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Opportunities for Advanced Vehicle Control Systems in Commercial Vehicle Operations and Public Transportation Systems

Research and Development
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FOREWORD

This report is a product of the Federal Highway Administration's (FHWA's) Advanced Vehicle Control Systems (AVCS) program. The AVCS program also encompasses the Automated Highway System (AHS) program and is part of the larger Department of Transportation (DOT) Intelligent Transportation Systems (ITS) program. The ITS program is a multi-year, multi-phase effort to develop the next major upgrade of our Nation's vehicle-highway system. The contract that produced this report was initiated to identify and analyze technologies and applications that can support the deployment of vehicle control systems at intermediate stages of development. Some of these systems may provide a significant efficiency of safety enhancement to existing vehicle-highway operations. These interim steps are important in the progression of the FHWA's AVCS program from the manual highway system of today to the automated highway system of the future.

A. George Ostensen
Director, Office of Safety and Traffic Operations
Research and Development

NOTICE

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16. Abstract

In the course of developing automated vehicle-roadway systems, opportunities to deploy vehicle control systems at intermediate stages of development may emerge. Some of these systems may provide a significant efficiency or safety enhancement to existing operations with manually driven vehicles. Under certain circumstances, public transportation and freight movement systems provide an ideal application domain for vehicle control. The work presented here represents a feasibility study for the application of Advanced Vehicle Control Systems (AVCS) to transit bus and commercial vehicle operations. This paper explores past and present research relevant to automatic control for trucks and buses, and recommends specific operations that could be better performed by AVCS-assisted or controlled vehicles. A survey of feasible technologies for the guidance and control of such vehicles is also presented for various levels of automation.

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APPROXIMATE CONVERSIONS TO SI UNITS

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

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
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m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact)		
°C	Celcius temperature	1.8C + 32	Fahrenheit temperature	°F
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

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

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EXECUTIVE SUMMARY

There are many Intelligent Transportation Systems (ITS) initiatives currently underway to improve the mobility, efficiency, and safety of ground transportation. Of particular interest in this study are applications of advanced vehicle control systems (AVCS) for transit bus and commercial vehicle operations. While the improvement of these operations through new technology is being addressed by the APTS (Advanced Public Transportation Systems) and CVO (Commercial Vehicle Operations) functional areas of ITS, specific vehicle control approaches have largely gone ignored. Despite the profound impact that AVCS promises for increased mobility, many in the transportation community regard vehicle control as high-risk technology, either doubting its technical capabilities and cost-effectiveness or fearing the legal and institutional repercussions of deployment. As a consequence, AVCS developers are moving cautiously, with their investments directed toward more distant rather than near-term deployments. This trend may be seen most notably in the automotive industry where a great deal of vehicle control research has been performed, but very little has been applied towards production. Similarly, the Federal Highway Administration (FHWA), in cooperation with various public and private sector partners, is developing a specification for a technically advanced automated highway system (AHS) that will not be deployed for at least 5 years. Rather than wait for assured public acceptance of AVCS and resolution of all system issues, it is proposed here that existing AVCS work be leveraged for focused applications to demonstrate near-term benefits and encourage wider acceptance. This study addresses the excellent opportunities offered in the areas of truck and bus operations.

Freight movement and public transportation are vital functions that depend heavily on the performance of the vehicles and drivers. In many instances, the driving operations performed are highly repetitive and thus are more appropriate for automation or assisted driving rather than conventional operations. This is particularly the case for transit and freight facilities reserved for a narrow set of functions, such as terminals, vehicle maintenance areas, and dedicated roadways. Such facilities offer a further advantage for vehicle control applications. Because they are designed to streamline specific vehicle operations, the operating environments are typically well structured. A final advantage of exclusive facilities is the fact that the vehicles, infrastructure, and labor force are likely to be managed by a single entity, thus minimizing the institutional issues that frequently plague ITS deployment efforts.

For the study presented here, the contractor analyzed vehicle operations for transit buses and trucks, with a particular emphasis on operations in dedicated facilities. A separate analysis of available AVCS technologies and providers allowed an integration of operational needs with feasible technologies. The report outlines all findings and provides specific recommendations for near-term and long-term AVCS deployment opportunities in freight movement and transit.

FEASIBILITY OF ADVANCED VEHICLE CONTROL SYSTEMS FOR TRANSIT BUSES

INTRODUCTION

Several nationwide initiatives are currently underway to increase the efficiency of surface transportation. Two of the most important goals stemming from these initiatives are to increase the capacity of the existing transportation infrastructure and reduce energy consumption associated with driving. The idea that we can "build our way out of congestion" has long been rejected and strategies to increase highway efficiency have been evolving for more than 20 years. Within the national Intelligent Transportation Systems (ITS) program, among those areas which attempt to address these problems are the Advanced Vehicle Control Systems (AVCS) and Advanced Public Transportation Systems (APTS) user services. AVCS has already contributed to improved safety and efficiency of driving; however, its future impacts may be far more significant as enabling technologies develop into fully automated vehicles and roadways with dramatically higher capacity. Like AVCS, applications of technology to public transportation may also revolutionize the service quality and operating costs of transit modes and thus steer more travelers away from automobiles. Rather than let these research areas develop independently, it is desirable to study ways in which AVCS and APTS can evolve together. The increased operating efficiency and safety which AVCS promises could have a particularly high payoff for transit buses. This report investigates the technical and economic feasibility of applying AVCS to transit buses.

The purpose of this study is to identify bus operations that could benefit from the application of automatic guidance methods. This study requires an assessment of typical bus system operations as well as the state-of-the-art in navigation and control systems. The output shall be a recommendation for the integration of existing needs with available technologies. To arrive at recommendations, a three-step approach was used:

(1) Examine the history of vehicle control and automation associated with transit vehicles.
(2) Assess the user's needs for operational improvements.
(3) Assess the available AVCS technologies to achieve improvements.

To get a complete picture of the opportunities and technologies available, transit operators, vehicle manufacturers, consultants, and various researchers were contacted. An expert from the public transportation field provided personal insight and access to management at transit properties around the country. From meetings and discussions with this varied group, concepts emerged for incremental deployment opportunities as well as a better understanding of the capabilities and contributions that each could provide toward a system deployment.

AVCS IN TRANSIT BUSES—BACKGROUND

While vehicle control has been extensively developed for rail/guideway-based vehicles such as trains and Automated People Movers (APMs), relatively little automation technology has been applied to buses. Likewise, despite underlying similarities among buses, automobiles, and trucks, the significant work performed in vehicle control for passenger cars (and to a lesser degree trucks) has largely gone untested for buses. On the one hand, this is surprising given the sensitivity of transit operators to incremental improvements in operating efficiency—improvements which appear achievable through the application of AVCS. On the other hand, because transit is so heavily subsidized there is typically little funding available for the development of new technology; available funds are more likely to be spent on low-risk systems that show a more obvious or immediate return on investment. In addition to concerns regarding the cost-effectiveness of AVCS, there are many legal and institutional questions surrounding AVCS and vehicle automation, for example, liability issues in the case of accidents as well as passenger and driver fears associated with the replacement of drivers by computers.

There is, however, a small body of work in transit bus guidance which demonstrates some of the potential benefits to be derived from AVCS. During the 1920s, and then again in the 1960s and early 1970s, various attempts were made to provide guided bus systems. Early studies investigated railbuses that could run on existing railways, taking advantage of existing infrastructure and excess capacity. More recently, electronically guided buses were studied for use on roadways. The Barrett Corporation, General Motors, and others investigated and demonstrated bus guidance systems in the 1960s and 1970s, but did not place vehicles into service. Since that time, several European bus manufacturers have tested or deployed lateral and longitudinal control systems for buses. Most notably, Daimler-Benz, Volvo, and M.A.N. developed buses that provided semi-automated bus service for extended periods, some of which are still operating. The M.A.N. and Daimler-Benz buses ran under automatic lateral control on dedicated bus rights-of-way (O-Bahn transit system), while the Volvo bus demonstration ran under lateral and longitudinal control in the immediate vicinity of bus stops.

The most significant work in bus guidance has been demonstrated by the O-Bahn system, which was deployed in Adelaide, Australia; Essen, Germany; and elsewhere. The system provides automatic lateral control on express segments of the bus route and conventional (manual) vehicle control elsewhere. Special bus and roadway modifications are required for automatic operations. Both mechanically and electronically guided systems have been deployed since the late 1970s; however, the mechanically guided systems are much more commonly found in service. The mechanical system is guided by horizontal rollers that are connected to the steering linkage and projected from the sides of the bus, bearing against tall curbs. The electronically guided bus follows a current-carrying wire in the pavement using an inductive guidance principle. The magnetic field induced by the current provides a path for the bus, which the bus follows by detecting its lateral position above the wire and actuating the steering rack to center itself in the lane. Similar in principle to conventional bus operations in exclusive bus lanes, the O-Bahn buses run on uncongested bus-only rights-of-way (busways) when under automatic control and on the conventional street network when under manual control, providing the benefits of rapid transit performance on line-haul segments and flexible collection/

distribution service elsewhere. Furthermore, since the guided buses deviate only slightly from their busway lane, only a very narrow right-of-way is required. This allows for lower infrastructure costs and the ability to construct busways where very little space is available (this is particularly valuable for bridge and tunnel applications). As a result, O-Bahn systems may be viewed as a favorable alternative to light rail in some transit corridors. The ability to run in narrow rights-of-way may also allow guided buses to share subway rights-of-way with trains. This capability was demonstrated in Essen, allowing improved bus service in the downtown area by taking the buses off the congested surface streets and running them in under-utilized rail tunnels.

