Precursor Systems Analyses of Automated Highway Systems

RESOURCE MATERIALS

Commercial and Transit Aspects

U.S. Department of Transportation
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FOREWORD

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

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

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

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

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

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16. Abstract
The Automated Highway System (Al-ISI program component of the Intelligent Transportation Systems (ITS) Is a broad national effort to provide the basis for, and transition to, the next major performance upgrade of the U.S. vehlcle(hlghway system. through the use of automated vehicle control technology. As part of the Analysis Phase. the Precursor Systems Analysis (PSA) was performed to identify Issues and risks associated with AHS . This report addressed part of activity Area "F" for Commercial and Transit aspect. In Activity Area "F" Commercial Motor Carriers and Transit Aspects of AHS , many areas were researched Including: European mechanical/electronic guided bus state of the art technology summarization, motor carrier market segmentation by specific AHS Cluster Map descriptions. Dual Mode Transit prototypical applications for Al-IS. and right-of-way needs for Meter Carrier Transit vehicles at statlons'malnilne locations. There Is a correlation between the extent of standardizalion on the one hand and complexity of the AHS on the other. The morn the characteristics of vehicles are subjected to rules and standardized. the less the expenditure for integrating an AHS Into vehicles and guiding them automatically. The AHS Commercial Motor Carrier AHS Cluster Map allows for combinations of vehicle action controllers (vehicle vs. guideway Carrier segment being studied. The recommended concept is to allow AHS Transit to be developed on a parallel path. while. at the same time. ensuring mat Its technology development program be a subset of the larger AHS research effort. To help distribute the construction. Operations costs of a possible Dual mode AHS so" Transit (which functions heavily in the AM/PM rush hours) would be by providing possible elf-peak AHS Commercial Motor Carrier vehicle usage on a schedule. If major high speed segments of the AHS network could be provided which guarantee high performance operations. with the cost of those segments borne by budgets beyond the transit sector, significant cost savings could result compared with presently available technology.

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Preface

This Commercial and Transit (C&T) aspects for the Automated Highway System (AHS) report is a summary of current literature, European automated transit state of the art summary, special analysis of motor carrier sector needs, future research needs, summarization of the AHS context of legislative/regulatory/institutional issues, and a protypical AHS Transit scenario.

The project is one of 15 PSA research contracts totaling $14.1 million from Federal Highway Administration (FHWA) to investigate the issues and risks related to the design, development, and implementation of AHS . The AHS program is part of the major initiative of the US Department of Transportation (USDOT) in the intelligent Transportation Systems (ITS), or as it was previously known as intelligent Vehicle-Highway Systems (IVHS). The 15 PSA contracts involving a total of 69 contractors focused upon 16 activity areas that were defined in the original November 1992 Broad Agency Announcement. The C&T Activity Area "F" included this research area presented in this report.

This C&T report was sponsored by the USDOT and the FHWA. The BDM Federal, Inc. Team under contract to FHWA had the responsibility of processing and analyzing the data, preparing the reports, and coordinating the presentations at the Interim Results Workshop and the Final Results Workshop. The BDM Federal, Inc. C&T Team also consisted of Cambridge Systematics, inc.; Matthew Coogan - Consultant; Studiengesellschaft Verkehr MBH (SNV) Germany; and Sverdrup Civil, Inc.

CHAPTER 1: INTRODUCTION

The Automated Highway System (AHS) program component of the Intelligent Transportation Systems (ITS), formerly known as Intelligent Vehicle Highway Systems (IVHS), Is a broad national effort to provide the basis for, and transition to, the next major performance upgrade of the U.S. vehicle/highway system, through the use of automated vehicle control technology. The long range goal is to significantly improve the safety and efficiency of the nation's surface transportation system through a national effort that best ensures the early, successful deployment of AHS . As part of the Analyses Phase[1] the Precursor Systems Analyses (PSA) are being performed to identify issues and risks associated with AHS .

1.1 DESCRIPTION OF C&T ACTIVITY AREA

In Activity Area “F”., Commercial and Transit AHS Analysis, a number of technical evaluations were studied, ranging from guideway right-of-way requirements, market needs determination, shared/separate guideway issue identification, and comparisons of U.S. and European automated system technologies. Theoretical right-of-way design requirements based upon research into vehicles and guideways were provided. Using the geometric characteristics of the transit guideway, the option of totally separate rights-of-way and optional physical time shared management of common rights-of-way were evaluated. In this geometric and functional study, the concept of platooning was explored.

1.2 PURPOSE AND OBJECTIVES

This report documents the findings of the analysis of AHS Commercial and Transit Aspects. This section identifies the purposes and objectives of the precursor level of analysis for commercial truck motor carriers and transit bus operators. Defining trucking industry regulators constraints, documenting European automatic bus technology summarization, and creating a prototypical AHS Dual mode Bus concept are the primary objectives of this study.

1.2.1 Purpose

The purpose of the motor carrier industry aspects portion of the study were as follows:

- Identify the needs of the industry, given its past experience with new technology, industry trends, and available AHS motor carrier market through topology/market segmentation.

- Develop a method of identifying the parts of AHS operations that uniquely defined motor carrier trends and relationships.

- Define the best approach, applicability, and benefits of AHS to motor carrier operations.

For the Transit industry, several aspects of research and prototype development were the defined purposes of this study:

- Research the existing and past technology for advanced bus concepts and define its applicability for AHS 'Transit.
- Develop a prototypical intermodal corridor using technologies like the Dual Mode Bus for a hypothetical AHS application.
- Prepare an exclusive research analysis on the state-of-the-art in advanced European bus technology, looking at electronically and mechanically guided bus systems.

1.2.2 Objective

The report's objective is to present the key issues relating to the implementation of AHS in the commercial motor carrier and transit industries. Each industry has its unique set of needs, regulations, design restrictions, and funding sources. The relation between private, public, and joint public/private issues for these groups is a combined objective for the study.

The commercial motor carriers objectives relate to defining its industry's unique needs and redefining the standard AHS Representative System Configurations (RSOs) into a more correctly delineated AHS truck type duster mapping. Then the definition of what portions of AHS could become applicable technological potentials for successful deployment can better be identified.

The transit objectives in this study focus on researching past advanced technologies and identifying "lessons learned." The European and Dual Mode 'Transit Bus experiences are used to help identify a potential successful U.S. implementation system for AHS deployment

1.3 DEFINITION OF GENERAL MOTOR CARRIER ISSUES

'The issues of AHS applicability in the motor carrier industry are governed by its truck vehicle composition, public/private ownership, market service area, and local/state/federal regulatory requirements. The private auto and transit vehicle market do not have these complex operating characteristics. A dear delineation of the size and needs of these truck segmentations are required to more accurately determine what AHS RSCs or Clusters might potentially work.

1.3.1 Motor carrier Industry Overview

If all trucks were large 1 8-wheel, tractor-semitrailers operating long haul from coast-to-coast, defining the needs of the motor carrier industry for automated highways would be relatively straightforward. In tact, the motor carrier industry is highly fragmented, reflecting the varying needs of the thousands of industries that are served by trucking. ft is often said that the only thing motor carriers share in common are rubber tires and the taxes they pay to the government. 'To understand how the industry might use automated highways, it is necessary to understand the trucking industry's operations and needs.

A total of 44.6 million trucks are registered in the United States; however, about 41 million of these, or about 92 percent of the fleet, are pickup trucks, panel trucks, minivans, and similar light trucks, many of which are used for personal transportation.(1) For traffic and congestion management purposes, these light trucks are indistinguishable from automobiles and are seldom counted as trucks. Light trucks will not be included in this analysis under the assumption that the AHS market for light trucks will be very similar to the AHS markets for personal and commercial fleet automobiles.

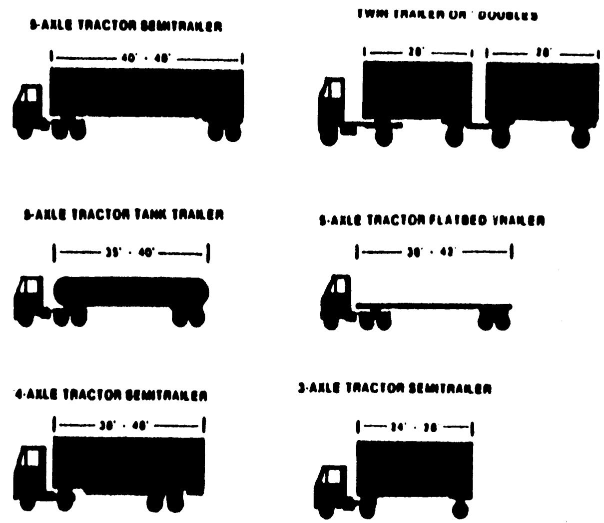
The balance of the U.S. fleet approximately 3.6 million vehicles or about 8 percent of all trucks, are medium and heavy trucks, ranging from 4,540 kg (10,000 lb) local delivery trucks with 2 axles and 6 tires, to large, 36,320 kg (80,000 lb), over-the-road tractor semi-trailers with 5 axles and 18 tires. ('The size classes used to categorize trucks as light, medium, or heavy are described in figure 1.) About 400,000 of these trucks are oft-road construction vehicles, daily rental vehicles, and trucks used for personal transportation. 'The remaining 3.2 million large trucks constitute the primary potential motor carrier market for AHS services.

'These large trucks (classes 3 through 8) are the primary focus of this analysis. 'They are significantly different from automobiles and light trucks because of their size, weight, and handling characteristics; the types of roads that they can use; and the business and safety regulations governing their use. More important, they account for most truck-miles of travel. As a group they are thought to account for over three-quarters of all truck-miles of travel and most of the ton-miles and revenue-miles of travel in urban areas.(2)

'These trucks are owned and operated in 870,000 fleets; however, the vast majority of these fleets are small most are under 50 trucks and many are under 5 trucks. It is estimated that only 4,000 out of the 870,000 fleets have more than 50 trucks. Although they do not account for many trucks, these larger fleets dominate the industry. ft is estimated that the 2,000 largest motor carrier firms account for 80 percent of total industry revenues. 'This pattern of ownership and operation -- a few large fleets generating most of the industry revenues, and many small fleets operating most of the trucks -- is very different from the pattern of ownership and operation of automobiles and light trucks, and will strongly influence the market for AHS services within the trucking industry.

About *80* percent of the trucks in the analysis, are in private fleets owned and operated by a company to move its own products. Included in this group are trucks employed in local distribution activities, such as delivering gasoline to service stations, restocking supermarket shelves, and delivering retail goods to community' stores and shopping mails. Other private trucks are employed in long-haul transportation, which typically involves moving processed foods and manufactured products between company manufacturing plants and warehouses. The remaining 20 percent of the trucks in this study are operated by for-hire motor carriers, providing common or contract carriage of freight and goods for other firms, usually manufacturers and retailers.

Size Class	Weight Class	Gross Vehicle Weight (lbs)	Axles/Tires	Examples
Heavy-Heavy	8	>33,000	7/22+ 6/18+ 5/18	Multi-trailer trucks Tractor-semitrailers and doubles
			4/14 3/10	Concrete mixers and dump trucks
Heavy	7	26,000 - 33,000	3/10	City tractor with 28-foot pup trailer
Light-Heavy	6	19,500 - 26,000	2/6	Beverage truck Home heating fuel truck
	5	16,000 - 19,500	2/6	Stake truck
	4	14,000 - 16,000	2/6	Flat bed
Medium	3	10,000 - 14,000	2/6	Metro van (UPS)
	2	6,000 - 10,000	2/4	Step van (Mail)
Light	1	<6,000	2/4	Pickup truck, Van



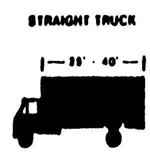


Figure 1. Truck Size Class Categories

CHAPTER 2: COMMERCIAL AND 'TRANSIT AHS DEVELOPMENT IN THE CONTEXT OF LEGISLATIVE REGULATORY AND INSTITUTIONAL SETTINGS

2.1 POLICY DEVELOPMENTS IN ISTEA

The AHS program is being developed as one aspect of the larger mandate of the Intermodal Surface 'Transportation Efficiency Act (IS'TEA) of 19911 a landmark piece of legislation with far reaching policy implications. This section of the Commercial and 'Transit Report reviews certain key policies and mechanisms called for in that legislation which could have an impact on the development and deployment of a national AHS program, with particular reference to those policies issues relevant to the development of Commercial and 'Transit aspects of the program.

2.1.1 New Emphasis on Freight Concerns

A major direction brought about by IS'TEA is the mandate to incorporate freight planning into the established surface transportation planning process. At the metropolitan level, Section 1024 of IS'TEA modifies the established transportation planning process in several ways, including the requirement that metropolitan planning incorporate 15 factors, which specifically include:

- Methods to enhance the efficiency of freight
- International border crossings and access to ports, airports, intermodal transportation facilities, major freight distribution routes, national parks, recreation areas, monuments, historic sites and military installations.

At the statewide level, the law calls for a new requirement of a statewide planning process, which makes reference to 20 factors, which include:

- International border crossings and access to ports, airports, intermodal transportation facilities, major distribution routes.
- Methods to enhance the efficiency of commercial motor vehicles.

2.1.2 New Emphases on Non-SOV Solutions

Because the implementation of an AHS system could result in a major increase in the capacity of a roadway, it is important to review the general policy orientation of ISTEA towards the construction of general purpose roadways. Section 450.320 (b) of the State and Metropolitan planning regulations state:

> “In 'TMA's designated as non-attainment for ozone or carbon dioxide, Federal funds may not be programmed for any project that will result in a significant increase in carrying capacity for single occupant vehicle (a new general purpose highway on a new location, or adding general purpose lanes, with the

exception of safety improvements or the elimination of bottlenecks) unless the project results from congestion management system ~

New special purpose capacity, such as the creation of an High Occupancy Vehicle (HOV) lane$_1$ or a truck-only highway are specifically not included in this category. However, the creation of such a facility' would most probably be integrally interrelated with the development of the Congestion Management System (OMS) and the Intermodal Management System (IMS). 'The following sections of this chapter review the role of these Management Systems in the ISTEA planning process.

