature in terms of operational experience: docking systems' safety must still be evaluated in the environment of their intended use. For example: in the United Kingdom, the certification and regulation of signaling systems for electronically controlled rubber-tired buses falls under the jurisdiction of Her Majesty's Railway Inspectorate (HMRI), which bases its decisions about certification and other safety matters on its evaluations of "safety cases." A safety case consists of recommendations as to a system's fitness for use in specific operational contexts [20]. The system's fitness is presented in terms of arguments as to how well safety issues have been assessed, and to what extent the implementation of the system addresses safety concerns. Each safety case also includes all evidence supporting the arguments, such as a safety plan, results from a preliminary safety analysis, and records of safety reviews and incidents.

The levels of safety to be afforded by the partial or full automation of passenger rail systems, such as the driverless subway systems in the San Francisco and Paris metropolitan areas, were unknown prior to obtaining operational data from fielded systems. The safety cases that were developed for these transit systems provided the basis for making decisions on whether to field the systems. The safety record of these systems, such as that reported in Mass Transit [7], has been quite good. The lessons learned by this section of the transit community can be used to shape the

process by which the safety cases for bus guidance and control are prepared and presented for both policymakers and transit operators. Public officials and their constituents need to have access to safety cases in order to make informed decisions about whether the risks associated with the deployment of these systems is acceptable.

#### **4. Safety Cases**

PATH has investigated ways to collect, manage, and present safety information about automated docking systems to regulatory, certification, and other decision-making bodies. The work to date has focused on French and British standards, practices, techniques, and tools for constructing and maintaining safety cases for driverless subway systems. Key findings include:

- Because each safety case may need to be presented to different audiences, a “pre-safety case” could be used to pre-plan the structuring of the safety case to support the generation of different views that could then be addressed in an effective presentation tailored to a specific audience. The Human Communication Research Centre at the University of Edinburgh has done extensive research on this topic.
- Each safety case is a “living” record: it must document all changes to the system, all incidents, and other safety-relevant information. Paper-based safety cases have been difficult and tedious to assemble and maintain over the lifetime of a system, but computer-based tools have now been introduced for constructing, storing, and managing safety cases. The Safety Argument Manager developed at the University of York (England) consists of a suite of tools for inputting safety analysis information and tracing this information back to system requirements and designs.
- Partitioning system functions into different categories can be a useful way of focusing the safety case on a system’s most critical functions. Safety cases for French driverless subway systems center on the automatic train protection system, which is responsible for hazard monitoring, emergency braking, and power shutdown, as opposed to automatic train operation and other functions.
- In France, system developers of fully automated subways work directly with independent evaluators appointed by the Ministry of Transportation, who provide the developer with non-binding suggestions for improving the safety case. After this feedback process, the evaluators recommend that the Ministry either approve or deny certification. The Ministry does not dictate, via standards or other means, the contents of the safety case or the manner in which it is presented: this is left up to the independent evaluators and system developers.
- In the United Kingdom, by contrast, there are standing regulatory and certification authorities for all rail-based systems, in addition to a large body of industry standards and guidelines. However, standards for certain aspects of such novel systems as automated buses do not exist. They are expected to be developed as the systems are introduced.

#### **5. Field Observations**

To develop an initial set of safety considerations upon which to build safety cases for automated bus docking systems, field observations of manual bus docking were made in downtown San

Francisco. This area has a high volume of transit bus and other traffic, including pedestrians and bicyclists. Five sites were chosen to observe bus docking for different docking configuration-location pairs: near-side at curb, far-side at curb, nub with queue-jumper lane, and open bay.

One of the hazardous conditions observed was a vehicle parked illegally in the bus docking zone. See Figure 1. A car is parked illegally at the forward most point of a bus stop. The driver was waiting on a passenger who was conducting business at the store located at the corner of the intersection. There was not enough distance between the car located in the metered parking space and the illegally parked vehicle for a full-size transit bus to position the bus next to the curb. We observed that the bus that arrived while these cars were located in positions pulled into the bus stop at an angle, leaving a very large gap between the bus and the curb.