In parallel with the work in guided buses has been the development of Automated Guideway Transit (AGT) systems. While these systems have been demonstrated using a wide range of vehicle and guideway designs significantly different than those used for bus systems, AGTs set a precedent for unmanned, fully automated transit vehicle control (figure 1). Some notable examples of such systems have been deployed at airports around the world (Denver, Orlando, Chicago, etc.). Similar systems have been deployed in cities such as Detroit, Miami, Lille (France), Vancouver (Canada), London, and other locations. It is worth noting that the automated SkyTrain in Vancouver has among the lowest operating costs of any light rail or metro system in North America, with its cost reduction largely attributed to labor savings due to automation.(12)

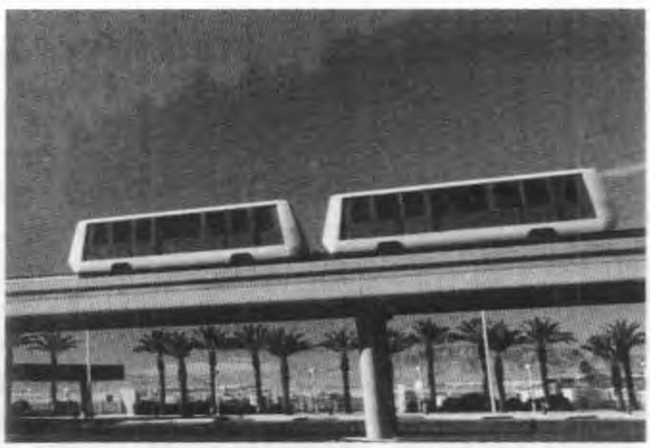

Figure 1. Automated People Mover at Las Vegas International Airport

Personal Rapid Transit (PRT) concepts involving the use of small automated guideway-based vehicles serving a dense network of origins and destinations have been investigated for at least 30 years, but the last few years have shown a renewed interest in these concepts as traffic congestion has worsened and technology has improved. Raytheon Electronic Systems of Marlborough, Massachusetts is currently building a small PRT system for Northeastern Illinois Regional Transportation Authority (RTA) in Rosemont, Illinois, and feasibility studies of other systems are underway around the world. As an automated public transportation system, there are some parallels between PRT and Automated Highway Systems (AHS) transit, but unlike mass transit, PRT attempts to provide automobile-like service, with very small vehicle capacities and point-to-point service.

BENEFITS OF AVCS FOR TRANSIT BUSES

It is clear that the value of public transportation is based on the achievement of many different and often conflicting goals. Among transportation system users, operators, and decision makers, there exist many competing needs, such that what one group may perceive as a benefit may be viewed by others as a cost. To avoid these complexities, this study assumes the viewpoint(s) of transit operators and users (and potential users). From this perspective, one can say that any system that reduces capital/operating costs or improves transit service quality (where service quality is loosely defined by such parameters as travel time, fare, safety, comfort, convenience, etc.) will be considered an improvement.

In assessing the benefits of AVCS for transit buses, a review of existing transit bus operations was performed. From literature reviews, system tours, and interviews with transit experts, several operational areas emerged as suitable for AVCS improvement:

- Lane keeping.
- Platooning.
- Curbside docking.
- Terminal operations.
- Maintenance operations.
- Collision avoidance.

Each of these operational areas and the associated AVCS benefits are discussed below.

Lane Keeping

The performance of the lane-keeping task, common to all roadway vehicle operations, is more critical for wide vehicles such as buses and trucks than for automobiles, since lateral distances to the lane edges are reduced. Lane-keeping systems have been prototyped to provide various degrees of lane-centering control, ranging from driver warnings to full steering control. The value of a lane-keeping system exists for all road-going vehicles, particularly as an aid to driver inattention where lane changing is infrequent (such as freeway driving). However, there exist specific operations for transit buses that could be substantially improved with the aid of a lane-keeping system. One example is operations in tunnels or other narrow segments of the bus right-of-way. There are a number of bus systems in the United States that incorporate bus operations in one or more tunnels. Operations on these narrow segments require the drivers to trade-off operating speed for safety. A fatal January 1996 collision between two buses in Pittsburgh was caused by one bus crossing out of its lane and into the lane of an approaching bus. Following this accident, the system operator was required to reduce the speed of operations on this route, thus creating a longer schedule and reduced service quality. This could be a case where a lane-keeping system would provide a better level of safety while allowing higher speed operations.

Other benefits of a lane-keeping system could accrue as the transit system infrastructure was adapted to take full advantage of the bus' lateral control capabilities. For example, as demonstrated in Essen, Germany, there may be significant benefits associated with running buses along with trains in subway tunnels. (See figure 2.) Significant bus service improvements could be realized in cities by moving buses from congested surface streets to under-utilized subway tracks. A lane-keeping system would be a critical enabling technology for such a transition. Likewise, land acquisition and construction costs would be reduced where guided busways or segments are built as a result of reduced lane-width requirements. This advantage for laterally guided buses would be most significant where adding or reallocating bridge or tunnel right-of-way is necessary. As an example, London Transport is considering the construction of two narrow guided bus lanes in addition to four conventional traffic lanes for a new bridge to the Docklands area. The agency perceives that the modest increase in bridge width required for guided bus lanes would provide substantially more traveler-carrying capacity than other alternatives. Finally, a lane-keeping system could provide an early deployment opportunity for AHS as a system building block. While paving the way to more sophisticated vehicle control systems, a lane-keeping system would also provide immediate benefits for existing transit bus operations.

Figure 2. Bus and Electric Trolley Sharing Tunnel Right-of-Way

Longitudinal Control

Operations that would benefit from the application of longitudinal control can take one of two forms: general automatic speed control or the special case of platooning. General automatic speed control would be employed to precisely maintain desired headways between buses for high-frequency service (greater than 30 buses/hour) where slight headway variations could severely disrupt operations. Platooning represents the high-frequency operational limit of speed control where headways approach several seconds or less. The efficiency advantages of platooning vehicles are clearly demonstrated by the superior productivity of trains relative to buses on high passenger demand routes.

In the case of high-volume transit service, there are very few North American bus operations that carry sufficient passenger volume to justify platooning to increase capacity. Perhaps the only U.S. operation of this scale runs on the Lincoln Tunnel exclusive bus lane connecting northern New Jersey and Manhattan, carrying more than 700 buses per hour during peak hours.[5] There is the potential to expand the capacity of this lane further by applying longitudinal control systems that can safely maintain very short headways between buses without mechanical couplings and keep the bus flow very steady. In the long term, a successful demonstration of platooning in an express lane might motivate transit planners to consider dedicated guided busways with bus platoons as an alternative to light rail in more heavily traveled corridors. This system could conceivably be demonstrated to run platoons of buses under lateral and longitudinal control with a single lead driver (or perhaps no driver), to significantly reduce labor costs. Such a system could approach the operating efficiency of trains on moderately high-volume routes while utilizing much cheaper vehicles with the flexibility to be run on conventional roads (figure 3). Automated vehicle-following technology has been successfully demonstrated for several years by various research institutes and vehicle manufacturers.

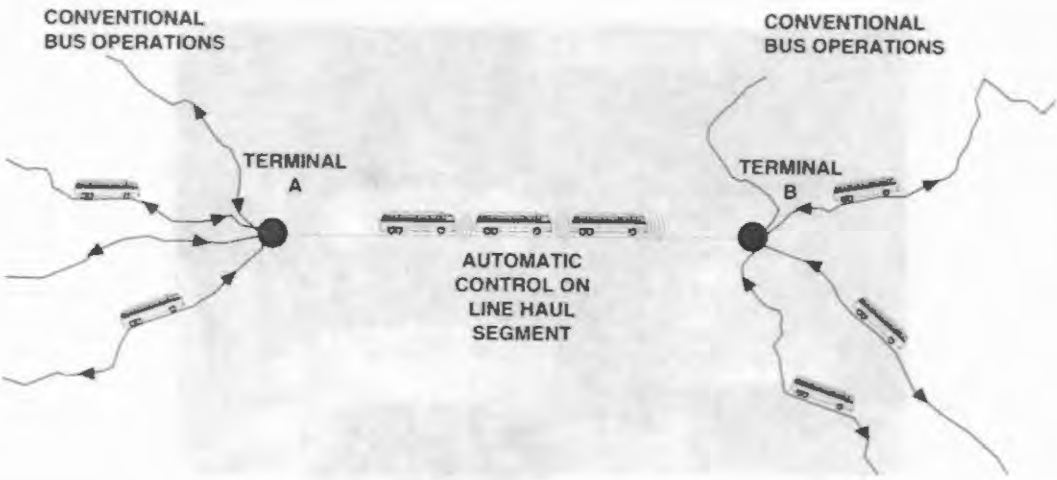

Figure 3. AVCS Concept for Bus Operations

While the Lincoln Tunnel case would provide an opportunity to demonstrate longitudinal control to improve the capacity of an express segment of a bus route, much shorter platoons could also provide capacity benefits for non-express operations. The concept of a "virtual articulated (artic) bus" (two or three platooned buses that move as a single bus with the passenger-carrying capacity of a single or double articulated bus) comes to mind. On some routes or route segments, it may be advantageous to utilize the operational efficiency of large-capacity vehicles, even if each vehicle still retains a driver onboard. An example of a transit system where this approach might be feasible is Seattle (King County Metro). If Seattle determines that it needs to significantly increase bus volume through its downtown bus tunnel it may need to use platooning methods to achieve this increase. The use of platoons in the tunnel would allow dwell time at stops to be shared simultaneously by several buses and would thus provide for a significantly higher bus capacity than could otherwise be offered. A longitudinal control system could safely facilitate the formation and maintenance of these platoons in the tunnel.