2.2 THE CONGESTION MANAGEMENT SYSTEM

ISTEA calls for the preparation by the states of six "management systems" and a program of traffic monitoring. Those systems cover pavements, bridges, safety public transportation facilities and equipment, traffic congestion and intermodal transportation facilities. The management Systems are seen by US Department of Transportation (USDOT) as a strategic approach to meet the objective of operating the existing system better, and to plan for its future. In each of these systems the emphasis is on performance operations and maintenance. This chapter will briefly review the nature of these two management systems, and examine the implications of the Environmental Protection Agency's (EPA[1]B) General Conformance rules on the implementation of major investment, such as a possible AHS system.

The joint planning regulations of Federal Highway Administration (FHWA) and Federal 'Transit Administration (FTA) provides the following definition of Management Systems:

> “A management system is a systematic process, designed to assist decision makers in selecting cost effective strategies/actions to improve the efficiency and safety of and to protect the investment in, the nation's infrastructure
>
> Under these regulations each state must develop a CMS that:
>
> "...results in the identification and implementation of strategies that provide the most efficient use of existing and future transportation facilities in all areas of state, where congestion is occurring or is expected to occur. In both metropolitan and non metropolitan areas consideration shall be give to strategies that reduce single-occupant vehicle (SOV) travel and improve existing transportation system efficiency. Where the addition of general purpose lanes is determined to be an appropriate strategy, explicit consideration shall be give to the incorporation of appropriate features Into the SOV project to facilitate future demand management and operational improvement strategies to maintain the function integrity of those lanes.[(5)]

Importantly the strategies to deal with the phenomenon of increased highway capacity are not limited to the boundaries of the facility' itself. Once a decision has been made to include a highway which expands capacity, the OMS program is expected to provide for programs throughout the corridor in which the new facility' is located.

> "'The CMS shall provide an appropriate analysis of all reasonable (including multimodal) travel demand reduction and operational management strategies for the corridor in which a project that will result in a significant increase in capacity for SOVs (adding general purpose lanes to an existing highway or constructing a new highway) is proposed."

The regulations provide a dear mandate for the scale of 'mitigation' activities proposed in cases of additional general purpose highway capacity, as they call for the incorporation of "all identified reasonable travel demand and operational strategies" into the affected transportation corridor.

> "If the analysis demonstrates that travel demand reduction and operational management strategies cannot fully satisfy the need for additional capacity in the corridor and additional SOV capacity is warranted, then the CMS shall identify all reasonable strategies to manage the SOV facility' effectively (or to facilitate is management in the future.) Other travel demand reduction and operational management strategies appropriate for the corridor, but not appropriate for incorporation into the SOV facility' itself shall be identified through the CMS. As required by 23 CFR 450.320(b) *all identified reasonable travel demand reduction and operational management strategies shall be incorporated into the SOV Project or committed by the State and MPO1 for implementation.*[(6)]

The scope of strategies goes beyond many traditional definitions of transportation policies, and deals with the relationship between transportation and land use planning considerations. One FHWA official writes that the CMS “is important because of a legal mandate and increasing skepticism concerning the addition of a capacity to alleviate congestion and enhance mobility'." Brian Hoeft writes "Much of today's congestion is attributable to the lack of an integrated transportation system -the multimodal and land development aspects - and the continuing preference of travelers to drive alone.”[(7)] To many critics, the IVHS program, and the AHS concept in particular, may involve capacity and travel speed changes which could conceivably affect both the multimodal (i.e. the effect on transit) and land development aspect (i.e. increased trip distance) of the total system.

The legislation in specific concerning the range of strategies that is supposed to be considered within a CMS. The regs state that a CMS is "systematic process of identifying and implementing strategies that provide the most efficient use of existing and future facilities in all areas of a State where congestion is occurring or expected to occur." The CMS calls for "considering strategies that reduce single occupant vehicle travel and improve existing transportation system efficiency." Such strategies include:

- Transportation Demand Management.
- Traffic Operation Improvement.
- High Occupancy Vehicles.
- Public 'Transit Capital and Operation Improvements.

- Nontraditional Modes (e.g., bicycles and pedestrian facilities).
- Congestion Pricing.
- Growth Management and Activity Center Strategies.
- Access Management Techniques.
- Incident Management.
- Intelligent Vehicle-Highway System 'Technologies.
- Addition of General Purpose Lanes.

2.2.1 **IMPLICATIONS of the CMS for Advanced FREIGHT Technology**

According to the regulations, the CMS is “a systematic process that provides information on transportation system performance and alternative strategies to alleviate congestion and *enhance* the mobility *of people* and goods". Given that the OMS calls for the evaluation of projects and Systems In terms of their ability to "enhance the mobility of people and goods,” the mandate of the legislation is dear; the movement of goods is to receive attention similar to (or .equal to) the movement of persons. Thus, the candidate AHS project - just like very other project in the system--will be examined for its contribution to the improvement of the flow of goods. Any early deployment of the concept which fails to incorporate freight elements would be at a significant disadvantage for processing through the CMS process.

The congestion management system is the mechanism for the analysis of the possible role of additional highway capacity in the region. ft should be noted, however, that the legislative mandate is not against all capacity, but rather single auto occupant capacity. Thus, either an exclusive byway or an exclusive truck road could be built without such policy restriction. The dear policy thrust here calls for an incorporation of freight considerations into every project that is developed. From the beginning of the concept, Incorporation of freight needs into the design of an AHS system would seem to be essential for the deployment of the technology within the context of the required CMS procedures.

2.2.2 IMPLICATIONS of the CMS for Advanced Transit Technology

ISTEA's policy limitation on the creation of new general purpose highway capacity outside of the context of a program to discourage SOV travel has major impacts on the development of the AHS program, and its need to incorporate both HOV and public transit elements from the outset of the program. Once the case for new lanes which would accommodate SOVs has been established, the CMS procedures call first for the incorporation of "all reasonable strategies to manage the SOV facility effectively (or to facilitate it's management in the future.") Thus$_1$ before the examination of on-facility strategies to discourage SOV travel (such as carpooling, variable work hours, etc) the facility' Itself is to incorporate elements which are consistent with the lS'TEA policy towards SOV demand management. If, for some reason, early AHS deployment falls to include a vigorous program of higher-occupancy vehicle encouragement, the conflict with the legislative mandate revealed in the CMS could have highly negative consequences for the possibility of later deployment which did include such strategies.

2.3 THE INTERMODAL MANAGEMENT SYSTEM

The regulations define the Intermodal Management System (IMS) as a "systematic process which:

- Identifies key linkages between one or more modes of transportation where the performance of use of one mode will affect another.
- Defines strategies for improving the effectiveness of these modal interactions.
- Evaluates and implements these strategies."

Under the ISTEA planning regulations:

> "Each state shall develop, establish and implement, on a continuing basis, an IMS that provides efficient, safe and convenient movement of people and goods through integration of Transportation facilities and Systems and that improves the coordination in planning and implementation of air, water, and the various land based facilities; and systems. [(8)]

The regulations focus policy attention on "intermodal facilities" which refers to:

> "A transportation element that accommodates and interconnects different modes of transportation and serves intrastate, interstate, and international movement of people and goods. Intermodal facilities include, but are not limited to, highway elements providing terminal access, coastal, inland and Great Lake ports, canals, pipeline fans, airports, marine and/or rail terminals, major track terminals, transit terminals including park and ride facilities, and intercity bus terminals.[(9)]

When reviewing the concept of Intermodal transportation for its impact on the need to develop new transportation technology, it is worthwhile to go beyond the issue of the actual points of interconnection and their operation. Summarizing the results of 'TRB's first conference on ISTEA and Intermodalism, Prot Michael Meyer wrote:

> "In intermodal planning, key interactions between modes, including not only transfers but also the policy and service interactions between alternative modes, are identified. An intermodal transportation system should be viewed from the perspective of the total trip. Therefore, not only are the points of interconnection between modes important, but so too are the links that connect these points.[(10)]

The IMS, then, draws policy attention not only to the points of transfer (and their internal operations) but also to the quality of the mobility created by the sum of the separate segments of the total trip. ft is in this context that IVHS technologies in general, and AHS technology is specific may play their most robust role in the development and implementation of IMS strategies. The next two sections develop this theme, first in terms of freight movement, and second in terms of passenger movement.

2.3.1 IMPLICATIONS of the IMS for Advanced FREIGHT Technology

The movement of goods in a state or metropolitan area is addressed both in the CMS and in the IMS. However, it can be argued that the CMS tends to examine the quality of this service largely as a subset of the larger issue of level of congestion, and the development of strategies to decrease that congestion. The IMS, on the other hand, is tasked with the evaluation of the quality of the flow of goods, to be examined through the application of performance measurement which goes far beyond the question of roadway congestion. Professor Meyer writes that "IMS focuses on the intermodal movement of people and goods. However, transportation planning has not had a long record of successfully dealing with goods movement of either a technical or a process perspective. IMS now places greater emphasis on these issues. [(11)] To many, this may seem like an understatement, as it can be argued that freight concerns have been functionally excluded from the planning process. For many states, it is the necessity of creating an IMS that is bringing representatives of the freight industry back to the table.

Thus, the IMS calls attention to the quality of freight service, and pointing attention both to those points of interconnection in the system, including (truck distribution facilities, ports, airports) and quality of the performance of the full system. Performance measures included total travel time (door to door), time spent in transfer, and time spent in congestion oriented delay. A decade ago, these were not considerations in the analysis of expenditure of Federal transportation dollars. 'Today under the terms of the IMS, they are factors in project evaluation.

The IMS calls for the monitoring and evaluation of the quality of freight flow, as part of larger policy orientation to incorporate freight concerns into the transportation planning process. ft would seem essential that the national AHS program develop in a manner consistent with this very dear policy direction from the enabling legislation. As will be discussed later in this report, there are several valid paths to the implementation of a fully developed AHS system for commercial vehicles. As the early steps of AHS deployment are taken, the IMS process will be used to evaluate these policies and projects for their consistent with freight-oriented objectives.

2.3.2 Implications of the IMS for Advanced Transit Technology

The Intermodal Management System calls for the monitoring and evaluation of the quality' of non-SOV connections to major modal facilities, such as airports seaports and intermodal passenger terminals. 'The argument can be made that these locations are good candidates for the kind of higher quality' transit services that AHS Transit would be able to provide. The IMS should help to monitor the kinds of trends that are happening now, such the trend towards demand-activated services at airports. Section Five of this report will note that major components of a total IVHS strategy are now being implemented at major airports including Automatic Vehicle Identifications Systems and Advanced Passenger Information systems.

At present, the search for intermodal solutions for passengers is greatly influenced by intermodal solutions which have found successful application in the freight sector. Looking at this metaphor, the freight package is carried over several modes (say, truck to ship to rail to truck) under one information and control system. Applying this metaphor to transit suggests the need to interconnect various modal segments of the trip in as "seamless" a manner as possible. It can be argued that this is exactly what AHS Transit could be designed to do. In this concept, one single vehicle could play the role of the collector bus, the line-haul train, and the downtown distributor. Consistent with the concepts discussed above, this mode has been designed to maximize the efficiency of "the total trip," the result of applying the principles of intermodal planning, (even though the passenger did not need to transfer between modes.) The IMS process is designed to encourage this inclusionary view of planing, whether applied to an international container, or a local commuter.

2.4 THE ROLE OF THE CLEAN AIR ACT'S CONFORMITY REGULATIONS

In November of 1993, the EPA issued new Conformity Regulations which govern the manner in which a given transportation investment, whether funded by traditional surface transportation sources such as FHWA and FTA (the 'Transportation Conformity' Regulations), or by other sources, including FAA, FRA and MARAD funds (the General Conformity Regulations). 'These Regulations establish the process for determining if a given proposed investment can be found to be in conformity' with the established State Implementation Plan, created under the terms of the Clean Air Act Amendments of 1990.

With the publication of the new regulations, EPA clarified that the owners of facilities covered under the "General" conformity' regulations would indeed have to follow the procedures already established under the "'Transportation" regulations, concerning the indirect emissions caused by a project outside of the boundaries of that project. As the final rulemaking notes, "the general conformity' rule covers all other Federal actions, including those associated with railroads, airports, and ports." Importantly for the study of new transport technologies, EPA has made it dear that the general conformity' rule will cover the indirect emissions caused by vehicles coming to and going from the new facility. In their preamble to the General Conformity' Regulations, EPA noted:

> "Congress dearly intended the transportation conformity rule to cover the indirect emissions from vehicles that would travel *to and on* highways constructed with Federal support. 'Thus, the conformity review does not focus on emissions associated with only the construction of the highway project, but includes emissions from vehicles that later travel *to and on* that highway. The general conformity rule originates from the same statutory language and so must meet the same congressional intent... As described above, the *transportation treatment provisions of the* Act *clearly require consideration of indirect emissions. Therefore, EPA concludes that the general conformity rule must also cover indirect emissions.*[12]

This clarification has considerable impact on the study of access to intermodal facilities, and the potential role of advanced transportation technologies in providing that access. 'The regulation establishes that when an airport or seaport manager intends to spend federal funds on a project within the boundaries of his/her facility, the air emissions impacts experienced off of the facility must be documented to the standards required by the managers of the State Implementation Plan. In short, this means that the owners of major facilities, such as airports must become involved in the issue of HOV and other transit access to those facilities. In Section Five of this report, a case study is presented which illustrates the potential role of AHS technology is such as airport ground access strategy.

2.4.1 Policy IMPLICATIONS of New Conformance RegulatIons

Like other regulations issued in association with ISTEA/CIean Air Ac' Amendments (CAM), the two conformity regulations, ('Transportation and General) call upon decision makers to deal proactively with the consequences of their operations and investments. The early applications of the AHS program, when deployed, will have to be processed through these regulations, as they are refined over time. 'The regulations make it even more dear that the deployment of AHS projects will have to be accomplished --at least in areas of non-attainment- within the context of an overall State Implementation Plan (SIP), and within the goals of overall Clean Air Act polices. From a methodological point of view, this ensures that the candidate AHS project will be evaluated in terms of its overall impact on trip making, vehicle miles of travel, and impact upon travel patterns - including issues of trip length and land use alteration.