Another type of hazard we observed was bus drivers allowing passengers to board and alight from a lane other than that which abuts the curb. Note that in Figure 2, one can see a passenger boarding a bus in the center lane at the intersection, in a position that is not even perpendicular to the bus loading zone. In addition, the passenger crossed in front of vehicles moving forward in the lane next to the curb.



Figure 1. Car parked illegally in a bus loading zone.



Figure 2. Pedestrian boarding a bus in the center lane.



Construction barriers located just prior to the bus zone shown in Figure 3 forcing drivers to approach the bus stop at a sharp angle, resulting in small and large gaps between buses and the curb, depending on the number of buses vying for a place to dock. The construction zone was in place for many weeks along this stretch of Market Street.

Figure 4 highlights two types of hazards existing along one city block. One the far left side of the street, a sport utility vehicle is about to pull enter the street from a driveway that is partially screened from the driver's view. The bus loading zone is located just past the driveway. The bus driver cannot begin the docking maneuver until he or she clears the position of the front bumper of the SUV, which is sticking out into the lane. The grooves in the pavement (see the two dark lines on the street) provide us with the indication that bus drivers often begin their maneuvers by staying within close proximity of the curb prior to the position of the SUV.

The other hazard shown in Figure 4 is the a commerical truck parked in front of a nub stop. (A nub stop is an bus zone that juts out into a lane that is otherwise a through-lane.) It is difficult for the bus to dock within a few centimeters of the curb. If the bus docks at an angle, then the driver cannot see vehicles approaching the bus from the rear because the truck obscures the driver's view. Moreover, the bus must maneuver back into the center lane, which is designated as bus-only.



Figure 3. Buses docked at a bus loading zone located just in front of a construction zone in which the lane was closed to all traffic.



Figure 4. Vehicle pulling out of hidden driveway and truck parked in front of a nub stop.

We also observed a pedestrian jaywalking as a bus approached a far-side stop; see Figure 5. The pedestrian bolted out in front of the bus. In addition to avoiding the pedestrian, the bus driver had to cross a busy intersection at a diagonal and begin the docking maneuver while in the intersection: the bus stop is located just outside the intersection. Also note that there is a pedestrian standing at the edge of the curb (in front of the cross walk on the left side of the picture), as there was pedestrian standing right next to the curb in Figure 3 as two buses arrived in tandem. If the bus driver misjudges the distance to the curb, then he or she might hit the pedestrians standing next to the curb.

At one site, metered parking ran right up to the beginning of the bus zone, but the bus zone was not long enough to accommodate the bus; see Figure 6. Thus, there was no way for the bus to dock parallel to the curb unless the metered parking space was vacant. In this and the previous figure, it is evident that the designs of the bus stops were made based on tradeoffs between safety and non-safety considerations.



Figure 5. Bus approaching a far-side stop.



Figure 6. Bus loading zone that is shorter than the overall length of the bus.

## 6. Recommendation

The current design and location of the preceding sites would necessitate extreme vigilance by the bus driver in a partially automated system, and very effective and reliable avoidance systems for detecting pedestrians, bicyclists, and other obstacles. The necessary dimensions of bus stops have been published [1, 2, 9, 10, 11, 16] for full manual operation of buses, including pull-in and pull-out angles as a function of bus length, but these guidelines are sometimes not followed due to considerations such as technical feasibility, cost, or acceptability (in terms of public policy, e.g., acceptability of congestion caused by the location of a bus stop) of modifying the existing infrastructure or vehicles. As a basis for recommending changes for the location and design of bus stops to the Institute of Traffic Engineers and the International Union of Public Transport, field studies based on formal protocols should be conducted to identify special docking requirements for partially and fully automated docking.

## 7. Other Unresolved Issues

Other aspects of automated bus docking than safety remain to be investigated. The safety and technical constraints associated with obstacle avoidance of an automated docking system could possibly result in high development, operation, or maintenance costs. Will bus drivers in Germany, who tend to be well-trained and very experienced, or in London, where there is a high turnover of drivers, accept partial or full automation? Can designs of automated docking systems be developed that will be usable on a wide range of bus chassis, and result in operating costs that are lower than costs for trams? How will automated docking systems interact with collision warning and avoidance systems? These and other issues are fertile areas for further research and development within the State of California.

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