Short of automatic platooning, a speed control system to precisely maintain short headways of approximately 1 minute or less would be advantageous on some high-volume transit lines. This approach could help to reduce the problem of bus bunching that often occurs on such routes when one bus slips from its schedule and following buses "close the gap" from behind. Within bus terminals, longitudinal control could also be used to ensure sufficient slot size (traffic gaps) to allow safe merging of accelerating buses from ramps or platforms. The Chicago Transit Authority (CTA) is interested in maintaining steady speeds and short headways on approaches to major bus stations where multiple lines share a single platform. By carefully maintaining headways on the approach to the station, each bus will arrive separately, thus minimizing passenger confusion. One possible limitation for automatic speed control applications may arise where buses drive in mixed traffic, as the desired vehicle speed may not be possible given existing traffic conditions.

Curbside Docking

The presence of a gap or height differential between bus doors and the curb/platform area causes inefficient and inconvenient operations at bus stops. The provision of a level loading surface without gaps allows for much easier passenger access/egress and thus minimizes dwell time at stops. Another significant advantage for level loading is the improved access for the physically disabled. Level loading buses also eliminate the need for wheelchair lifts which are expensive, maintenance intensive, and time consuming to operate. However, in order to capture the advantages of level loading, there must be little or no gap between the bus and the curb, and thus automatic control of the bus for precise placement is desirable to ensure consistent and efficient docking. The curbside docking concept was successfully demonstrated in Sweden by Volvo in the late 1970s, but was later removed because drivers did not believe that it was necessary.[10] This system, which used an inductive wire guidance principle, is also noteworthy because it incorporated both steering and braking control on the approach to a bus stop.

Terminal Operations

There are a wide variety of bus terminals—from the very complex, like the Port Authority in New York, to the simple suburban bus depot. Within a terminal, there is generally a significant amount of starting, stopping, turning, and, perhaps, backing up within a confined area. In higher volume facilities, there may be frequent conflicts, wrong turns, and occasional accidents—all of which contribute to reduced safety and operating efficiency. AVCS may have some applications in terminals, particularly congested ones where drivers must quickly determine where to go or else risk causing a bottleneck (or worse). Some concepts which may have future use in terminals are: automatic sorting of incoming buses into berths and outgoing buses into access lanes, assisted or controlled backing operations, merge control via a longitudinal control system, and collision avoidance systems. If high-volume busways and bus lanes become more popular in the future, the automation of terminal operations will become more critical at the entrance and exit points to these facilities. Ultimately, if all buses are assumed to run under automatic control in the terminal areas, the terminals can be designed smaller with less lateral clearance and shorter entrance and exit lanes.

Maintenance Operations

From discussions with several transit system operators, it is clear that any incremental reductions in operating expenses would be embraced. A significant number of operators interviewed believe that bus service and maintenance operations could be streamlined with the application of AVCS. Every day, there are routine operations repeated by dedicated maintenance staff who drive buses between stations to perform various tasks. For example, at Port Authority Transit (PAT) in Pittsburgh, there may be anywhere from one to five drivers at each of several garages across the city. At the end of the service period for each bus, the driver takes the bus through a fueling area, a fluids check area, a washing area, and then parks the bus in a designated space (figure 4). By automating the movement of buses through these areas, PAT could reduce operating expenses. Instead of using several drivers at each facility, perhaps there would be one or two dedicated service technicians performing the necessary maintenance operations while the bus would move autonomously through the facility. Heavy-duty Automated Guided Vehicles (AGVs) currently exist for the precise and automatic movement of 45-tonne containers within large port areas. Perhaps a dedicated AGV could be installed at each service facility to pull buses between stations. The relatively controlled environment of the maintenance area, combined with the immediate benefits provided by AVCS, make this a strong candidate for a system deployment.

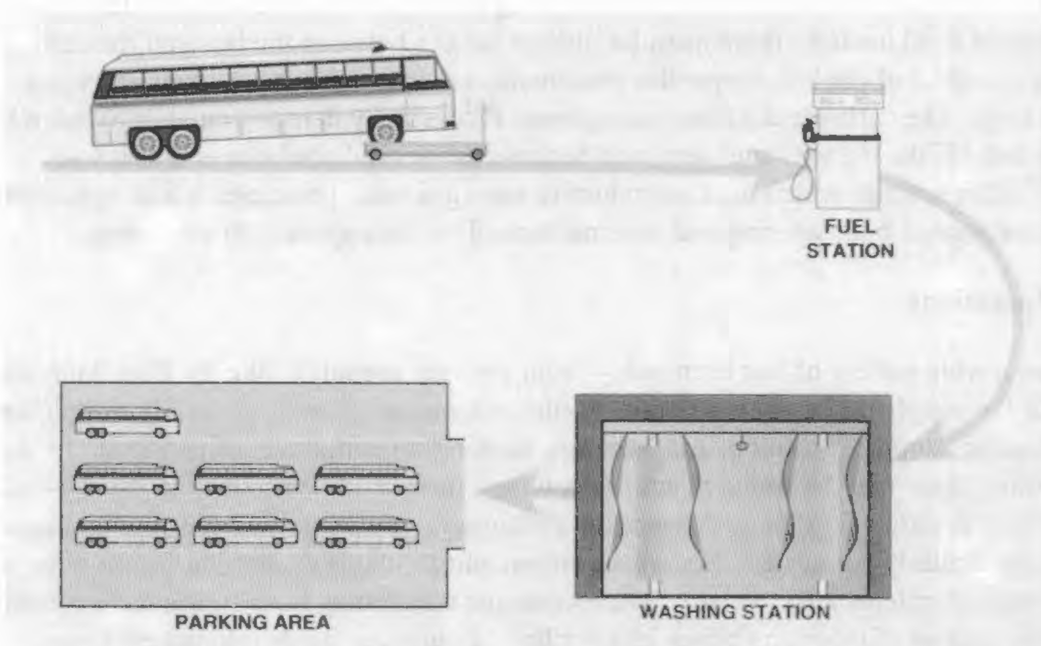

Figure 4. Concept for Automatic Movement of Buses in Maintenance Garage

Collision Avoidance

Like lane keeping, collision avoidance is under investigation for all types of vehicles. Several transit operators interviewed expressed interest in cost-effective collision avoidance systems, particularly rear-end collision avoidance systems. The National Highway Traffic Safety Administration (NHTSA) and various automotive manufacturers and suppliers are actively working toward collision avoidance systems to reduce the frequency and severity of a wide assortment of collision types. Delco Electronics currently markets a near obstacle detection system for school buses using radar transmitters mounted below the bus to warn the driver of obstacles outside the driver's field of view, and until very recently, Greyhound's intercity bus fleet was equipped with Eaton VORAD's forward-looking radar systems for collision avoidance. If these systems proliferate and prove their value, transit buses may gradually become equipped as well.

ATTITUDES OF TRANSIT COMMUNITY TOWARDS AVCS

In the course of this research effort, many transit and AVCS studies were analyzed and a wide variety of transit industry experts were interviewed, including transit system operators, transit planners, bus manufacturers, transit consultants, and researchers. The question underlying this examination was: what tangible benefits can AVCS provide for public transportation systems? In particular, the focus was to determine feasible and near-term AVCS opportunities for transit buses. Through the course of the study, it became readily apparent that there was very little appreciation within the transit community for the benefits that AVCS could provide.

Once the AVCS concept was thoroughly explained, the overall consensus of the transit community was that AVCS showed exciting potential for the distant future, but much less promise for the immediate future. The more visionary planners imagined dramatic service and operating cost improvements with guided buses running on busways and subway tracks and automated buses moving assembly line-style through maintenance garages, while less optimistic planners did not believe that AVCS could provide many significant benefits even if the technological and institutional hurdles could be overcome. New technology comes slowly to the transit world, and vehicle control systems are perceived to be several steps beyond the current cutting-edge systems, which are typically information flow-oriented, like real-time fleet management and traveler information systems. Transit managers cannot afford to be adventurous, either from a cost or operations standpoint, because there is little or no funding available for experimentation, and a system failure is unacceptable to the riders who rely on the service. A transit consultant in Ft. Lauderdale who unsuccessfully lobbied for the deployment of a guided busway (O-Bahn type) to connect the airport and ship port area found decision makers to be unreceptive to the new technology, with their attitude being that other transit properties would already have deployed such systems if they were cost-effective and reliable. Another planner from a forward-thinking agency said of new technology initiatives: "I like to be the second guy to adopt new technology, but not the first." Reflecting the fear of system failure, one transit system manager indicated that he would seriously consider vehicle automation technologies if it could be proven to him to be "100 percent reliable"—obviously an unrealistic goal for any system.