Therefore, if an AHS project emerges with inadequate incorporation of transit and commercial elements, it will be hard for it to be included in the SIP. The policy thrust here is to move away from a facility orientation, and towards a network performance orientation. In such an orientation, it is not enough to say that a given project receives congestion on its particular segment, or in a subcorridor of direct influence. Thus, while examined under such a local orientation virtually all AHS projects could be said to decrease congestion for that particular facility or link, the framework becomes more demanding when the scope of observation is changed to a network orientation.

A recent court decision concerning the adequacy of SIP conformity has required what the Court called the "state of the practice" to be applied. In this decision, the court ruled that projects must be evaluated in a systematic way which allows for the propensity of a candidate project to increase trip distance, to divert from transit, and to cause dispersal in land use patterns.

Thus, we have noted two areas of influence of the EPA conformity regulations on policies relevant to AHS deployment. First, and most positive, the regulations call for operators of airports, ports and freight facilities to come to the table to be responsible for the impacts of their facilities on off site situations. This, in itself widens the constituency of those concerned about the possible use of new technology for access to intermodal facilities. Secondly, the CAAA-based press of SIP review changes the way in which an individual project is evaluated. By throwing the analysis into the larger arena, the project gets evaluated in a broader perspective of modal diversion, trip generation, trip distribution and land use change. 'The implications for the development of the AHS program seem to be dear: the given facility investment must be seen an a context beyond that of facilitating and encouraging the growth of SOV 'Travel.

2.4.2 Industry Implications of New conformance Regulations

In a way, the provider of an AHS facility is affected by the regulations in a manner similar to the provider of the airport services. In both cases it becomes imperative that the project be designed from the outset to deal with the totality of its impacts -- impacts which may occur on the facility and impacts which may occur off of the facility. For the AHS provider industry (whether that be an entity which is private, public, or a combination of both) the product of the investment should be planned from the beginning to have a proactive role within the context of the SIP. Early incorporation of both commercial and transit vehicles into the AHS candidate project will, in many cases, be an essential element of a strategy to bring about conformity with the SIP process.

CHAPTER 3: THE NEEDS OF THE MOTOR CARRIER INDUSTRY

The application of AHS technologies to the motor carrier industry has not been well understood. The operating characteristics of the motor carrier industry are more complex operating characteristics than those of private automobiles. Moreover, the motor carrier industry is in rapid transition amidst a sea of technological, regulatory, and economic changes. A better understanding of the industry's characteristics is necessary to evaluate the application of AHS .

'This chapter considers some of the more important trends shaping the motor carrier industry in the recent past and foreseeable future, and assesses the implications of these trends on the development and implementation of AHS programs. In addition, the chapter develops a methodology for segmenting and characterizing the motor carrier industry according to five principal dimensions --principal product carried, geographic range of operation, fleet size$_d$ routing variability, and time-sensitivity' of deliveries. Three industry segments are characterized according to this taxonomy, providing a representative cross-section of trucking activities for use in evaluating specific AHS configurations.

3.1 INDUSTRY EXPERIENCE WITH PUBLIC RESEARCH

'The motor carrier industry has had a mixed response to public research in the area of new technology. ft is however, becoming more active in public sector field test operation throughout the U.S. Historically, publicly-funded research related to motor carriers has been modest, and carriers have played a limited role in ongoing research activity. Over the last decade, public/private cooperation on motor carrier-related research has strengthened. However, collaborative public(private research continues to struggle with the legacy of a long-standing adversarial relationship.

3.1.1 Nature of Cooperation with PUBLIC Research

Until recently$_1$ public sector investment in research related to motor carriers and motor carrier operations has been modest. Most public sector research conducted at the state and university level has been directed toward structural and materials engineering problems involved in designing roads, bridges, and pavements. The portion of this research that has focused directly on trucks typically has involved the collection of empirical data on tire pressures, axle loading ad spacing, and gross truck weights. These factors are needed to determine how loaded trucks consume pavement and stress bridges. Because these data can be collected by weighing trucks during regular weight and safety inspections, the need for formal involvement of motor carriers in the research has been limited.

The public sector has worked directly with engine and truck manufacturers on energy consumption and engine emission issues. For the most part, this work has focused on the ability of truck designs and engine technology to meet regulatory standards in those areas. This research has involved dose cooperation between truck manufacturers and motor carrier operators, and between truck manufacturers and the public sector, but seldom directly between the motor carriers and the public sector.

The major link between highway research and vehicle research has been in the area of safety. The public sector invests heavily in this area, but automobiles, rather than trucks, have been at the center of this research. Since much of this work is done through statistical analysis of accident records, motor carrier participation in truck-involved accident research has been indirect, generally limited to providing data and reviewing findings.

At the metropolitan level, public research on trucks has focused almost exclusively on the establishment of building and zoning standards to accommodate truck docks and loading zones. 'Traffic engineering research on truck movements has been limited to specific projects. The major exceptions to this have been research during the 1960s and 1970s on truck movements in the garment district of New York City, New York and research on metropolitan truck movement patterns in Chicago, Illinois by the Chicago Area 'Transportation Study, the region's metropolitan planning organization.

The public sectors most controversial attempt to apply new technology research to the motor carrier industry involved anti-lock braking systems (ABS). After ABS emerged as a viable technology in the 1970s, Federal regulations were put in place requiring the introduction of ABS to trucks. The trucking industry resisted the technology vociferously, concerned as much about the additional cost of the systems as their technical performance. In application, ABS technology proved to be more difficult to maintain and less reliable than expected, and eventually the regulations were rescinded. ABS technology has evolved rapidly over the last two decades and, although it is not mandated, it is now gaining acceptance among motor carrier operators as a desirable safety system. Nevertheless, the experience left the motor carrier industry with an abiding skepticism about the public sectors ability to develop and introduce new technology to the trucking Industry.

Over the last decade, the relationship between public sector research and the motor carrier industry has shifted from an arm's-length relationship to something approaching a handshake. Much of the impetus for this has come from the motor carrier industry, which has built a modest in-house and contract research capability through the American 'Trucking Associations' 'Trucking Research Institute (ATA(TRI), and more recently through the National Private 'Track Council's Private Fleet Management Institute (NPTC/PFMI). From an early base of studies on tax and regulatory policy, the industry has expanded into safety and technology issues. The ATA and NPTC are doing joint contract research with the U.S. Department of 'Transportation and the Federal Highway Administration on topics ranging from driver fatigue to statistical reporting on the motor carrier industry.

Closer research relationships also have been developed between individual states and the motor carrier industry. The catalyst for this has been Federal and state investment in Intelligent 'Transportation Systems (ITS) research, which has sought to improve the productivity' of state administration and enforcement of motor carrier regulations through the application of information and communications technologies. The research and project development work done under the ITS programs has provided a forum for the public sector and the motor carriers to discuss their business and the potential of technology to improve productivity and profitability'.

To date ITS research has focused on issues pertaining to state regulation of the motor carrier industry and interstate travel by motor carriers. Issues related to metropolitan truck travel, including congestion and road pricing, are still largely ignored in urban ITS research, which has its eye on the larger metropolitan automobile market. Consequently, as AHS programs evolve, they are likely to find a stronger base of public sector and motor carrier research on interstate transportation issues than on metropolitan transportation issues.

3.1.2 The Industry Expectations of the Public Sector

Recent Federal and motor carrier joint research notwithstanding, the trucking industry's expectations of the public sector are shaped primarily by the long-standing adversarial relationship between government and the motor carrier industry. Most state agencies view their primary roles with respect to the motor carrier industry as that of regulators and tax collectors. 'The states derive considerable revenues from motor carrier vehicle registrations and motor fuel taxes, and most are diligent about collecting those taxes. The motor carrier industry, whose heavy trucks account for most of the wear-and-tear inflicted on roads and bridges, are perennially anxious about state and Federal taxes, arguing loud and long that the motor carrier industry is over-taxed and over-regulated compared to other industries.

As a consequence of this tug-of-war, both cultures, that of the highway engineer *and* that of the motor carrier manager, have a deeply ingrained suspicion of the motives of the other. This distrust has been strongly evident in the debate over the value of its technology to the motor carrier industry. The earliest its program, the West Coast HELP (Heavy Vehicle Electronic License Plate) Program and its Crescent Corridor Demonstration along Interstate 5, was marked by constant feuding between carriers and states over the ultimate purpose of the program. 'The state highway engineers maintained that the purpose of the program was to improve the productivity of the motor carrier industry, while the motor carriers maintained that the program was a technological Trojan horse designed to improve tax collection and, ultimately, to facilitate a national weight distance tax. Similar concerns are likely to arise from AHS programs, which raise many of the same issues of taxation, the business confidentiality of truck movement data, and the distribution of benefits.

3.2 TRENDS

In the past decade, an assortment of forces - from deregulation to the rise of intermodal freight movement to the application of new information technologies -- have dramatically reshaped the motor carrier industry. Additional changes are likely in the future. Many of these trends facing the industry have important implications --both positive and negative -- for the development and implementation of AHS in the motor carrier industry. 'These are listed in 'Table 1.

Table 1. Motor Carrier Industry Trend implication. for AHS

Industry 'Trend	Implication for AHS
Deregulation of intrastate trucking and subsequent restructuring and cost-containment pressures	AHS must offer motor carriers a competitive edge in their markets, but carriers are not likely to support significant new costs
Evolution of trucking companies into full-scale, global providers of multimodal transportation and logistics services	AHS systems must be designed from regional, national, and multimodal perspectives
Rapid application of emerging information and communication technologies	Sophisticated trucks should easily adapt to new technologies but motor carriers will be increasingly discerning consumers
Rising labor costs due to changing demographics and increasing government regulation	Cost-effective AHS systems will offset higher labor costs, but AHS training will be an added expense

3.2.1 Modal share of Freight Movement:

The U.S. economy generated 6.5 billion tons of freight in 1991, which was carried almost 3 billion ton-miles, generating $350 billion in freight revenues.[13] Trucks carried 41 percent of the freight tons, accounted for 25 percent of ton-miles, and received almost 79 percent of freight revenues. Figure 2 shows the distribution of tonnage, ton-miles, and freight revenues by mode.

Trucking industry freight revenues amounted to $285 billion, accounting for about 5 percent of the Gross Domestic Product (GDP). By comparison, revenues for all transportation services In 1991 were $379 billion, accounting for 6.4 percent of GDP; and total logistics costs, including transportation, warehousing, administration, and other inventory carrying costs, were $647 billion, accounting for 10.9 percent of GDP.[14]

Figure 2. Freight Activity by Mode, 1991

	Tonnage	Ton-Miles	Revenues
Truck	41.5	24.5	78.7
Rail	26.8	34.8	8.8
Air	0.1	0.3	4.0
Water	15.8	21.9	6.0
Pipeline	15.8	18.5	2.5

Source: Transportation Statistics Annual Report 1994, USDOT Bureau of Transportation Statistics.
Numbers represent percent of total.

Over the next decade, the trucking industry's share of domestic freight tonnage is expected to drop by about 0.5 percent while its share of revenues declines by about 3 percent, with most of the loss in market share going to air freight and intermodal rail freight.[(15)] The major factors that are shaping the industry and which will influence its need for and perception of AHS are discussed in the next several sections.

3.2.2 Deregulation

Until the 1930's, truck movements were local. Concerns about road construction costs and taxation to pay for repairs were local and state issues, and regulations governing motor carriers were tailored to the need of the local economy and geography. By World War II, the situation had changed dramatically. Better truck engines, more sophisticated paving techniques, and public investment in roadways gave trucks greater range and capacity, permitting businesses and industry to locate away from railroads and ports. As businesses expanded their markets, truck operations expanded along with them. Interstate motor carrier operations became more commonplace, providing relatively uniform freight services across the United States, but motor carrier regulations remained "balkanized" as motor carriers were subject to regulation by every state through which they Passed Because each state had regulations and administrative agencies uniquely fitted to its own needs, the regulatory system was staggeringly complex and costly for interstate motor carriers.

The problems with interstate motor carrier regulation were widely acknowledged by the motor carrier industry, state governments. and the Federal government by the 19605. Numerous efforts were made to standardize equipment, permitting, and tax reporting for trucks in interstate operation. Most of these efforts had limited effect, due to organizational inertia and other common institutional problems. The states were concerned about protecting their own business traditions and their revenues. The motor carrier industry was fragmented and sought to protect local motor carriers from out-of-state interests. While the Federal government watched all this with frustration, it was unwilling to push into areas where states' rights were paramount and the Federal capacity to intervene was limited.

The situation had become acute by the 19708, especially for business and industry, which were serving growing national and international markets and looking for ways to improve productivity and reduce costs. 'The response was the economic deregulation of the motor carrier industry in 1980 and the imposition of uniform Federal size/weight standards for trucks operating on the Interstate System. 'These actions triggered a massive restructuring of the motor carrier industry and sharp competitive pressures to reduce costs. Freight rates dropped, business entry and failure rates shot up sharply and cost savings were found in motor career management, engine/vehicie technology, and labor.

In the decade since the deregulation of interstate motor carriers, the motor carrier industry today has evolved from a highly regulated industry to an extremely competitive one. While the motor carrier industry as a whole has grown at about the same rate as the gross national product, profit margins in today's industry are relatively small, particularly compared to the period prior to deregulation. 'The regulated for-hire segment of the industry has undergone the most change, but deregulation has also forced parallel changes in the management of private fleets.

The industry is about to undergo a second wave of deregulation. This time, deregulation is being applied to intrastate motor carrier operations. In Congressional legislation passed in August 1994 and due to take effect in January 1995, states will be preempted and prohibited from regulating business entry, pricing, and service provision by intrastate motor carriers. The practical effect of the legislation will be to "level the playing field" among motor carriers operating in commercial port districts, operating intrastate, and operating interstate. Although some deregulation of intrastate motor carrier operations had been anticipated for year's, this complete preemption and deregulation of intrastate trucking was a shock to most states and many motor carriers. The action is expected to trigger another round of restructuring, consolidation, and cost-cutting across the industry.

As the motor carrier industry approaches automated highways, it will be a much changed, very competitive, and very cost-conscious industry. ft will be an economically deregulated industry, but many aspects of its operations (e.g., safety, vehicle registration, fuel taxation, driver hours of service, size and weight standards hazardous materials transport and agricultural clearance) will still be regulated and enforced by the states through procedures that are as arcane and balkanized today as they were in the 19305.

3.2.3 **Customer Service**

The pressures and opportunities of the global marketplace are forcing many U.S. companies to change the way they do business. Many of the changes such as the use of overseas parts suppliers, the introduction of just-in-time manufacturing and retailing systems, and the increased emphasis on quality and customer service, directly affect motor carrier operations. As manufacturing and retail industries seek to reduce inventory carrying costs through just-in-time logistics they are asking carriers to provide more frequent and timely deliveries to resupply assembly lines and restock retail shelves. As more companies establish overseas production facilities to take advantage of low labor and material costs, they are asking carriers to participate in very long, time-sensitive, global intermodal supply chains and distribution networks. addition, as the value of shipments increases businesses are asking carriers to provide greater control over shipments, tracking not only trucks but also individual packages.

The motor carrier industry spurred on by the competitive pressures unleashed by deregulation, has moved rapidly to accommodate these demands. 'This is affecting the industry in two ways that are relevant to AI-IS. First, the level of management and technological sophistication in the industry are increasing. The leading sectors of the industry have made the transition from "mom and pop" operations to national and international scale business operations, able to recruit and retain first class technical, managerial, financial, and legal staff. This has given the industry a much greater capability to appreciate, develop, and apply new technologies. At the same time, it has given the industry a much stronger and more knowledgeable voice in public policy debates about transportation. As the industry approaches AI-IS, it will be more active and more sophisticated in voicing its needs and concerns and it will be under more pressure from its shippers and receivers to demonstrate the cost-effectiveness of their operations.

A second effect of changing customer service demands has been to catalyze the evolution of trucking companies into transportation companies. Companies as diverse as J.B. Hunt, a national truckload carrier, and United Parcel Service, once exclusively a small parcel less-than-truckload carrier, now provide multimodal transportation services. In some cases, these companies also provide complete logistics services, including transportation, warehousing, scheduling, final assembly, tagging, Packaging, and billing for their clients. 'These companies (and their clients) will evaluate the impact of AHS not only on motor carrier operations, but also on their total logistics supply chain and distribution network. An AHS may provide significant cost-efficiencies to local truck movements, but if that truck movement is not a time- or cost-sensitive link in the company's national or global logistics network, the AHS may not be supported. This means that metropolitan areas and states must be willing to look well beyond their borders in determining the costs and benefits of AHS for the trucking industry.

3.2.4 Information Technology

A revolution is occurring in today's transportation industry', brought about by the introduction of information and communications technologies. 'These technologies have enabled business and industry to organize and control regional, national, and international networks of suppliers and distributors for their' products and services. 'The application of the same technologies to trucking has enable motor carriers to closely monitor and manage the operation of their fleets regionally and nationally.

Today's more sophisticated trucking fleets are equipping their vehicles with onboard computers and communication systems that keep the drivers in constant contact with their dispatchers and clients. These systems enable the carriers to provide clients with information to assure the safety and security of their cargo. For example, a truckload carrier hauling food for a national fast food chain will electronically monitor the temperature of a refrigerated trailer. The trailer may be compartmentalized so that different foodstuffs$_1$ such as vegetable, meats, and bakery products, can be refrigerated at different temperatures. Each compartment will be monitored and a continuous temperature record will be kept in the onboard computer as part of the truckers quality assurance program. The truck’s location also may be monitored by a global positioning system (GPS) that calculates the truck's position by the triangulation of timed satellite signals.

At periodic intervals, the status of the refrigeration equipment as well as the truck's location, speed, and rate of fuel consumption will be transmitted by satellite communication link to the motor carrier's dispatch office, which in turn will relay information on the status of the load and its expected time of arrival to the shipper and receiver. Leading-edge carriers routinely provide large clients with direct dial-in access to their computers, and offer automated menus and voice synthesizer reporting for smaller clients who call in to track the progress of their shipment.

Some carriers are complementing this equipment with automated vehicle control systems that monitor truck speed and vehicle spacing, warning the driver and, in emergencies, automatically applying the brakes when the truck follows another vehicle too closely. The cost of these systems, which maintain a record of the vehicle's movements, often are underwritten by the carriers insurance company.

Electronic transponders constitute another layer of technology on trucks. Mounted behind the windshield or on the bumper of the tractor, on the trailer, or on the container and its chassis, electronic transponders can be interrogated by roadside readers while the track is traveling at highway speeds. Transponders are used today to collect tolls without stopping trucks; to Identify trucks and permit legally compliant trucks to bypass state weigh stations and ports-of-entry; to verify credit at fuel stations; and to track the location of tractors, trailers, containers, and chassis in large intermodal terminals and track yards.

The next generation of information and communications technologies being deployed to trucks will move many of the business functions from the office into the cab of the truck. Order taking, route planning, waybill processing, and similar functions, which are done today in the motor carriers office, are being transferred to the truck. 'Today's Federal Express truck is a sophisticated mobile office, but even less time-sensitive operations routinely carry onboard fax machines to communicate with dispatchers and clients.

The number of trucks and fleets currently equipped with such systems is limited; however, customer service expectations and competitive pressures will force the rapid adoption of these technologies among many segments of the motor carrier industry over the next decade. For AHS programs, this means that trucks will be among the most electronically sophisticated vehicles on the road. Many will be pre-wired for this equipment by truck manufacturers and ready to accept AHS equipment. Conversely, motor carriers will be equipped to assess the value of any AHS facility in term’s of time savings and costs, making them more demanding customers for the AHS operator.

3.2.5 Labor Pressures

Changing demographics and increasing government regulation of the workplace will require trucking companies to dedicate more resources to recruiting, training, and managing drivers. [16] The average age of the U.S. workforce is increasing, and the motor carrier industry is having a difficult time recruiting younger drivers at current wage rates. Annual driver turnover rates of 100 to 400 percent per year are not uncommon in some segments of the for-hire industry. ft is likely that the trucking industry will have to turn to new sources for qualified drivers, including women, minorities, and military veterans.

As the cost of recruiting and retaining drivers rises, the pressure on motor carrier managers to make cost-effective use of their time also will increase. 'To the extent that AHS systems make it easier and more cost-effective to operate trucks, AHS will be attractive to the industry because it will help to offset the increased labor costs although training drivers for AHS will be an added expense. However, if the cost of using AHS facilities is high, because of user charges or special equipment that must be installed on a truck, then AHS will be resisted.

3.2.6 Intermodal freight Operations

A significant change in the last decade has been the accelerating integration of truck and rail service to provide intermodal freight service. Freight movements by intermodal containers have been growing rapidly. The number of intermodal containers coming into and out of the United States has been growing at an average annual rate of just over seven percent. Domestic containers, which are a new, small, and rapidly growing market, are expected to increase at an average annual rate of about 25 percent between 1992 ad 2000, according to the American 'Trucking Associations, Inc. Roadtrailers (truck trailers equipped with detachable railroad wheels and retractable highway wheels) and other new haif-rail carl half-truck-trailer vehicles are expected to grow at about 10 percent per year, cutting into the volumes of piggyback trailers (conventional truck trailers carried on railroad flatcars), which are projected to decline about 10 percent annually.

'The major force driving the expansion of intermodal freight services has been pressure to cut total transportation costs. 'The introduction of intermodal stack trains, especially double-stack trains, has cut the cost of moving a container long distance [over 1,932 km (1,200 miles)] approximately in half, making intermodal service competitive with long-haul truck service. Improvements in equipment, competition among railroads, and economies of scale in handling containers at terminals are expected to drive the cost of container movements down further, eventually making intermodal services in high volume corridors competitive with truck services at distances of 805 to 966 km (500 to 600 miles).

This growth in intermodal traffic will generally work against long-haul AHS facilities, since for all practical purposes intermodal service is an automated highway system that uses existing guideways and proven technology very cost-effectively. The constraint on the growth of intermodal service will be the capacity of railroad mainlines and terminals to absorb the anticipated increases in traffic. Some sections of the U.S. rail system are nearing capacity today, requiring new track or new right-of-way. In addition, expansion of intermodal terminals requires track space, trailer/chassis storage space, and good highway access. Many rail properties in urban areas meet one or two of these criteria, but few meet all three.

There are fewer opportunities to shift freight from truck to rail within metropolitan areas. The rail distribution networks that flourished in the late 1800's are largely gone, and short-haul rail service does not compete effectively with truck service in terms of quality or cost within urban areas except for the movement of certain bulk products, such as coal, chemicals, sand, and gravel. In general, intermodal services will not provide competition for trucking and AHS in metropolitan areas.

3.2.7 Truck Size and weight

Labor costs account for upwards of 60 percent of truck operating costs, which makes reducing shipping costs difficult. 'To make a truck trip more productive, a motor carrier must generate more revenue per mile. The most direct way to do this is to increase the capacity of truck, and therefore, the amount of revenue freight that can carried per trip/driver. This calculus has lead to steady pressure from motor carriers and shippers to increase the size and weight limits for trucks. A major step in this direction was achieved In the Surface Transportation Act Amendments of 1982 (STAA) when Congress established an interstate standard truck by setting maximum size and weight limits for trucks operating on the designated national truck network (effectively, the interstate highway system) and preempted states from setting lower limits on these roads.

Subsequent efforts by the motor carrier industry to increase truck size and weight limits to accommodate larger and longer combination trucks (i.e., tandems, turnpike doubles, and triples) have been resisted by the states and the railroads the former anxious about pavement wear and the cost of bringing substandard bridges up to new weight standards and the latter anxious about the potential of freight and revenue diversion from steel-wheeled railroads to rubber-tired railroads (i.e., trucks). ISTEA declared a moratorium on the expansion of longer combination vehicle routes, forcing the FHWA, the states, and the motor carrier industry to restudy the economic and safety implications of larger and heavier vehicles. This effort is underway; however[1] it is unlikely that the issue will be resolved by the time of the next highway reauthorization bill in 1997.

The longer term outlook is for some increase in the size and weight of trucks. It is likely that longer combination vehicles will be allowed to operate over more routes than they do today, but under permitting programs that regulate driver and vehicle safety and tax the vehicles in proportion to the additional wear that they are expected to place on the highways. ft is also likely that tractor semi-trailers eventually will be allowed to operate at higher gross weights if additional axles are added to spread the weight and reduce the weight on each individual axle. 'The Canadian motor carrier industry operates single- and multi-trailer trucks (researched and developed in partnership with the Canadian government) that have lower individual axle weights, higher gross weights, and better stability than comparable American trucks. The demonstrated effectiveness of these designs is pressuring the Federal Highway Administration to consider similar designs. This trend suggests that AHS programs must anticipate greater diversity in truck size and weigh across the U.S. fleet than exists today.

3.2.8 Safety

Truck-involved fatal accident rates have declined over the last two decades despite a steady increase in truck-miles of travel over the period. Nevertheless, trucks are still involved in a disproportionately high number of fatal accidents. Moreover, truck accidents, especially major accidents that block urban freeways for two, four, or six hours at a time, impose a huge economic cost because of the congestion and delay that they cause to the other truck and automobile drivers caught up in the queue behind an accident.

The Occupational Health and Safety Administration (OHSA) classifies trucking as a high hazard industry because it shows higher rates of worker injuries and lost workdays than railroad transportation construction, and private industry. These rates are reflected, in turn, in higher insurance and compensation rates that undermine the profitability of the industry.

There are two broad initiatives underway to address these problems. The first is a slowly emerging consensus that safety enforcement must focus more closely on the driver. Although there are questions about the reliability of accident reports, the general pattern of research findings suggest that driver error, not mechanical failure, is the primary cause of truck-at-fault accidents. Nonetheless, current enforcement programs focus on the mechanical condition of the truck and only secondarily on the condition of the driver. Shifting the focus of enforcement efforts to the driver is difficult because driver inspections require that the truck be stopped and the driver interviewed out of the cab, which is a time-consuming and difficult process on congested urban freeways and high volume interstates.

The second and closely related[1] initiative is to use technology to monitor the condition of drivers and trucks. 'The FHWA and motor carrier manufacturers are experimenting with driver fatigue monitoring and onboard equipment monitoring and diagnostic systems, with much of the early attention going to brake failure and rollover warning systems. This technology is in development, but is several generations away from commercial deployment in motor carrier fleets.

Truck safety is a significant and politically visible problem. AHS technology that can demonstrate significant safety benefits, either by improving driver performance, stabilizing vehicle handling, or reducing the risk that other vehicles will collide with trucks, would be perceived by the motor carrier industry and government as a positive investment.

3.3 MOTOR CARRIER INDUSTRY TYPOLOGY

To evaluate the potential applicability of AHS to the motor carrier industry, it is necessary to understand the industry's characteristics. 'Traditional industry typologies based on regulatory status and revenues are not adequate because they overlook key operational characteristics. In this section, an alternative typology of the trucking industry is developed based on the following characteristics:

- Principal Product Carried, which differentiates among trucks carrying various types of products and accounts for the differing needs of the industries they serve.

- Geographic Range of Operation, which differentiates local, regional, and national operating scopes.

- Fleet Size, which differentiates motor carriers and their need and capacity for fleet management technology.

- Routing Variability, which differentiates motor carriers that operate repetitive$_1$ fixed routes, and therefore might make use of an AHS facility in their territory$_1$ from variable route carriers, who may change their destinations daily and therefore have less opportunity to use a specific AHS facility.

- Time sensitivity of Deliveries, which differentiates those segments of the industry that operate ~just-in-time~ delivery operations and may be particularly sensitive to travel time savings provided by an AHS .