In Pittsburgh, PAT planners expressed a willingness to invest capital funds in new technologies that could reduce their operating costs, but were concerned that AVCS approaches might spark fear of job cuts among workers and lead to poor labor relations. Most planners also expressed concern that completely unmanned bus concepts would be difficult from a fare collection and passenger security issue; however, they accepted that these concerns might possibly be addressed, at least in the short term, by providing lower paid bus attendants on automated buses. While many transit systems demonstrated opportunities for short- and long-term AVCS deployment, it is the long-term deployments (with facilities and vehicles designed to accommodate AVCS) that offer the highest payoffs. Unfortunately, the enabling technologies for the future must evolve from the short-term applications, such as lane keeping and other systems, which may not provide such a high cost-benefit advantage. Even the most pro-technology transit property will require a compelling economic analysis of the costs and benefits of an unproven technology approach such as AVCS.

From the industry side, there was also cautious interest in AVCS. A transit industry consultant with expertise in the design and deployment of automated guided transit (AGTs) pointed out that with labor typically representing 75 percent of operating costs, any incremental labor cost reduction that AVCS could provide should be considered seriously. He also indicated that it would be important to get the bus manufacturing industry interested in AVCS as they would obviously need to contribute to the design and production of an AVCS-equipped bus. This may be a challenge because the level of R&D funding is typically very low in the bus industry and manufacturers would need to see a strong demand from their customers to justify any exploration of AVCS. An engineering representative from the North American bus industry echoed this sentiment, saying that his company is customer driven and does not have the resources or desire to develop new systems. Several European bus manufacturers, however, have proven their interest in vehicle control technology by deploying guided buses and investing in guidance technology.

FEASIBLE AVCS TECHNOLOGIES FOR TRANSIT BUS APPLICATIONS

This section does not intend to provide an exhaustive list of all guidance systems available, but instead attempts to illustrate the most promising technologies for a near-term system deployment. The particular emphasis here is on navigation systems, with less focus on mechanisms and algorithms for vehicle control. While several distinct systems are described here as alternatives, it is quite possible that the ideal AVCS for a given task will incorporate more than one of these technologies simultaneously.

Wire Guidance

As described above, the inductive guidance system demonstrated on O-Bahn buses has a long history in vehicle control. The guidance system has been used for years by AGVs on factory floors, as well as in cars and trucks for automated vehicle test tracks (Chrysler's vehicle proving grounds, etc.). Among its technical advantages, wire guidance is robust, proven, and relatively simple. Among its disadvantages, wire guidance is infrastructure intensive and inherently inflexible as it requires the presence of a wire path to any location that a vehicle may need to reach. Furthermore, while switching (following a different wire from an intersection of wires) is achievable, it becomes increasingly complex and cumbersome for multiple switches. It also consumes electricity and requires some means of backup in case of a power outage.

Differential GPS

The Global Positioning System (GPS) has been used for several years in the tracking of vehicles, seacraft, aircraft, etc. The system, which incorporates line-of-sight communications between orbiting satellites and a receiver at any point of interest on earth, provides positional accuracy on the order of 100 m for general users. To improve accuracy, several approaches have been introduced to correct signal transmission degradation between the satellites and a receiver. Correction methods that eliminate both intentionally induced (by selective availability) and atmospheric errors are collectively called differential GPS (DGPS). Research in recent years has shown that DGPS can provide positional accuracy in the 10-cm range—sufficient to make this technology viable as a navigation system. The Intelligent Systems group at the National Institute of Standards and Technology (NIST), for example, has demonstrated such results and has successfully guided vehicles using DGPS supplemented by an inertial navigation system. NIST claims that this hybrid navigation system is very accurate and robust.

The major advantage of GPS-based systems is their ability to operate with a minimum of additional infrastructure; GPS satellites have been functioning reliably for years and differential correction requires only the periodic placement of ground stations (kilometers apart) at surveyed reference points. A major disadvantage of GPS-based systems is the line-of-sight and multipath problem: satellite transmissions to the guided vehicle may be obscured completely by buildings, etc., and those signals that do reach the vehicle may have taken an indirect (longer than line-of-sight) path. The view expressed by several AVCS system integration experts was that DGPS systems are now extremely accurate and will continue to become less expensive and more robust; DGPS may become the guidance backbone for future vehicle control systems—from automobiles to transit buses.

Machine Vision

Image processing techniques have been under development for many years and have been successfully implemented in automobiles and mobile robots for guidance. Perhaps the most advanced work to date in machine vision for vehicle navigation was performed by a German research team led by Daimler-Benz. Their work has demonstrated completely automated driving functions by an automobile on conventional roads in real traffic. The specifics of the machine vision systems vary by application, so the following generic advantages and disadvantages must be weighed according to the desired system function. Among its advantages, machine vision systems require little or no infrastructure modifications, have been shown to provide excellent positional data for vehicle guidance, and may be configured to perform many different tasks (from lane keeping to collision avoidance to road sign reading, etc.). Some disadvantages are: current system expense, complexity, and inherent limitations of the basic sensor (camera), which can only provide information on the scene immediately visible to it.

Passive Magnetic Trails

Like the guided wire system, the underlying guidance principle of magnetic trails is to provide a path in the pavement for a vehicle to easily follow. Unlike guided wires however, passive magnetic trails do not require electricity. Two approaches are currently under investigation: discrete magnetic markers and continuous magnetic stripe. The California Partners for Advanced Transit and Highways (PATH) program, based at the University of California, Berkeley, has investigated the discrete markers method and has successfully demonstrated its capability for lane keeping. Magnetic stripe research is underway in Minnesota by 3M and Honeywell. Their work focuses on the incorporation of a magnetic substrate into a conventional pavement marking tape. Such a tape would provide visual road markings such as conventional stripes and would also allow for magnetic trail following as well as magnetic encoding of information for the driver or vehicle guidance information. With the exception of the passive vs. active issue, the basic advantages and disadvantages of the magnetic approaches are similar to those of the wire guidance approach. They may promise to provide reliable and accurate lane keeping, but they are infrastructure intensive and inflexible. Passive magnets may be cheaper to operate than current-driven wires, however, the magnetic path may be harder to follow depending on local magnetic interference.

Miscellaneous Laser and Radio Frequency (RF) Techniques

Numerous laser and radar-based systems have been developed and successfully deployed in recent years. Trilateration approaches using spinning radar or laser beacons and reflectors or receivers at known locations have been used for AGV guidance systems both in and out of doors. These systems are infrastructure-intensive and susceptible to line-of-sight problems between the beacon (typically vehicle-mounted) and the receivers/reflectors (strategically placed in the environment). For outdoor operations, radar-based systems are less susceptible to faulty measurements in poor weather than laser-based systems. Both types of systems, however, can provide very good positional accuracy and allow path versatility. Other laser and RF methods have been deployed that illuminate roadway/roadside stripes or reflectors and measure the vehicle position with respect to them. A recent program in truck guidance demonstrated the use of guardrail-mounted corner reflectors and truck-mounted side viewing radar to provide lane-keeping control.

OPPORTUNITIES IN SPECIFIC TRANSIT SYSTEMS

Pittsburgh

PAT's system is perhaps the most suitable for AVCS deployment because it could benefit from AVCS in both the near and long term. In addition, PAT operates the only dedicated and grade-separated busways in the country (figure 5), providing an excellent testbed for vehicle control testing and development. Based on conversations with PAT staff, it appears that they are generally receptive to new technologies that can legitimately reduce operating costs or improve service quality. They expressed willingness to contribute at least some capital funding to the deployment of AVCS if such a system could be justified. Given the controlled nature of the busways relative to conventional roads, as well as the fact that PAT owns and operates both the busways and the buses, Pittsburgh may be an ideal location for AVCS deployment.

Figure 5. PAT Bus on Pittsburgh's East Busway

The PAT system includes two dedicated busways (East and South Busways) built on existing rail rights-of-way and a third busway (Airport Busway) currently under construction. Unlike the existing two busways, the Airport Busway will share its right-of-way with high-occupancy vehicles (HOVs) (at least initially). The system also incorporates reserved bus lanes on surface streets in the Central Business District (CBD) as well as a small subway network in the CBD. Some promising possibilities for near-term AVCS deployment include a lateral control system for lane keeping on the busway as well as automated vehicles for bus maintenance in service garages. In light of a recent fatal accident on the East Busway in which a bus crossed into the approaching lane and hit another bus head-on, there is genuine interest in any system that could supplement the driver in the lane-keeping function. With respect to the maintenance garage automation, there may be an opportunity to deploy an AGV to push/pull buses through the garage during servicing. In the longer term, lateral and longitudinal control could be applied to allow buses to run in the subway with trains. This vision of PAT's executive director, Bill Millar, would improve trip times significantly and eliminate the need for downtown transfers in some cases. Another possibility for automation exists on the East Busway between downtown and the Wilkensburg terminal nearly 10 km away, where the busway ends. Buses could be run autonomously or in platoons (with or without a leading bus driver) between these points and drivers could board the buses at either end to service routes from there. This would allow for continued service levels with fewer drivers due to automation of the line-haul portion of the trip.