3.3.1 Traditional Segmentation

The highly fragmented trucking industry reflects the complexity and diversity of the many businesses, industries, government agencies, and consumers it serves. The most common approach to industry segmentation has been to divide the industry by regulatory status and type of operation:

- For-Hire Truckload TL Carrier. 'These carriers haul general freight and special commodities in truckload quantities, usually in a single move directly from the shipper to the receiver. Most for-hire truckload carriers are either regional or long-haul (i.e.,$_1$ transcontinental) carriers, which operate on irregular schedules determined by the demands of shippers and receivers.

- For-Hire Less~Than-Truckioad (LT.) Carriers. These carriers haul general freight in less-than-truckload quantities usually combining freight from many shippers to achieve cost-effective operations. Less-than-truckload carriers have two types of operations: a local pickup and delivery operation running urban trucks on regular routes from a central terminal; and a line-haul operation running over-the-road trucks in relays from terminal-to-terminal across the country.

- Private Truckload (TL) Fleets. Like their for-hire counterparts, these carriers haul special commodities in truckload quantities, usually between manufacturing plants or from manufacturing plants to warehouses. These fleets make shorter moves and more scheduled moves than for-hire carriers.

- Private Distribution Less~Than-Truckload (LT.) Fleets. Private distribution fleets haul general freight and special commodities, typically with short-haul scheduled moves between warehouses and retail outlets. Also included in this category are local non-ICC-regulated for-hire carriers and local rentail moving fleets.

- Service Fleets These include utility company fleets, Federal government vehicles state/local highway department trucks, fire apparatus, etc. Generally, these fleets operate dedicated equipment from a local garage with irregular routes and schedules.

This typology based primarily on the regulatory status of the carrier has been widely used in the Pt to describe the trucking industry because these categories implicitly defined industry characteristics in a regulated environment. Indeed, the Interstate Commerce Commission required for-hire fleets to report fleet size, revenues, and other data according to these regulatory categories. The deregulation of the industry in 1980 led to the elimination of many statistical and financial reporting requirements; consequently, there has been a decline in the amount of information available (particularly for the for-hire segments).

At the same time, deregulation has led to considerable restructuring of the trucking industry:

- For-hire LT. carriers have acquired The operations.
- Private fleets have applied for ICC licenses to provide for-hire 'TL back-haul services'
- Firms that were once exclusively truck lines have diversified into air freight and intermodal services.

Therefore, segmentation of the trucking industry according to regulatory status may not be meaningful with respect to future fleet operations. In addition, this segmentation falls short because it ignores the types of operational characteristics that are the most likely to affect the industry's adoption of AHS technologies. 'To identify the segments of the motor carrier industry that might benefit from the application of AHS technology, it is necessary to develop a trucking industry typology based on the characteristics most relevant to determining AHS needs.

3.3.2 Fleet Management Segmentation

The new trucking industry taxonomy is based on the following operational characteristics, which are the most important for fleet management purposes:

- Principal Product Carried. 'Truck fleet operations are influenced, first and foremost, by the commodities they haul most often. 'Trucks carrying frozen vegetables, for example, will have different delivery schedules and production-to-distribution mutes than will trucks hauling gravel or gasoline, both because of the nature of the products themselves, and because of the characteristics of the industries that produce and consume the products. Thus, different AHS configurations may be appropriate for different truck fleets, depending on the kinds of products they most often carry.

- Geographic Range of Operation. Fleet operations may vary depending on their geographic scale. 'Trucks operating locally within metropolitan areas ['.e., within 80.5 km (50 mi) of their base of operation] may face very different scheduling and routing conditions, and may operate on different classes of roadways, than trucks operating primarily at a regional scale ['.e., 80.5 kn~322.0 km (50 to 200 mi) from base of operation] or national scale [1.e., over 322.0 km (200 mi) from base of operation]. These differences may influence the choices made by fleet managers and truck owners regarding investment in AHS systems.

- Another important way in which the geographic range of operation may affect the adoption of AHS relates to system compatibility. If different versions of AHS are implemented in different par's of the country, truck owners and fleet managers whose operations are primarily national may be reluctant to invest in onboard equipment, since such equipment may be incompatible with the different AHS operations that their trucks encounter on long-distance trips.

- Fleet size. 'The most obvious way in which fleet size may affect the adoption of AHS systems is that companies with large fleets may have proportionately more resources available for maintaining and upgrading their fleets than will companies that operate only a few trucks. Even if budgets are proportional across fleet sizes, the absolute per-truck cost of installing certain AHS technologies may simply be out of range for small companies. Conversely, the total initial cost of implementing some AHS technologies may prove to be a significant burden for the larger fleets.

- Routing variability'. ft is unlikely that every roadway in the United States will be - of an AHS . Instead, AHS probably will be limited to a subset of major interstate and urban arterial highways. 'Therefore, AHS may be more attractive to owners and operators of trucks with fixed routes, which operate on a limited number of roadways, than to owners of trucks whose routing is more highly variable. Route variability is determined by the product carried, range of operation, and fleet size.

- Time sensitivity of deliveries To the extent that AHS permit faster or more constant operating speeds and reduce congestion, they will benefit all trucks that use them. However, the ratio of these benefits to the costs of installing onboard AHS equipment may vary across fleets, depending on how ultra-sensltlve each fleet's deliveries are. For fleets whose deliveries are highly time-sensitive (i.e., "just-in-time deliveries), AHS may be well worth an investment; fleets whose deliveries are not time-sensitive may not be able to justify the expense of AHS . 'Time sensitivity is determined primarily by the product being carried, and, to a lesser extent, by range of operation.

3.3.3 Sample Selection Methodology

The potential use of various AHS technologies can be estimated by analyzing the needs of specific segments of the motor carrier industry. This section of the report describes the methodology through which data on the national truck inventory can be used in conjunction with detailed discussions with truck fleet operators and industry analysts to estimate the size and operating characteristics of trucking activity in a specific industry segment.

3.3.3.1 Data Source

The primary data source used in this analysis is the 1987 'Truck Inventory and Use Survey (-"'TIUS), published by the U.S. Census Bureau. The TIUS database is based on a stratified probability' sample of trucks in every state. The total sample includes approximately 135,000 trucks out of an estimated "universe" of 44.6 million trucks. 'The sample is stratified by truck body type, as follows:

- Pickup.
- Van.
- Single-Unit Light.
- Single-Unit Heavy.
- Truck Tractor.

Within each state, a predetermined number of truck from each stratum were randomly sampled. (The average number of trucks sampled per state was 2,653.) A weighting factor based on the actual number of truck registrations within each state and stratum was applied to each track in the sample to produce an estimate for the total truck "universe".

3.3.3.2 Classification Methodology and Assumptions

The TIUS database contains information on the geographic range of operation and fleet size, but not on routing variability or the time-sensitivity of deliveries. Discussions were held with truck fleet operators from various segments of the trucking industry and with industry analysts to gather information about the nature of trucking operations for each of the commodities analyzed. The information was used to make assumptions regarding route variability and time sensitivity. These assumptions guided the assignment of trucks to the different categories of these variables.

'The methodology and assumptions used to assign trucks to particular categories vary with different product groups. Therefore, the findings described in the following examples may not be directly transferable to other product groups.

3.3.3.3 Selection Criteria

The 'TIUS database contains information on numerous classes of trucks, including many trucks that are not appropriate for inclusion in this Study.[2] 'To limit the analysis to appropriate truck categories, the following selection criteria were used:

- Trucks with a gross weight of over 4,540 kg (10,000 lb).
- Trucks operated by and for private businesses (i.e., private fleets), or for hire.
- Trucks operating on public roads and highways.

The entries meeting these criteria were extracted from the main 'TIUS data file for further analysis. Figure 3 illustrates the process by which the survey sample was selected.

3.3.4 Analyses of Taxonomies for Selected trucking Industry Segments

The TIUS database classifies trucks according to the percentage of their operating time spent crying each of 27 categories of commodities (based on the responses of truck operators to the survey). From these responses, a "principal product" (i.e., the dominant product carried) is identified for each truck included in the TIUS. For this study, analyses were conducted of three principal products which provide a representative cross-section of trucking activities. These principle products, and the number of trucks associated with each product in the 'TIUS, are as follows:

- Liquid petroleum (including, for example, gasoline, heating oil, diesel fuel, and aviation fuel; but excluding paving and roofing materials): approximately 109,000 trucks.

- Processed foods (including, for example, canned foods, frozen foods, prepared meats, beverages, and dairy products; but excluding grain, produce, livestock, and raw milk): approximately 290,000 trucks.

- Building materials (including, for example, sand, gravel, concrete, and fiat glass; but excluding lumber): approximately 500,000 trucks.

3.3.4.1 Liquid Petroleum

The majority of petroleum tankers operate locally, in small fleets. Most tankers are on fixed routes, and most of their deliveries are not time-sensitive.

<u>3.3.4.1.1</u> <u>Geographic Range and Fleet Size</u>. Approximately 109,000 tankers move liquid petroleum products in the United States (figure 4). of this total, nearly 75 percent (approximately 80,000) operate at the local level [i.e., within 80.5 km (50 miles) of their home bases]. These local operators are primarily home heating oil distributors and gasoline tankers supplying service stations within metropolitan areas. Almost all of the remaining petroleum tankers operate regionally [1.e., at a range of 80.5 km to 322.0 km (50 to 200 miles)from their home bases. ft can be assumed that these tankers are principally moving products from regional supply facilities to service stations, heating oil

dealers, and other local destinations.

The majority (83 percent) of local petroleum tankers operate in fleets of fewer than 20 trucks. At the regional level, trucks are more uniformly distributed among the different fleet size categories.

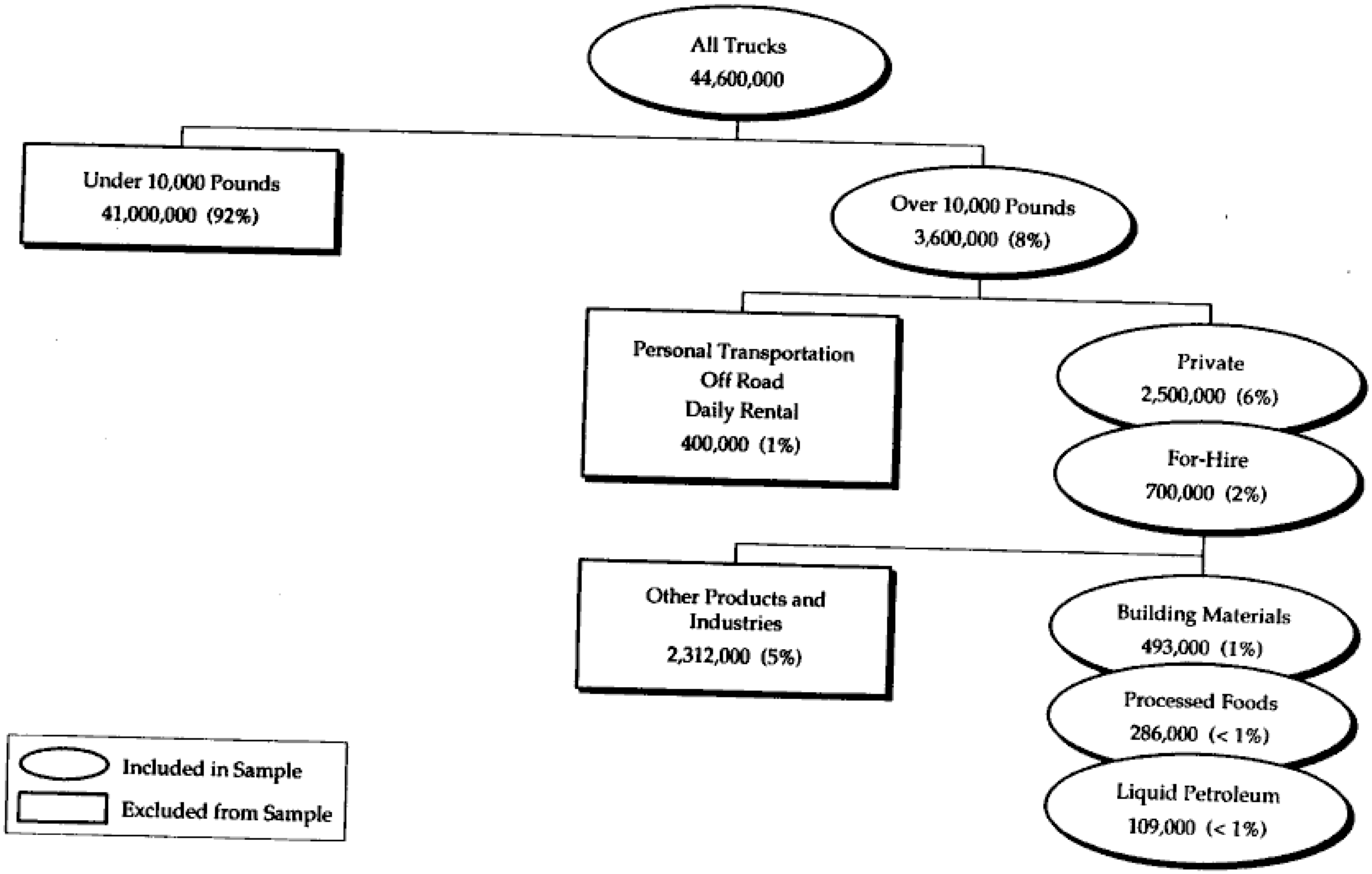


Figure 3. Commercial Motor Carrier Industry Market Segmentation Analysis: Sample Selection

Total	Operating Range	Fleet Size	Route Variability	Time Sensitivity	
109,100* Total	National (> 200 Miles) 3,300 (3%)	500+ Trucks 0	Variable 0	Time Sensitive	0
				Non-Time Sensitive	0
			Fixed 0	Time Sensitive	0
				Non-Time Sensitive	0
		100-499 Trucks 500 (16%)	Variable 100 (25%)	Time Sensitive	100 (5%)
				Non-Time Sensitive	100 (95%)
			Fixed 400 (75%)	Time Sensitive	100 (5%)
				Non-Time Sensitive	400 (95%)
		20-99 Trucks 900 (27%)	Variable 200 (25%)	Time Sensitive	100 (5%)
				Non-Time Sensitive	200 (95%)
			Fixed 700 (75%)	Time Sensitive	100 (5%)
				Non-Time Sensitive	700 (95%)
		6-19 Trucks 800 (24%)	Variable 200 (25%)	Time Sensitive	100 (5%)
				Non-Time Sensitive	200 (95%)
			Fixed 600 (75%)	Time Sensitive	100 (5%)
				Non-Time Sensitive	600 (95%)
		1-5 Trucks 1,100 (32%)	Variable 500 (50%)	Time Sensitive	100 (5%)
				Non-Time Sensitive	500 (95%)
			Fixed 500 (50%)	Time Sensitive	100 (5%)
				Non-Time Sensitive	500 (95%)
	Regional (50-200 Miles) 26,200 (24%)	500+ Trucks 500 (1%)	Variable 100 (25%)	Time Sensitive	100 (5%)
				Non-Time Sensitive	100 (95%)
			Fixed 400 (75%)	Time Sensitive	100 (5%)
				Non-Time Sensitive	400 (95%)
		100-499 Trucks 2,600 (10%)	Variable 600 (25%)	Time Sensitive	100 (5%)
				Non-Time Sensitive	600 (95%)
			Fixed 1,900 (75%)	Time Sensitive	100 (5%)
				Non-Time Sensitive	1,800 (95%)
		20-99 Trucks 7,100 (27%)	Variable 1,800 (25%)	Time Sensitive	100 (5%)
				Non-Time Sensitive	1,700 (95%)
			Fixed 5,300 (75%)	Time Sensitive	300 (5%)
				Non-Time Sensitive	5,000 (95%)
		6-19 Trucks 8,100 (31%)	Variable 2,000 (25%)	Time Sensitive	100 (5%)
				Non-Time Sensitive	1,900 (95%)
			Fixed 6,100 (75%)	Time Sensitive	300 (5%)
				Non-Time Sensitive	5,800 (95%)
		1-5 Trucks 7,900 (30%)	Variable 3,900 (50%)	Time Sensitive	200 (5%)
				Non-Time Sensitive	3,700 (95%)
			Fixed 3,900 (50%)	Time Sensitive	200 (5%)
				Non-Time Sensitive	3,700 (95%)
	Local (< 50 Miles) 79,600 (73%)	500+ Trucks 100 (< 1%)	Variable 100 (25%)	Time Sensitive	100 (25%)
				Non-Time Sensitive	100 (75%)
			Fixed 100 (75%)	Time Sensitive	100 (25%)
				Non-Time Sensitive	100 (75%)
		100-499 Trucks 1,600 (2%)	Variable 400 (25%)	Time Sensitive	100 (25%)
				Non-Time Sensitive	300 (75%)
			Fixed 1,200 (75%)	Time Sensitive	300 (25%)
				Non-Time Sensitive	900 (75%)
		20-99 Trucks 11,400 (14%)	Variable 2,800 (25%)	Time Sensitive	700 (25%)
				Non-Time Sensitive	2,100 (75%)
			Fixed 8,500 (75%)	Time Sensitive	2,100 (25%)
				Non-Time Sensitive	6,400 (75%)
		6-19 Trucks 30,500 (38%)	Variable 7,600 (25%)	Time Sensitive	1,900 (25%)
				Non-Time Sensitive	5,700 (75%)
			Fixed 22,900 (75%)	Time Sensitive	5,700 (25%)
				Non-Time Sensitive	17,200 (75%)
		1-5 Trucks 36,000 (45%)	Variable 18,000 (50%)	Time Sensitive	4,500 (25%)
				Non-Time Sensitive	13,500 (75%)
			Fixed 18,000 (50%)	Time Sensitive	4,500 (25%)
				Non-Time Sensitive	13,500 (75%)

* All figures are rounded to the nearest 100.

Figure 4. Representative Market Taxonomy: Petroleum Tankers (Trucks Over 10,000 Pounds)

3.3.4.1.2 Route Variability and Time Sensitivity. It can be assumed that the majority of petroleum delivery routes are fixed. Most tankers make the same deliveries, in the same order, on a regular schedule. When we consider how differences in fleet size might affect route variability, however, some differences emerge. Companies with large fleets may be able to assign specific trucks to specific routes, thereby maintaining fixed routes. Companies with small fleets do not have this option; they must dispatch trucks in a more variable fashion, serving one route one day, and a different route the next. 'Thus, it is estimated that, in fleets of more than five trucks, 75 percent of the trucks operate on fixed routes, whereas in fleets with five trucks or fewer, 50 percent of the routes are fixed.

Petroleum is not a particularly time-sensitive commodity because it is always stored in large quantities and can be held for long periods. Therefore, it can be assumed that petroleum tankers have a fairly flexible delivery schedules; in most cases, a delay of one or two days will not create critical problems. The exception to this is home heating oil dealers, who, during winter months, frequently respond to emergency calls from residential customers who have used up their oil before their regular delivery date. In these cases, petroleum delivery is highly time-sensitive. Thus, it is assumed that 25 percent of local petroleum deliveries are time-sensitive, while only 5 percent of regional and national petroleum deliveries are time-sensitive.

3.3.4.2 Processed Foods

Processed foods trucks are fairly evenly distributed among different fleet sizes. Slightly less than half of these trucks operate locally; about 30 percent operate regionally and about 20 percent operate nationally. The routing of trucks operating nationally and regionally is more variable than is the routing of local trucks.

3.3.4.2.1 Geographic Range and Fleet Size. Nationwide, approximately 290,000 truck are carrying processed foods (figure 5). Slightly fewer than half (approximately 130,000) of these trucks operate locally, while about one-third (approximately 95,000) operate regionally, and about one-fifth (approximately 62,000) handle long-haul (national) shipments.

Overall, these trucks are fairly evenly distributed among the various fleet size categories. In contrast to petroleum tankers, which operate mainly in small fleets, 26 percent of processed food trucks operate in fleets with 100 or more vehicles.

3.3.4.2.2 Route Variability and "-Time-Sensitive". Based on conversations with food distributors, it is assumed that a large percentage of the processed food trucks operating nationally and regionally are engaged in moving truck loads of single (or highly similar) products from production facilities (e.g., canning, freezing and bottling plants) to warehouse and distribution facilities. On the local level, however, it can be assumed that each truck carries a variety of different processed foods to stores. Because of this difference in the composition of cargo, the routing of local trucks is less variable than that of national or regional trucks.

Total	Operating Range	Fleet Size	Route Variability	Time Sensitivity	
286,200*	National (> 200 Miles) 60,100 (21%)	500+ Trucks 8,400 (14%)	Variable 2,100 (25%)	Time Sensitive	100 (5%)
				Non-Time Sensitive	2,000 (95%)
			Fixed 6,300 (75%)	Time Sensitive	300 (5%)
				Non-Time Sensitive	600 (95%)
		100-499 Trucks 16,800 (28%)	Variable 4,200 (25%)	Time Sensitive	200 (5%)
				Non-Time Sensitive	400 (95%)
			Fixed 12,600 (75%)	Time Sensitive	600 (5%)
				Non-Time Sensitive	1,200 (95%)
		20-99 Trucks 13,200 (22%)	Variable 3,300 (25%)	Time Sensitive	200 (5%)
				Non-Time Sensitive	3,100 (95%)
			Fixed 9,900 (75%)	Time Sensitive	500 (5%)
				Non-Time Sensitive	9,400 (95%)
		6-19 Trucks 6,600 (11%)	Variable 1,700 (25%)	Time Sensitive	100 (5%)
				Non-Time Sensitive	1,600 (95%)
			Fixed 4,900 (75%)	Time Sensitive	200 (5%)
				Non-Time Sensitive	4,700 (95%)
		1-5 Trucks 14,400 (24%)	Variable 3,600 (25%)	Time Sensitive	200 (5%)
				Non-Time Sensitive	3,400 (95%)
			Fixed 10,800 (75%)	Time Sensitive	500 (5%)
				Non-Time Sensitive	10,300 (95%)
	Regional (50-200 Miles) 91,600 (32%)	500+ Trucks 5,500 (6%)	Variable 1,400 (25%)	Time Sensitive	100 (5%)
				Non-Time Sensitive	1,300 (95%)
			Fixed 4,100 (75%)	Time Sensitive	200 (5%)
				Non-Time Sensitive	3,900 (95%)
		100-499 Trucks 20,200 (22%)	Variable 5,100 (25%)	Time Sensitive	300 (5%)
				Non-Time Sensitive	4,800 (95%)
			Fixed 15,100 (75%)	Time Sensitive	800 (5%)
				Non-Time Sensitive	14,300 (95%)
		20-99 Trucks 24,700 (27%)	Variable 6,200 (25%)	Time Sensitive	300 (5%)
				Non-Time Sensitive	5,900 (95%)
			Fixed 18,500 (75%)	Time Sensitive	900 (5%)
				Non-Time Sensitive	17,600 (95%)
		6-19 Trucks 21,100 (23%)	Variable 10,500 (50%)	Time Sensitive	500 (5%)
				Non-Time Sensitive	10,000 (95%)
			Fixed 10,500 (50%)	Time Sensitive	500 (5%)
				Non-Time Sensitive	10,000 (95%)
		1-5 Trucks 19,200 (21%)	Variable 9,600 (50%)	Time Sensitive	500 (5%)
				Non-Time Sensitive	6,800 (95%)
			Fixed 9,600 (50%)	Time Sensitive	500 (5%)
				Non-Time Sensitive	6,800 (95%)
	Local (< 50 Miles) 131,700 (46%)	500+ Trucks 1,300 (1%)	Variable 100 (5%)	Time Sensitive	100 (25%)
				Non-Time Sensitive	100 (75%)
			Fixed 1,200 (95%)	Time Sensitive	300 (25%)
				Non-Time Sensitive	900 (75%)
		100-499 Trucks 19,800 (15%)	Variable 1,000 (5%)	Time Sensitive	200 (25%)
				Non-Time Sensitive	700 (75%)
			Fixed 18,800 (95%)	Time Sensitive	4,700 (25%)
				Non-Time Sensitive	14,100 (75%)
		20-99 Trucks 40,800 (31%)	Variable 2,000 (5%)	Time Sensitive	500 (25%)
				Non-Time Sensitive	1,500 (75%)
			Fixed 38,800 (95%)	Time Sensitive	9,700 (25%)
				Non-Time Sensitive	29,100 (75%)
		6-19 Trucks 30,300 (23%)	Variable 7,600 (25%)	Time Sensitive	1,900 (25%)
				Non-Time Sensitive	5,700 (75%)
			Fixed 22,700 (75%)	Time Sensitive	5,700 (25%)
				Non-Time Sensitive	17,100 (75%)
		1-5 Trucks 38,200 (29%)	Variable 9,500 (25%)	Time Sensitive	2,400 (25%)
				Non-Time Sensitive	7,100 (75%)
			Fixed 28,600 (75%)	Time Sensitive	7,200 (25%)
				Non-Time Sensitive	21,400 (75%)

* All figures are rounded to the nearest 100.

Figure 5. Representative Market Taxonomy: Processed Food (Trucks Over 10,000 Pounds)

When processed food producers alter their production schedules because of fluctuating demand or seasonal variations, this may cause the routing and scheduling of regional and national truck-load carriers to change but production changes are less likely to affect the routing of local trucks. Instead, the composition of local trucks' loads may change. For example, although long-haul and regional movements of canned fruits from California may increase sharply during the summer, this does not mean that local delivery routes or schedules will change; if anything, local trucks may simply carry more canned fruit during summer months.[3]

For the same reasons that petroleum tankers in small fleets experience greater variability than tankers in larger fleets, processed food trucks operating in smaller fleets may have more variable routing than those in large fleets: smaller fleets may be less able to dedicate trucks to specific routes. Thus, we estimate that among regional and national fleets, the percentage of trucks operating on variable routes ranges from 25 percent among the larger fleets (20 or more trucks), to 50 percent among the smaller fleets (fewer than 20 trucks). At the local level these estimates change slightly; five percent of trucks in large fleets, and 25 percent of trucks in small fleets operate on variable routes.

Most processed foods have relatively long shelf lives, and are typically stored in large quantities. In general, therefore, deliveries of processed foods are not highly time-sensitive. On the local level, however, a large number of deliveries are of time-sensitive foods with a short shelf life (e.g., milk and bread) which must be delivered on a frequent or daily basis. Consequently, we estimate that only five percent of processed food trucks operating regionally and nationally are making time-sensitive deliveries, while 25 percent of locally operating processed food trucks are making time-sensitive deliveries.

3.3.4.3 *Building Materials*

Small (under 20 power units), local fleets dominate the building materials segment. Local operations are more variable and more time-sensitive than regional or national operations.

3.3.4.3.1 Geographic Revenue and Fleet Size. 'There are lust under 500,000 trucks carrying building materials nationwide (figure 6). Nearly 80 percent (approximately 395,000) of these trucks operate locally. At every level of geographic range, small fleets are dominant. For example, over 75 percent of the trucks that operate locally do so in fleets with fewer than 20 power units.

Indeed, local trucks may not even experience differences in the composition of their loads due to production changes, since regional warehouse and distribution facilities may stockpile products during peak production periods and ship them out evenly over the course of the year.