Cleveland

The Cleveland RTA staff was interested in AVCS and new transit technology in general. Deputy General Manager Ron Barnes was particularly fascinated by the potential of AVCS for RTA's operations. His opinion was that Automated Vehicle Location (AVL) and traveler information are the new technologies of the next few years, but RTA must consider revolutionary technologies like AVCS now to effectively plan for the 5-, 10-, and 20-year time horizons. Of particular interest was the maintenance area automated vehicle concept described above. There are several major garage renovations planned in the coming years and Ron believed that AVCS should be considered in these plans.

Interest was also expressed by RTA planners for the Euclid Avenue corridor, which will undergo a major bus transit service improvement in the next several years. An option that may be considered for the corridor is a guided busway. Given the limited available road width and the guided busway's narrow right-of-way requirement, this approach might suit RTA's needs.

Chicago

The Chicago Transit Authority (CTA) is currently involved in major technology upgrades for their transit system, including a new state-of-the-art transit control center and AVL and radio improvements. The planners there were interested in AVCS, but viewed it as a long-term, unproven technology. Their strongest interest in AVCS was in the automation of their maintenance garage. CTA has a fleet of approximately 1,700 transit buses that are serviced daily at 8 garages across the city. As many as eight employees dedicated to driving the buses through the servicing circuit work at each of these facilities and it is possible that an automated bus movement system could reduce the dedicated servicing staff substantially.

Another possible application for AVCS exists in the Carroll Street right-of-way in the downtown area. This soon-to-be-abandoned rail right-of-way is approximately 1.6 km long and without significant grade crossings. Carroll Street parallels a major downtown street and it would be desirable to run buses there to avoid the congestion. Because the existing right-of-way is very narrow at some points, a guided busway could offer the best alternative for the use of the segment.

Seattle

King County Metro of Seattle has long been recognized by the transit community as one of the most innovative and forward-thinking agencies in the United States. The overall transportation system, particularly the transit system, reflects a real commitment to intermodalism, high-quality transit service, and consideration of all system users. The county is willing to apply unconventional transportation solutions as witnessed by its public horse trails, bike racks on buses, free electric bus service through its 2.1-km bus-only subway, and many other examples. In addition to the bus tunnel/subway, Seattle also has an approximately 6.4-km-long dedicated busway segment. Paul Toliver, the director of the King County Department of Transportation (DOT), is a strong proponent of new technology, and he and his staff were interested in AVCS. As with the other agencies visited, the automated servicing application was very interesting to them for their garages, and they indicated that such a system would be considered for a new garage design currently under study.

Other opportunities for AVCS might exist for lateral bus guidance (lane keeping) and/or platooning for the buses as they travel through the tunnel. Platooning may be the more significant capability in the future as there is a possibility that tunnel volumes will increase. In particular, if light rail vehicles are introduced to the tunnel it will become more critical that buses use their time in the tunnel more efficiently or else risk causing delay to other buses and trains on short headways. The use of low-floor buses in platoons should provide that level of efficiency in the future. As with Pittsburgh, these platoons could be completely automated or semi-automated (with driver in lead bus only) to provide significant operational labor cost reductions within the tunnel. Given the dedicated infrastructure and downtown free ride policy (no fare collection issues), the bus tunnel might provide an ideal point of deployment for fully automated buses. Drivers could enter and exit buses at the two ends of the tunnel for local service routes, while the line-haul tunnel segment in between would be automated.

Other Areas

In addition to the specific cities listed above, there are other cities and regions that may also be suitable for an AVCS deployment. In the course of this study, it became clear that transit systems in each city have their own unique opportunities for AVCS, whether it be for narrow tunnel segments, dedicated bus lanes, abandoned or shared rail rights-of-way, or other opportunities. New York City, for example, has the famous Port Authority terminal and Lincoln Tunnel express bus lane leading to it from New Jersey. As mentioned previously, this system could benefit from AVCS approaches, particularly automatic platooning in the bus lane and lateral control within the terminal. Houston Metro is a very pro-bus and pro-technology transit agency with the most extensive bus lane system in the country. They appear to be particularly receptive to AVCS and Automated Highway Systems (AHS) technologies and may be interested in an early deployment. In Miami, Metro-Dade Transit is preparing to open several miles of exclusive busway on an abandoned rail right-of-way running south from the city, with plans to open additional segments in the future. A transit planner there expressed interest in AVCS applications to improve service quality. Beyond the basic benefits of AVCS, he thought there might also be some marketing appeal to the public for a high-technology bus.

An interesting development that may encourage the introduction of AVCS is the increasing popularity of busways. While very few dedicated busways exist in this country today, many transit planners are now considering busways and, occasionally, guided busways as alternatives in their corridor studies. Boston, Milwaukee, Raleigh, and Cleveland are just a few of the jurisdictions that are considering or have recently considered busways. These bus-only facilities are the most suitable for the adaptation of lateral and longitudinal control systems as they present a relatively controlled environment for integrating new equipment on buses and the facility itself.

RECOMMENDATIONS FOR FUTURE WORK

From a review of transit industry needs and available AVCS technologies, some recommendations have been identified for continued work in the near term. These recommendations are summarized below:

- Automation of bus movement through service areas in bus garages was the most popular AVCS vision for transit operators. Some managers asked how much a system of this type would cost. This should be a high-priority area of study for future work. Specifically, a detailed study of vehicles, facilities, and servicing operations at an interested transit property should be performed and a small handful of AVCS technology providers should be contacted to work towards developing alternative design concepts and cost estimates for such a system.

- A design concept and cost estimate for a lateral control system for lane keeping should be developed. As described previously, there are many potential benefits for lane-keeping systems in the near and long term, as well as many levels of deployment possible—from warning systems to full lateral control. In cooperation with specific technology providers, transit agencies, and bus manufacturers, alternative system concepts should be developed and a cost estimate established for each alternative.

CONCLUSIONS

Through the course of this study, numerous contacts within the transit industry were interviewed and four major transit operations were toured and reviewed. There were also many meetings within the AVCS community, including briefings to the National AHS Consortium, the Intelligent Transportation Society of America (ITSA) AVCS Committee, and other AVCS experts and providers. While tremendous opportunity exists for AVCS in transit, successful implementation will require cautious steps. Short-term benefits of AVCS certainly can be demonstrated with modifications to existing vehicles and infrastructure, but to fully capture the larger long-term benefits will require vehicles, infrastructure, AVCS equipment, and many transit agency processes (like route planning, scheduling, and operations) to be coordinated together as a unified system. In the course of this study, two significant observations have emerged:

- Very little shared knowledge exists between the AVCS and the transit community.
- Like so many other pioneering Intelligent Transportation Systems (ITS) initiatives, the deployment of AVCS for public transit will encounter more significant institutional and legal hurdles than technical challenges.

The importance of the first point cannot be overstated. Effective system design requires understanding the entire system and the interactions between all the components. From a technical standpoint, an effective large-scale AVCS deployment would require a detailed understanding of issues associated with bus operations, vehicles, infrastructure, sensor technology, control system design, and many other issues. The second point indicates the importance of incorporating many non-technical issues into the design process. There are major financial considerations, as well as legal and institutional barriers. There are transit system managers, transit employees, and the riding public who would all need to accept the changes that AVCS would bring. From the standpoint of the transit management, there are many risks associated with AVCS, not the least of which are angry labor unions and law suits in case of system failure. With so little funding available for new technology at most agencies, there is a high opportunity cost associated with testing relatively unproven technology.

Despite the challenges, however, this study has served to start the transit community thinking about the potential benefits of AVCS. Some of those planners and administrators interviewed indicated that they may now start considering AVCS options in their alternatives analyses for future projects. A convincing case study of AVCS for transit buses, demonstrating cost and service quality advantages, would certainly provide further momentum to a vehicle control system-based approach.

FEASIBILITY OF ADVANCED VEHICLE CONTROL SYSTEMS FOR TRUCKING TERMINALS

ABSTRACT

Within the freight transportation system, transfer facilities provide areas of opportunity for AVCS to yield significant efficiency benefits. Freight movement operations often require goods to pass through several transfer points between an origin and a destination. Because these transfer terminals can limit system throughput, a variety of ITS technologies are presently under consideration by the freight industry to reduce processing inefficiencies. Among those technologies, AVCS is potentially significant, even though it is also the least known within the industry. Given the controlled nature of freight terminals as well as the dependence upon human labor to perform even the most simple and repetitive vehicle movements, AVCS is a logical improvement for terminal operations. Through a detailed examination of freight movement operations and available vehicle control technologies, this study explores opportunities for AVCS to improve the operational efficiency of freight terminals and recommends future directions for developing new systems.

INTRODUCTION

With responsibility for approximately 41 percent of the freight and commodity tonnage moved in this country, trucks play a vital role in our nation's economy.[13] As members of a highly competitive industry, truck fleet operators are constantly searching for the slightest competitive edge relative to other carriers as well as other modes of freight transportation. This industry desire to reduce costs and improve service, in combination with the Federal Government's recent efforts to improve the safety and efficiency of the transportation system, has fueled the application of high-technology solutions in the trucking industry. As with the transit bus industry, described earlier in this report, the current areas of technology deployment for trucks lie in data processing and communications applications that help to speed the flow of information. For example, the Commercial Vehicle Operations (CVO) user services group of ITSA focuses largely on systems that allow remote tracking and verification of the drivers, cargo, permits, fee collection, and so forth. The next significant step beyond information flow enhancement will likely be the deployment of AVCS and vehicle automation systems.