3.3.4.3.2 Route Variability and time-Sensitivity

Trucks carrying building materials at the national and regional levels tend to

Total	Operating Range	Fleet Size	Route Variability	Time Sensitivity
286,200*	National (> 200 Miles) 60,100 (21%)	500+ Trucks 8,400 (14%)	Variable 2,100 (25%)	Time Sensitive 100 (5%)
				Non-Time Sensitive 2,000 (95%)
			Fixed 6,300 (75%)	Time Sensitive 300 (5%)
				Non-Time Sensitive 600 (95%)
		100-499 Trucks 16,800 (28%)	Variable 4,200 (25%)	Time Sensitive 200 (5%)
				Non-Time Sensitive 400 (95%)
			Fixed 12,600 (75%)	Time Sensitive 600 (5%)
				Non-Time Sensitive 1,200 (95%)
		20-99 Trucks 13,200 (22%)	Variable 3,300 (25%)	Time Sensitive 200 (5%)
				Non-Time Sensitive 3,100 (95%)
			Fixed 9,900 (75%)	Time Sensitive 500 (5%)
				Non-Time Sensitive 9,400 (95%)
		6-19 Trucks 6,600 (11%)	Variable 1,700 (25%)	Time Sensitive 100 (5%)
				Non-Time Sensitive 1,600 (95%)
			Fixed 4,900 (75%)	Time Sensitive 200 (5%)
				Non-Time Sensitive 4,700 (95%)
		1-5 Trucks 14,400 (24%)	Variable 3,600 (25%)	Time Sensitive 200 (5%)
				Non-Time Sensitive 3,400 (95%)
			Fixed 10,800 (75%)	Time Sensitive 500 (5%)
				Non-Time Sensitive 10,300 (95%)
	Regional (50-200 Miles) 91,600 (32%)	500+ Trucks 5,500 (6%)	Variable 1,400 (25%)	Time Sensitive 100 (5%)
				Non-Time Sensitive 1,300 (95%)
			Fixed 4,100 (75%)	Time Sensitive 200 (5%)
				Non-Time Sensitive 3,900 (95%)
		100-499 Trucks 20,200 (22%)	Variable 5,100 (25%)	Time Sensitive 300 (5%)
				Non-Time Sensitive 4,800 (95%)
			Fixed 15,100 (75%)	Time Sensitive 800 (5%)
				Non-Time Sensitive 14,300 (95%)
		20-99 Trucks 24,700 (27%)	Variable 6,200 (25%)	Time Sensitive 300 (5%)
				Non-Time Sensitive 5,900 (95%)
			Fixed 18,500 (75%)	Time Sensitive 900 (5%)
				Non-Time Sensitive 17,600 (95%)
		6-19 Trucks 21,100 (23%)	Variable 10,500 (50%)	Time Sensitive 500 (5%)
				Non-Time Sensitive 10,000 (95%)
			Fixed 10,500 (50%)	Time Sensitive 500 (5%)
				Non-Time Sensitive 10,000 (95%)
		1-5 Trucks 19,200 (21%)	Variable 9,600 (50%)	Time Sensitive 500 (5%)
				Non-Time Sensitive 6,800 (95%)
			Fixed 9,600 (50%)	Time Sensitive 500 (5%)
				Non-Time Sensitive 6,800 (95%)
	Local (< 50 Miles) 131,700 (46%)	500+ Trucks 1,300 (1%)	Variable 100 (5%)	Time Sensitive 100 (25%)
				Non-Time Sensitive 100 (75%)
			Fixed 1,200 (95%)	Time Sensitive 300 (25%)
				Non-Time Sensitive 900 (75%)
		100-499 Trucks 19,800 (15%)	Variable 1,000 (5%)	Time Sensitive 200 (25%)
				Non-Time Sensitive 700 (75%)
			Fixed 18,800 (95%)	Time Sensitive 4,700 (25%)
				Non-Time Sensitive 14,100 (75%)
		20-99 Trucks 40,800 (31%)	Variable 2,000 (5%)	Time Sensitive 500 (25%)
				Non-Time Sensitive 1,500 (75%)
			Fixed 38,800 (95%)	Time Sensitive 9,700 (25%)
				Non-Time Sensitive 29,100 (75%)
		6-19 Trucks 30,300 (23%)	Variable 7,600 (25%)	Time Sensitive 1,900 (25%)
				Non-Time Sensitive 5,700 (75%)
			Fixed 22,700 (75%)	Time Sensitive 5,700 (25%)
				Non-Time Sensitive 17,100 (75%)
		1-5 Trucks 38,200 (29%)	Variable 9,500 (25%)	Time Sensitive 2,400 (25%)
				Non-Time Sensitive 7,100 (75%)
			Fixed 28,600 (75%)	Time Sensitive 7,200 (25%)
				Non-Time Sensitive 21,400 (75%)

* All figures are rounded to the nearest 100.

Figure 6. Representative Market Taxonomy: Building Materials (Trucks Over 10,000 Pounds)

operate on mostly fixed routes. These trucks are primarily delivering materials to storage and distribution facilities, rather than to individual construction sites. At the local level, the situation essentially reverses; most trucks are delivering to individual construction sites, and, hence, operate on highly variable routes. As with petroleum and processed foods, srnaller fleets may experience higher route variability than do larger fleets. Thus, we estimate that at the national and regional levels, five percent of building materials trucks in large fleets (100 or more trucks) operate on variable routes, and 25 percent of trucks in smaller fleets (fewer than 100 trucks) operate on variable routes. We estimate that at the local level 75 percent of trucks in large fleets and 95 percent of trucks in smaller fleets operate on variable routes.

It can be assumed that national and regional deliveries of building materials are not time-sensitive because these materials are generally stockpiled in large quantities. At the local level, trucks are primarily delivering building materials to individual construction sites, so delivery routes may change weekly or even daily. Furthermore, since a late delivery of building materials to a construction site may delay the entire job, local delivery of building materials is highly time-sensitive. 'Thus, we estimate that at the national and regional levels, five percent of building materials trucks in large fleets and 25 percent of trucks in smaller fleets are making time-sensitive deliveries. Locally, 75 percent of trucks in large fleets and 95 percent of trucks in small fleets operate on time-sensitive schedules.

CHAPTER 4: AHS COMMERCIAL TRUCK CONFIGURATION

The AHS technologies and services that might be available to the trucking industry need to be characterized for further analysis. Because the Representative System Configurations (RSC) developed by Calspan do not describe the world as seen by a motor earner manager, an alternative set of "clusters" of AHS services and technologies is developed with respect to the characteristics of greatest interest to the motor carrier: how much control the driver has over the vehicle, and how much investment in technology will be required for each vehicle.

4.1 BASIC REPRESENTATIVE SYSTEMS CONFIGURATIONS (RSCS)

The Calspan Corporation developed the Representative System Configurations (RSCs) as a system for classifying variations of AHS . Under the RSC approach, each AHS is classified in relation to the following dimensions:

- The amount of dedicated roadway infrastructure required.
- The degree of command, control, and communications required.
- The types of vehicles (i.e., single vehicle equivalents, such as private automobiles, and/or multiple vehicle equivalents such as large trucks).

The Representative System Configurations (RSC) developed by Calspan do not describe the world as seen by a motor carrier manager. To address this deficiency, an alternative set of "clusters" of AHS services and technologies is developed from the motor carriers perspective. 'These clusters array various bundles of services and technologies according to the factors that are the most important to the motor carrier: the options for control of the vehicle (i.e., from complete control by the driver to complete control by the infrastructure), and the location of control systems (i.e., completely within the vehicle or completely within the guideway). This framework is illustrated in figure 7.

4.2 MOTOR CARRIER AHS CLUSTER MAP: OVERVIEW

Most AHS categorizations to date rely on the physical characteristics of roadway design and layout (e.g., segregated vs. non-segregated, barriers vs. without barriers, and guideways vs. special lanes) as their distinguishing characteristics, but these categorizations address only infrastructure differences. There are two major variables, independent of technology or or configurat ion that must be addressed in order to categorize AHS scenarios: the agent of vehicle control (driver vs. infrastructure) and the location of vehicle control (vehicle vs. guideway). For motor carriers, these are the critical variables.

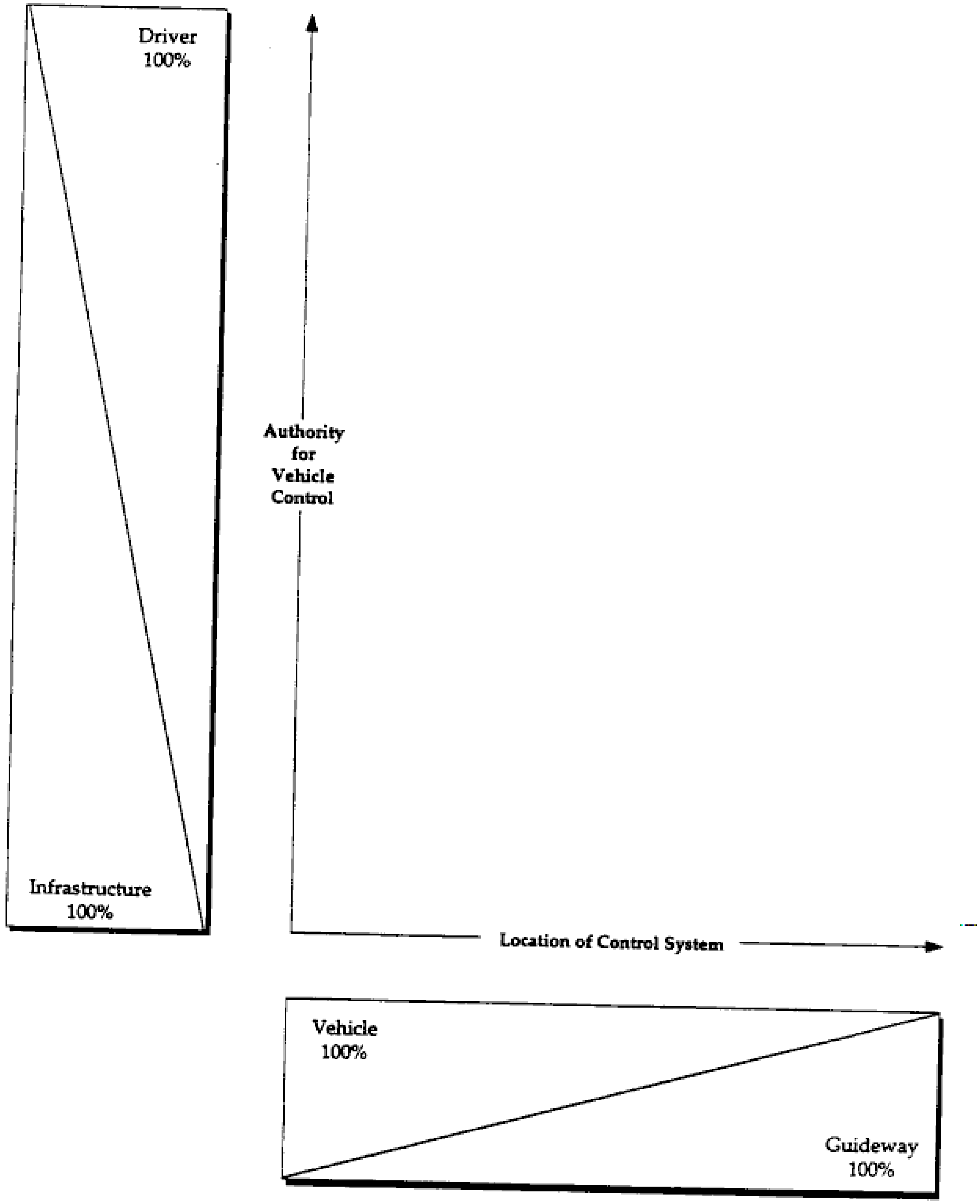


Figure 7. Framework for Mapping AHS Technology and Services

4.2.1 Authority for Vehicle Control: Driver vs. Infrastructure

The "authority for vehicle control" describes options for control of the vehicle, ranging from complete control by the driver to complete control by the infrastructure. This is a critical characteristic for the motor carrier because it affects such business considerations as driver training, wage rates, and the carrier's insurance costs and liability exposure, which have become a critical business factor, especially for carriers transporting hazardous materials.

The degree of freedom allowed to the operator of a vehicle is an important factor in the classification of AHS scenarios from the motor carrier's point of view. Under various AHS configurations, the authority for vehicle control may shift from the driver to the infrastructure. Today's driving situation has the largest possible number of degrees of freedom: operators have control over routing, speed, braking, steering, forward/rearward separation from other vehicles, and lane changing. The least amount of freedom would be in a system analogous to a fixed-guideway mass transportation system, where passengers or freight are moved in publicly provided vehicles or on pallets along pre-determined routes, and no decision making other than choosing to enter or exit the system is required. It should be noted that increasing the amount of "automation" in an AHS does not necessarily reduce the amount of freedom available to an operator.

4.2.2 Location of Control Systems: Vehicle vs. Guldeway

The "location of control Systems" describes options for the placement of AHS controls, ranging from installation on the vehicle to installation in the guideway. This characteristic is critical because it affects business considerations such as the cost of the vehicle; highway cost allocation decisions made by state highway agencies, which directly affect the tax rates paid by motor carriers; and the ability of the carrier to gain access to, and therefore any competitive advantages from, AHS technologies and services.

Under an AHS , the control of a vehicle's brakes, throttle, and steering system is located either within the vehicle (i.e., power brakes or anti-lock braking systems) or in the surrounding infrastructure (i.e., roadways, guideways, or "pallets"). Vehicle actions usually are controlled by some combination of both vehicle and guideway in each AHS configuration. For motor carriers, the combination is crucial because it affects the need for direct investment in their vehicles (vs. possible indirect investment in the infrastructure through various taxes and fees).

Figure 8 illustrates the array of AHS configurations, or "clusters," based on these two variables. Each mapped cluster has a horizontal range to indicate the various degrees of possible guideway involvement. Within any particular "platooning" cluster, for example, platoon establishment might be determined by individual vehicles, or the guideway may have the sole authority to determine platoon eligibility, entrance requirements, destination, and size. As well as accommodating this variability, the horizontal ranges help represent the gradual transitions between adjacent clusters.