The initial purpose of this study was to identify general applications of AVCS for trucks and trucking operations. However, given the level of Government-supported and industry work currently underway in AHS and AVCS, it became apparent that only those operations that differed significantly between trucks and automobiles would be warranted for study. As a result, the focus of this investigation shifted to terminal operations. Single-mode (truck only) and multi-modal terminal operations were examined, and freight operators, industry experts, and consultants were interviewed. To better understand the technical and economic feasibility of vehicle guidance and control hardware/software, a thorough study of AVCS technologies and system providers was performed.

Discussions with CVO and AVCS experts not only established the fit between freight operators' needs and available AVCS technology, they brought to light the institutional issues which likely will be of significance in dictating the future of AVCS in freight terminals (and elsewhere). Terminal operators expressed concern about labor union reaction to automation and how it will affect job descriptions (if not elimination) and salaries. Another issue is the reluctance of operators to invest in an advanced technology that is not fully understood or proven. Given the often narrow competitive advantage among carriers, the freight movement industry is very conscious of dollars invested versus dollars returned as well as impacts of new systems on quality of service or product.

AVCS IN TRUCKING TERMINALS—BACKGROUND

Terminology

In order to frame the discussion of AVCS applications in terminals, a brief description of freight terminal operations, vehicles, and common terminology will follow. A trucking terminal is defined as "any assigned area for the loading/unloading, temporary storage of vehicles, or the interchange of freight during transit."(13) This may include facilities where goods are loaded and unloaded from the trailers or intermodal transfer points where trailers or containers are loaded or unloaded from ships or railcars. A container is a box that carries and protects cargo for movement by ship, railcar, or truck (when chassis-mounted). Due to their uniform modular design, containers may be stacked to provide efficient use of space. Trailers are essentially containers with wheels—either permanently mounted or temporarily placed on a chassis. Movement within terminals is generally provided by cranes and forklifts for containers and by terminal tractors for trailers. Terminal tractors are similar to over-the-road truck tractors, but are dedicated to the terminal area. The movements are generally quite repetitive, with specific areas permanently dedicated to loading, unloading, or vehicle storage.

Rotterdam Delta Terminal

Due largely to the repetitive nature of movement within them, terminals make a very suitable point of deployment for AVCS. The efficiency improvements of AVCS have already been demonstrated in several terminal areas where container movement is performed by automated unmanned vehicles. The Port of Rotterdam's Delta Terminal is the best example to date. This terminal, in partnership with Sea-Land Services, is one of the most technologically advanced terminals in existence, with more than 50 unmanned AGVs carrying containers from ship to stacking areas (figure 6).(11) Currently, the Delta Terminal is the only container terminal that uses AGVs extensively. In 4 years, wage costs have decreased from 61 percent to 51 percent of the total costs. Due to the terminal's success since its deployment, a second terminal at Rotterdam, which will begin construction this year, will also utilize AGVs.(3,7)

At the Delta Terminal, the automated vehicle acts as a chassis that positions itself under the quayside crane where containers are unloaded from the ship. The crane places each container onto an AGV that "drives" across the yard to a stacking crane where the container is removed and stacked. A central Process Control System (PCS) instructs the AGVs where to go for each new task. Each AGV, built by Gottwald of Germany, runs on a diesel hydraulic drive line, weighs 13 tonnes, and is capable of carrying up to 45 tonnes. Frog Systems of the Netherlands produced the navigation system that utilizes fiber-optic line grids and transponders located throughout the facility for position update information. Between transponders, the vehicles use their onboard inertial navigation system.[2]

Figure 6. Automated Guided Vehicle at Rotterdam

Other Terminals

Another example of a successful, but limited, AGV deployment took place in 1992 at Thamesport intermodal port facility in England. This single AGV, built by Terberg, used millimeter wave radar (MMWR) for guidance and operated in conjunction with manned vehicles carrying containers from ship to stack. Initially, the navigation system encountered problems due to the high level of clutter within the container environment. While modifications to the control hardware and software resolved the problems, Thamesport removed the AGV due to lack of funding. While there were no reported incidents, there was concern expressed about vehicle safety throughout the test. Terberg representatives expressed the belief that quantifying operational safety will become a requirement in the future as terminals deploy more automated systems.[4]

The most significant automated terminal system is still under design for the world's largest port, the Port of Singapore (PSA). By the year 2000, PSA plans to operate hundreds of AGVs under a sophisticated traffic management scheme for container movement.[11] At present, there are two contractors (Kamag of Germany and Mitsui of Japan) developing test units. PSA has selected Tadiran of Israel to provide the navigation system for the test units.[1]

Far from being an untried technology, AGVs have been used for many years on factory floors for material handling applications to improve manufacturing efficiency. Many paper and copper mills use AGVs to move large, multi-tonne rolls rapidly through the factory, reducing the number of workers required to move a roll. AGVs are also commonly used for repetitive-motion tasks such as retrieving spare parts in assembly plants.[11] As demonstrated in Rotterdam and

Thamesport, truck terminal AGV applications represent a large-scale extension of conventional factory floor AGVs.

FUTURE OPPORTUNITIES FOR AVCS IN TERMINALS

At the heart of this AVCS study was a series of interviews with freight operators about their terminal operations and the suitability of AVCS for improving the efficiency of these operations. Because the concept of vehicle automation was generally foreign to this group, the AGV system deployed at Rotterdam was used as a real-world example to start the thought process about AVCS and unconventional applications for vehicle control. Many had heard of the AGVs at Rotterdam, but few had any further knowledge or experience with automation or AVCS. Their interest level in AVCS ranged from no interest to strong enthusiasm for deployment. Those not interested generally believed that the institutional barriers to deployment could not be overcome.

The discussion of possible uses for AVCS in terminal operations produced a wide range of responses by those interviewed (table 1). One of the most commonly mentioned applications was for the staging of trailers within the terminal yard. A description of staging, as well as other possible AVCS uses and applications, follow.

Table 1. Future Applications for AVCS

- **Staging within terminal yard**
- **Shuttling containers/trailers**
- **Valet parking**
- **Rearranging the yard**
- **Tracking container inventory**
- **Truck backing**
- **Washing**
- **Inspection**

Automated Movement

Staging Within the Terminal Yard

Staging is the movement of trailers between unloading/loading and storage areas. This process is repetitive and hence a likely candidate for automation. While staging operations differ slightly among facilities, they generally require similar vehicle movements.

In most terminals, a tractor driver must move each empty trailer from a storage area to a designated loading area. After the trailer is loaded, it is moved to a parking area to wait for the over-the-road truck. A similar operation occurs for incoming loaded trailers. In one facility's operation, each trailer moved only 130 m during the staging process. Even for such a short move, all the preparation and steps for movement are necessary. Another facility hires "spotters" (tractor drivers) to perform staging operations. Spotters are made available around-the-clock even though staging is often not required during certain times of the day. By automating the staging process, less labor would be required to provide an equal or greater level of service.

United Postal Service (UPS) uses a similar type of staging operation at its facility outside of Chicago. This facility, the Chicago Area Consolidation Hub (CACH), is the largest sorting facility in the world, with 4,000 staging bays, including 1,054 outbound doors. UPS estimates that processing capacity approaches 177,000 packages per hour. The CACH operation consists of loaded trailers arriving at the terminal and proceeding directly to an inbound door. The trailer is unloaded and then shuttled to an outbound loading area. At this point, the trailer is loaded and then shuttled to a waiting area where an over-the-road truck will transport the packages out of the facility. UPS decided against using automated vehicles because of the high pedestrian traffic in the area, but they feel there are other facilities and trucking companies that would benefit from an automated staging system.

In addition to efficiency improvements through labor reduction, another major benefit of automating the staging system would be the ability to maintain trailer inventory at the facility. The same hardware developed for staging could provide an inventory control system with real-time trailer location and status functions. Such a system could prevent the movement of trailers before they are loaded/unloaded and could find otherwise missing trailers that were placed at the wrong location in the yard.

Shuttling Containers/Trailers

Another application area for vehicle automation is the shuttling operation. Unlike staging operations, which are specific to movements between loading/unloading areas and holding areas, shuttling refers to general movements of trailers within terminals. Many applications fall under this category, some of which are described below.

Trailer movement between ships and parking areas in a port facility is one type of shuttling operation that could be automated. This is similar to the AGV operation in Rotterdam. A gradual deployment of automated vehicles at an existing terminal might be desirable to assess the impacts of automation on operating costs and labor relations. Even a partial deployment of automated vehicles to augment existing driver-operated vehicles could show benefits in terms of ship unloading time and yard productivity.

In conventional operations, once staging or shuttling is completed, the trailers await pick-up by an over-the-road truck. When an over-the-road truck driver checks into the facility, he or she is told where the assigned cargo is located and is allowed to retrieve it from the designated area. As an improvement to this approach, an automated shuttling operation could provide an automatic "valet" operation to bring the trailer to the over-the-road truck waiting at the gate. The timing of this operation could be coordinated with the arrival of incoming trucks to prevent wasted driver time and holding space in the yard. Another benefit would be the reduction of accidents and movement inefficiencies that can occur within the yard when large tractor-trailer combinations attempt to negotiate the constrained spaces of the terminal. One operator stated that this feature would be particularly useful at very old terminal facilities that were designed for 32-ft (9.8-m) trailers and do not easily accommodate today's 48-ft (14.6-m) trailers.

Another application for automation would be the task of rearranging the terminal yard. When ships or trains pull into an intermodal terminal for loading, the cargo often is widely dispersed throughout the yard. Automated vehicles could expedite loading by moving the containers into one general area prior to a vessel's arrival.

Truck Backing

Whenever a trailer backs up to a loading dock and hits it, the trailer is subject to stress and wear, which tends to shorten its usable life. Given the high cost of new trailers, some terminal operators expressed interest in an automated backing system that would take control of the vehicle when the trailer is in close proximity of the dock. Such a system would back the trailer into contact with the dock with a "feather touch," thus increasing the lifespan of the vehicles and generating a per trailer savings over time. For example, a system might include ultrasonic ranging sensors mounted on the back of the trailer with a driver warning or display in the cab to indicate distance to the dock. A more elaborate deployment would override the brakes and/or throttle when close to the dock.

Routine Tasks

There are many routine tasks, such as washing and inspecting, that occur throughout a trucking facility. These activities would be good candidate processes for automation because they are highly repetitive and labor-intensive. Significant labor savings in these activities could be realized by the replacement of drivers with automated vehicles.

Some terminals use dedicated drivers to move each trailer through a wash area several times a week or every time a truck leaves the facility. Using an automated vehicle to tow the trailer through the wash area or a dedicated vehicle to wash the trailers in their parking area could provide savings to the company through reduced labor costs. One AGV company is currently developing an automated washer for airplanes that could be adapted for this application.

Driving a truck through an inspection station is another routine task that could benefit from AVCS deployment. As trucks become increasingly sophisticated, inspections can become more complex and time-consuming. Automating the movement of trucks through inspection areas would reduce labor costs associated with the operation. In the future, this automated movement could be integrated with automated diagnostic systems to allow trucks to move through a maintenance tunnel with little or no human intervention and to emerge with all diagnostics data recorded through wireless transmissions. Such a system could automatically check all equipment and perhaps even adjust those components and systems that are out of calibration.

Restricted Area Operations

At least one fleet operator expressed an interest in automated truck movements within high-security or hazardous environments. Secure military facilities exist that allow only cleared personnel in the area. A civilian driver arriving with a shipment must give the truck to a dedicated driver who performs any necessary tasks in the compound and then returns the truck to the gate. A system that would automatically guide the truck through the base to the loading depot and then return it to the driver would reduce the workload of military personnel.

Another related application involves the movement of vehicles in hazardous areas. A national spokesman for truck drivers mentioned nuclear facilities in particular as dangerous for drivers and perhaps more suitable for automated vehicles. To reduce the risk of exposure for a driver, an automated truck could be employed to haul and unload dangerous materials within such a facility.

Automation of Other Terminal Yard Equipment

Two other types of yard vehicles were identified as suitable for AVCS enhancement or automation. One terminal operator indicated that he has a problem with accidents and resulting trailer destruction caused by inexperienced forklift operators who load goods into trailers. A badly controlled forklift causes severe damage to the inside of the trailer during loading and unloading operations. The best solution for this problem may be to replace the forklift operator with an automated forklift or pallet loader, or perhaps automate the loading and unloading operations.

Another operator expressed interest in an automated vehicle for tracking container inventory. Many freight operators are beginning to use RF identification tags to keep track of truck and trailer inventory. Currently, the most common operating frequency (915 MHz) for these tags requires a tag reader to be within several meters to accurately read it. In order to update container location data, an automated tag-reading vehicle could routinely patrol the container terminal, updating the terminal inventory database. This would eliminate the current practice where a person drives a vehicle through the yard and manually updates the computer or has to spend long periods of time hunting for lost containers. The opportunity for deployment of an automated RF tag reader would be facility-dependent since the extent of RF tag usage varies widely within the industry.

AVCS TECHNOLOGIES

The technical range of options for vehicle control at terminals is quite large. Depending on the cost and level of control required, either existing tractors and trailers could be modified to accommodate control systems or dedicated AGVs could be implemented at each facility. At one end of the range are supplemental driver warning systems, like that described for truck backing. At the other end of the cost/complexity spectrum are full-scale AGV deployments, like that in Rotterdam, with advanced traffic management systems providing path planning and motion control for every vehicle.

From a technical and an efficiency standpoint, the ideal AVCS approach for trucking terminals would employ AGVs (either a modified tractor or a dedicated platform) for trailer and/or container movement. An AGV would address many of the needs mentioned by the operators and AGVs have already been proven in operating terminals. Terminals would not have to implement AGVs and eliminate drivers all at once in order to gain benefits. AGVs and manned vehicles could be used together to increase the productivity of the terminal. Because the AGV represents a likely cornerstone for automating terminal movement in the future, a short discussion of AGV systems is provided below. The remainder of the section is devoted to a description of enabling technologies for AGVs.

AGVs: Automated Guided Vehicles

As described above, AGVs are driverless vehicles that transport material along a predetermined route through a work area. An AGV system includes:

- Vehicle.
- Navigation system.
- Traffic management system.
- Obstacle detection system.

The vehicle may either be a modified conventional vehicle or a newly designed vehicle. The navigation system allows the vehicle to determine its location and follow a path to its destination. A traffic management system is particularly critical to multi-vehicle AGV deployment: it determines where each vehicle needs to be, sends commands to vehicles, and ensures that conflicts are avoided. Even in a highly structured environment, the possibility for accidents exists. An obstacle detection system provides reassurance against accidents by detecting any objects in the AGV's path prior to impact and bringing the vehicle safely to a stop.

There are many benefits to deploying an AGV system (table 2). An AGV can help increase the efficiency of a terminal by augmenting the current fleet of manned vehicles, operating on extended schedules, or better utilizing personnel currently used for routine operations. In a port facility, ship turnaround time could be decreased, thus saving mooring fees for the shipping line. Lost and damaged cargo due to operator fatigue would also decrease. Maintenance costs are reduced because AGVs only require normal preventive maintenance, which would likely be less than current costs because the computer-controlled vehicles accelerate, stop, and steer in a consistent and controlled manner. Clearly, labor costs are reduced with AGV use because AGVs work around the clock without overtime pay, coffee breaks, or benefits. Container inventory is tracked more accurately because a computer knows precisely where each AGV places the container it is carrying at any given time. Safety can be improved because fewer people will be in areas where heavy cargo is being moved. Overall, AGVs provide a way in which freight terminal facilities can increase their efficiency, decrease overall costs, and become more competitive.[9,11]

Table 2. Benefits of AGVs

• **Increase efficiency**
• **Decrease turnaround time**
• **Decrease lost cargo**
• **Decrease damaged cargo**
• **Reduce maintenance costs**
• **Reduce labor costs**
• **Improve safety**
• **Better inventory tracking**

Navigation Systems

One of the keys to a successful AVCS is an accurate and reliable navigation system. Many methods of navigation exist for vehicles. Each has its trade-offs between cost, accuracy, flexibility, and performance in all weather conditions (table 3). Well-established guidance methods, such as guide path following, as well as systems that are still in development and testing, such as DGPS, are shown in the table below. Several of these methods were described in the accompanying study of transit bus automation and will not be repeated here. Those techniques not already described will be briefly explained.

Grid-Based Systems

A system called Free Ranging On Grid (FROG), developed by Frog Systems of the Netherlands, gives vehicles more freedom to move throughout an area than guidepath systems allow. The FROG system consists of a ground-based grid with transponders at each node that transmit "labels" containing unique identification and position data. The vehicle detects the signals from the transponder and uses the position information to update its dead-reckoned location in real time.

Rotterdam decided to use the FROG system after determining that wire guidance systems were not flexible enough and would require too many wires in the ground. During 1988-1989, when the navigation system decision was made, other technologies, such as laser or GPS, did not provide the accuracy required to meet the needs of the AGV system. In the Rotterdam terminal, fiber-optic lines are buried in a grid 20 cm below the surface. About 4,000 transponders are located throughout the facility. The FROG system is also designed to prevent collisions via commands communicated to the vehicles through the grid network. Positional accuracy of ± 3 cm can be achieved with this system.[2,6]

The primary drawback to the grid system is the transponder installation. At Rotterdam, this was not a serious problem for two reasons: (1) the system was installed during facility construction; and (2) the pavement surface is brick, which provides a dimensionally stable surface for embedding the transponders.[14]

Table 3. Advantages and Disadvantages of Navigation Systems[6]

Navigation System	Advantages	Disadvantages
Wire Guidance Systems	• Widely deployed • Reliable • Effective in all weather • Inexpensive	• Inflexibility • Expensive to repair • Disruptive to install • Vulnerable to magnetic interference
Magnetic Systems	• Reliable • Effective in all weather	• Inflexible • Vulnerable to magnetic interference • Could cause pavement problems
Free Range On Grid	• Deployed in Rotterdam • Flexible • Accuracy of ± 3 cm	• Disruptive to install • Transponders may shift in hot asphalt
Laser Guidance	• Low infrastructure cost • Flexible • Limited false reflections • Accurate	• Long set-up time • Large number of reflectors • Affected by adverse weather
Millimeter Wave Radar	• Not affected by clutter • Accurate in all weather • Able to make long-range measurements • Accuracy of ± 10 cm	• Long set-up time • Large number of reflectors • Expensive to procure
Differential GPS	• Accuracy of ± 5 cm • Low cost installation • Few modifications to area • Not affected by weather	• Can lose satellite signal • Has not yet been used on AGV

Millimeter Wave Radar

Similar to laser guidance systems, a rotating Millimeter Wave Radar (MMWR) (figure 7) detects the presence of beacons at known locations to determine the vehicle's position. The beacon observations are then processed to constantly update the vehicle's position. The Terberg AGV, deployed at Thamesport, used an MMWR for its guidance system. A total of 150 beacons were placed throughout the operation area at intervals of about 200 m. Typically, at least three beacons were within view of the AGV at any time to ensure navigational accuracy. During the AGV trials, the processing of the navigation system information was rarely a source of failure, indicating the high reliability of such a system. The position accuracy of the MMWR is about 20 cm, which can be increased to about 10 cm with a "super-resolution" algorithm.[4]

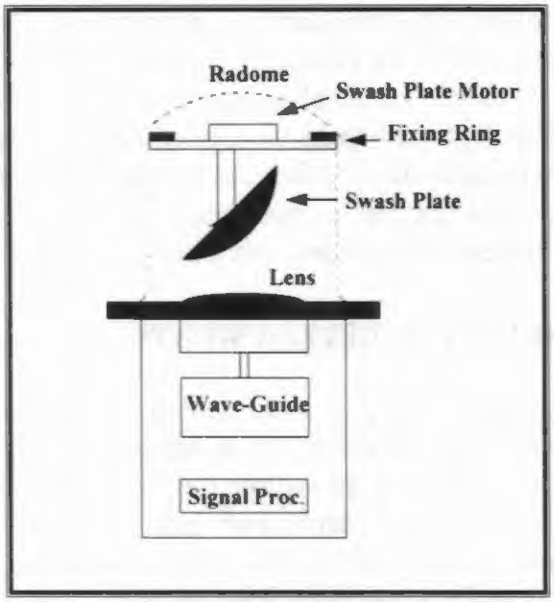

Figure 7. Millimeter Wave Radar[4]

By using an MMWR with a narrow beamwidth and short wavelength, the problem with clutter within the port is reduced. MMWR is accurate in all weather conditions and has the ability to make long-range measurements. As with laser systems, the disadvantage of MMWR is the number of beacons that must be placed throughout the facility. Current MMWR systems are difficult and expensive to procure, although the prices are beginning to decrease as development and deployment continue.[4,6]

INSTITUTIONAL ISSUES

While the research performed in this study suggests that opportunities exist for AVCS in terminals, there are various institutional issues that will make deployment a challenge in this country. The major concerns expressed by terminal and fleet operators are actually age-old ones: fear of new technology and labor issues associated with implementing automated systems. These issues have emerged in virtually every industry over the last 100 years or more. While there appears to be some acceptance of new technologies in the CVO area, there is also reluctance to invest in systems that will cause a major disruption in operations without an acceptable, proven return on the investment. Unfortunately, there is a lack of information on the proven benefits that AVCS can provide specifically for commercial vehicle operations.

A major area of resistance in U.S. ports is the labor unions. A possible solution to removing this resistance is to show that AGVs do not have to replace all drivers or leave them unemployed. AGVs can complement existing vehicles at the facility so productivity increases and containers move through the facility at a higher rate, thus increasing profit. In addition, drivers who are replaced by AGVs can help increase throughput elsewhere in the facility or they can learn to operate or manage the AGV fleet. For instance, in Rotterdam, labor unions were directly involved from the beginning of the planning process, helping to shape the automated operations and learning new roles to manage the equipment.

The fear of unproven technology is another common concern expressed by terminal and port operators. From their perspective, AGVs are extremely expensive to deploy, disruptive (at least initially), and generally foreign to them. Terminal operators want to see the costs and benefits of such systems demonstrated before deploying them. A limited field test would be a way to show operators the benefits of an automated system. American terminal and fleet managers might be much more influenced by the apparent success of the Rotterdam AGV system if it were installed in an existing U.S. port facility instead of in a European facility custom-built for AGVs.

RECOMMENDATIONS FOR FUTURE DEPLOYMENTS

Through discussions with terminal operators and research on AVCS technologies, it appears that a limited field test with the most potential for further deployment would incorporate an AGV into terminal operations. Such a test would demonstrate the feasibility and benefits of using AVCS within a U.S. terminal. The vehicle(s) deployed would be completely automated and could supplement the existing manned operations. Two alternative deployment schemes are possible, each of which will be described in greater detail below:

- Convert a tractor to an automated vehicle by adding the necessary controls and hardware. This would be deployed for a land terminal.
- Deploy an existing or slightly modified AGV. This would be deployed for a container port.

Modified Tractor/Truck

From conversations with terminal operators, the most AVCS interest lies in the movement of trailers within the terminal, such as staging or valet parking. This involves using a tractor to pull trailers from one area of the yard to another. The strongest support for the deployment of AVCS came from inland terminal operators where much of the cargo is loaded onto trailers.

An existing tractor (figure 8) could be modified for automation since most use automatic transmission and electronic controls. According to at least one AGV manufacturer, the process required to modify an existing truck could be performed by an experienced AGV firm.[8,16]

A navigation system could be installed in the truck fairly easily. While carrier-phase DGPS is a fairly new technology, several AGV developers believe it would be the navigation system of choice for terminal operations because of its accuracy and robustness for outdoor operations.[16] Prior to deployment of an AGV using DGPS, tests would have to be conducted to confirm system accuracy. An inertial guidance system would be installed on each AGV as well for redundancy. The only infrastructure requirement would be the installation of a second GPS receiver somewhere within the terminal area. Various alternative navigation systems could also be deployed.

For collision avoidance, any of the ranging systems discussed are options. Reportedly, the most accurate, reliable, and cost-effective system would use a pulsed laser beacon to detect objects in the roadway. Electronic bumpers would also be used for very close proximity objects.

A new traffic management system would not have to be designed—current systems are generally based on vehicle position updates, which DGPS and inertial navigation would provide.[15,16]

Figure 8. Yard Tractor

Depending on the level of deployment, an automated tractor could also provide some of the other functions described previously. For example, an automated tractor would provide for better inventory control as it would notify the central control computer of the location and identification number of every trailer pick-up and drop-off in the yard. Movement of trailers through maintenance areas could also be automated, as could trailer backing operations.

AGV for Container Movement

An AGV that carries containers (figure 9) would provide the greatest benefit in locations such as intermodal port facilities where most containers are not on trailers, but are moved via crane from ship to stack to rail or truck. This type of field test would be similar to the Rotterdam AGV deployment. Guidance technologies and vehicle capabilities would be essentially the same for both the container mover and the trailer mover just described.

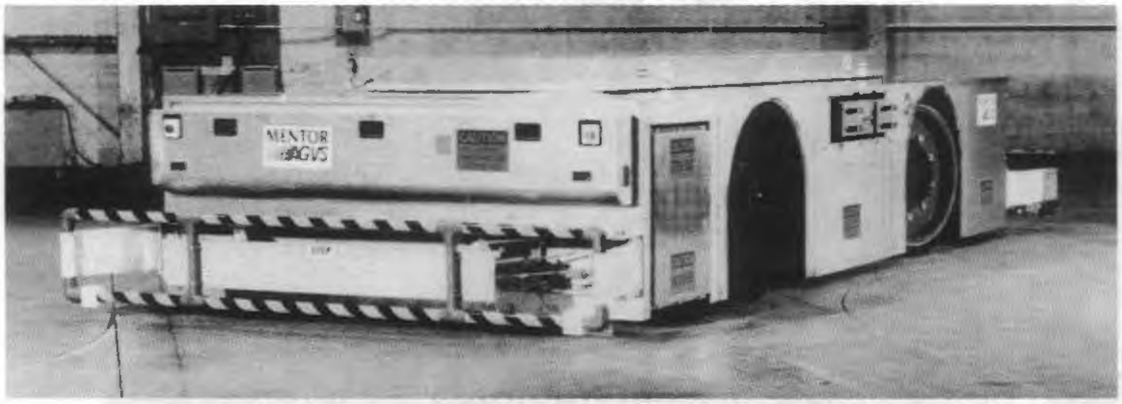

Figure 9. Dedicated AGV

CONCLUSIONS

As is often the case for the implementation of new technology, the technology itself is not the limiting issue. Quite often questions of cost-effectiveness and institutional impacts dominate the decision-making process. Highlighting the significance of these issues, one freight operator stated that while the AVCS/automation concept is desirable, the potential cost savings are small relative to the company's overall operational budget and could easily be outweighed by the alienation of the existing labor force.

The next steps for further study include detailed analysis of various terminal operations. This study should include monitoring of the physical movement of the trailers and tractors within the terminal, the job functions associated with those movements, and the economics of the operation. In addition to a detailed operational analysis, a deeper examination of the institutional barriers to deployment should be conducted. Potential team members will need to be firmly established, along with more rigorous estimates of deployment costs and cost-sharing strategies. Specific deployment alternatives will be considered. The results of the analysis should indicate overall costs and benefit/cost ratios for different levels of automation applied to various operations. That data, together with institutional considerations, will guide the decision of what type of system to deploy for a pilot test and where to deploy it.

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