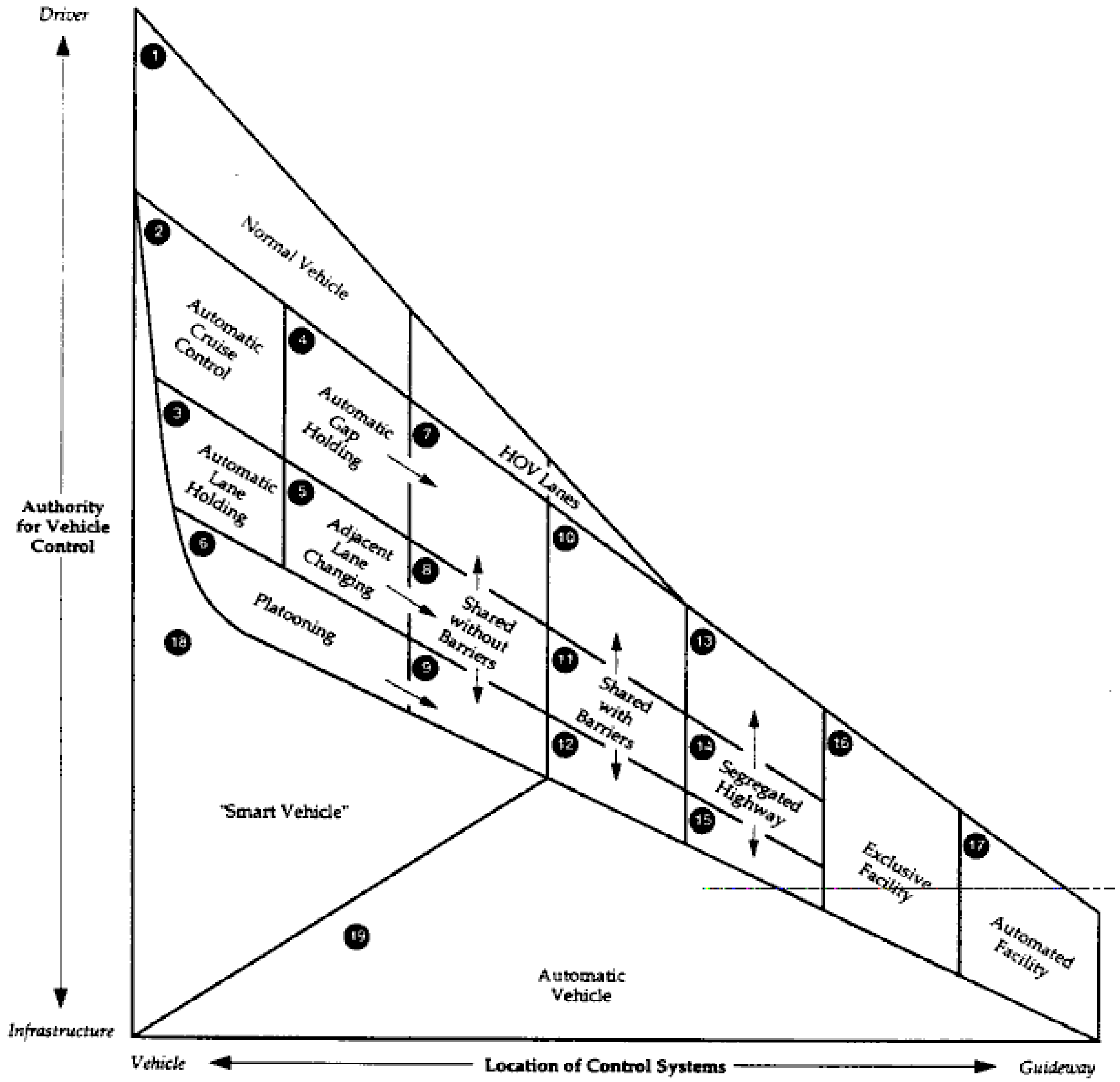


Figure 8. AHS Cluster Map

Each mapped cluster also has a vertical range to indicate the various degrees of vehicle control authority (driver vs. infrastructure). Within any particular "shared™ highway cluster, for example, independence can be greatly affected by the number of lanes available, the laws and restrictions on non-AHS vehicles, or the ease of access to and egress from the system. As well as accommodating this variability, the vertical ranges represent the gradual transition of driver independence between adjacent clusters with the same level of guideway control.

To provide a basic understanding of the roadway requirements for these clusters, the ™right-of-way" requirements for each cluster have been summarized as able to use the existing right-of-way ("existing"), requiring modification of the existing right-of-way ("modified"), or requiring that new right-of-way be secured ("new"). These are summarized in figure 9.

4.3 AHS CLUSTER DESCRIPTIONS

In attached appendix A, detailed information is provided for each of the 19 AHS clusters depicted in figure 8. This information is grouped into four categories:

- Functional Descrlptlon/Technologles. This category provides a functional definition of the cluster, and a listing of the technologies likely to be employed.

- Distinguishing Variables. This category describes the cluster in terms of its major distinguishing characteristics:
  - The authority for vehicle control.
  - The location of control systems.
  - Cost factors (both per vehicle and system-wide).
  - Right-of-way requirements.

- Positive Factors. This category describes the primary positive factors associated with each cluster, with particular reference to motor carriers.

- Negative Factors. This category describes the principal negative factors associated with each cluster, emphasizing the effects on motor carrier operations. Where appropriate, descriptions of any potential impacts on individual drivers, such as concerns about complacency, are included in this category.

It should be noted that these descriptions represent only the most likely configurations within each cluster, since each cluster includes a range of possible options. In addition, it may be possible to define additional clusters by merging components of adjacent clusters on the current map.

AHS Cluster	Right of Way		
	Existing	Modified (Extra Lanes, etc.)	New
1. Conventional Vehicle	•		
2. Automatic Cruise Control (ACC)	•		
3. Automated Lane Holding (ALH)	•		
4. Automated Gap Control (AGC)	•		
5. Adjacent Lane changing (ALC)	•		
6. Platooning	•		
7. AGC/Shared Right of Way/No Barriers		•	
8. ALC/Shared Right of Way/No Barriers		•	
9. Platooning/Shared Right of Way/No Barriers		•	
10. AGE/Shared Right of Way/With Barriers		•	
11. ALC/Shared Right of Way/With Barriers		•	
12. Platooning/ Shared Right of Way/With Barriers		•	
13. AGE/Segregated Highway			•
14. ALC/Segregated Highway			•
15. Platooning/Segregated Highway			•
16. Exclusive Facility/Private Vehicles			•
17. Automated Facility/Provided Vehicles			•
18. Smart Vehicle/Driver and System Control	. •	•	
19. Automatic Vehicle/Total System Control		•	•

Figure 9. Basic Right of Way Requirements for AHS Clusters

Figure 10 illustrates the overlap between the 13 Calspan RSCs and the AHS clusters. A review of this overlap indicates that it is not extensive, due to the fact that the AHS clusters are based on a different set of variables from those used in the development of the RSCs.

4.3.1 Technology Limitations

Certain physical and performance characteristics of large trucks limit the degree to which trucks can be accommodated by the various AHS clusters. For example, compared to single-vehicle equivalents such as automobiles, the commercial vehicles included in this analysis are larger in both length and width. Because of their size, trucks require wider lanes, longer' entry and exit ramps, and greater frontward and rearward separation from preceding and following vehicles than do automobiles. These requirements have a number of implications for AHS , particularly for configurations that include mixed traffic (i.e., including both cars and trucks). Figure 11 illustrates the areas in which truck characteristics may limit the applicability of various AHS clusters. This analysis focuses on the primary AHS clusters, rather than on all of their alternative configuration (e.g., the analysis of "platooning" does not distinguish among Clusters 6, 9, 12, and 15).

First, the requirement for wider lanes may conflict with a desire to maximize capacity by getting the largest possible number of lanes out of the smallest possible right-of-way. Technologies such as adjacent lane changing and automated lane holding may make it possible for lanes to be as few as eight feet wide; such lanes may enable an AHS to accommodate the maximum possible number of automobiles, but they effectively would preclude truck traffic from the facility.

The requirements for greater headway and rearward separation in mixed traffic increase the complexity of the technology required for both automated lane changing and automated gap control. Another factor affecting the application of both of these technologies is the relatively slower acceleration and deceleration of trucks as compared to cars. This factor contributes to trucks' need for greater separation from preceding and following vehicles.

To accommodate the size and acceleration characteristics of trucks, adjustments must be made to the infrastructure requirements (as compared to automobile-only traffic). For instance, in addition to wider lanes, trucks also require longer entry and exit ramps.

The size of trucks relative to cars also has a variety of implications for platooning. In mixed traffic, all-truck platoons might be seen as a significant obstacle by other vehicles. Including cars and trucks in the same platoon increases the sophistication of the technology required to assure safety because of their varying acceleration and braking performance.

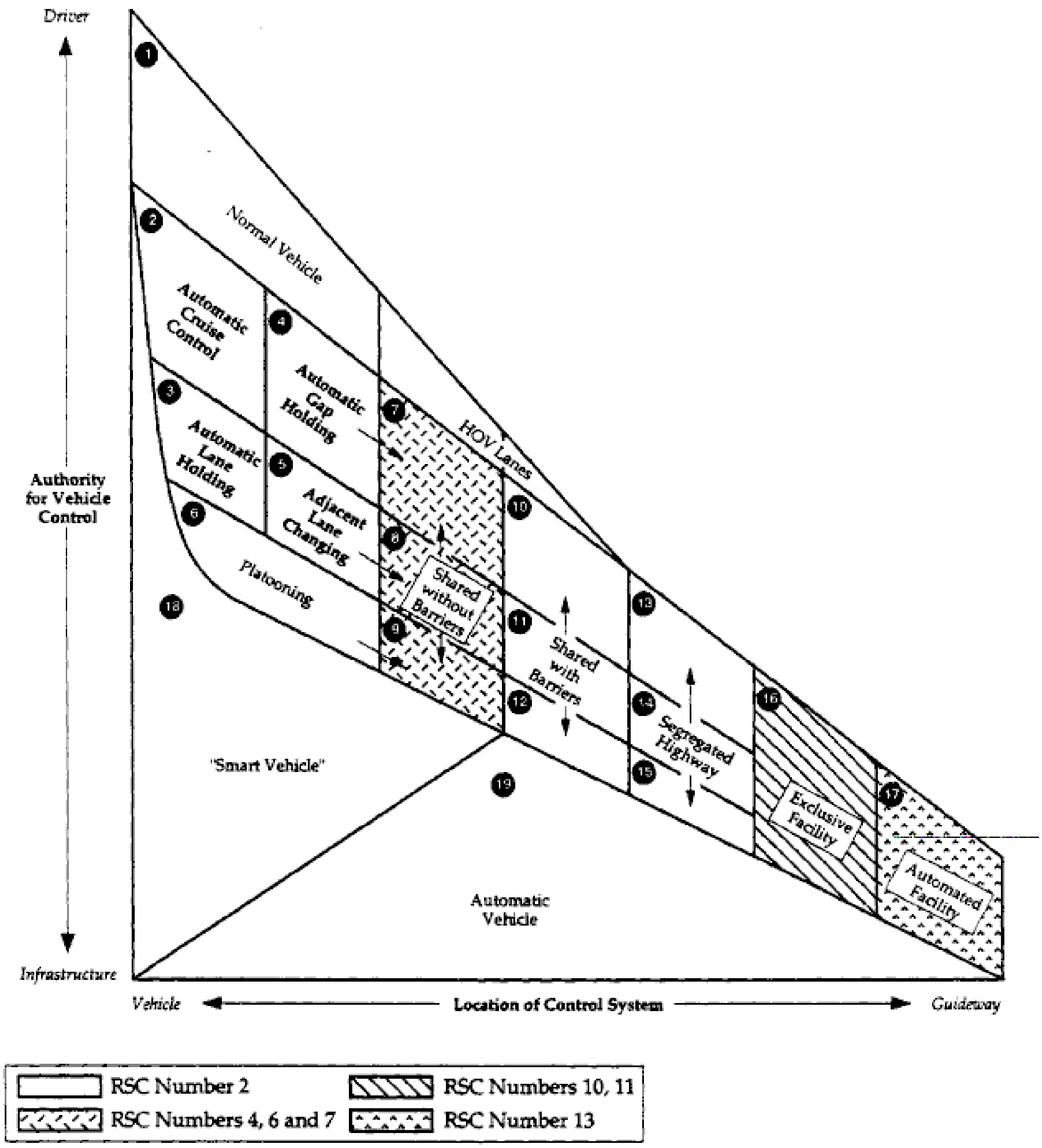


Figure 10. Relationship of Calspan RSCs to AHS Clusters

Performance Characteristics	**AHS Clusters**								
	Automatic Cruise Control	Automated Lane Holding	Automated Gap Control	Adjacent Lane Changing	Platooning	Exclusive Facility	Automated Facility	"Smart" Vehicle	Automatic Vehicle
• Size		•	•	•	•	•		•	
• Acceleration			•	•	•	•		•	
• GearShifting	•		•		•	•		•	
• Cargo Transfer							•		

• Technology Limitation

Figure 11. Technical Limitations on application of ASH Clusters Due to Truck Performance Characteristics

Another distinguishing characteristic of trucks is their multiple gear, manual transmissions; automated transmissions generally are not available on the largest trucks (class 8), as they are for automobiles. Frequent gear shifting is required, particularly when the terrain is not absolutely flat and speed conditions are not constant. These requirements could interfere with clusters and technologies incorporating automatic throttle control, such as automatic cruise control.

Finally, trucks pose special problems for any AHS cluster that includes provided vehicles. Under these scenarios, freight being moved by truck must be transferred from private motor carriers onto the system's pallets or vehicles. Although it may be relatively simple to provide pallets of varying sizes to accommodate different types of traffic, the inefficiencies involved in the cargo transfer may overcome any time savings afforded by the AHS , particularly for short-haul applications.[1]

4.3.2 Market Segments

'This analysis uses a two-step process to approximate the relative potentials for adoption of AHS by the commercial motor carrier industry. First, each AHS cluster is evaluated against the operational characteristics upon which the market segmentation taxonomies are based (see figure 12). This allows us to identify the segments of the trucking industry which have the potential to adopt AHS , and the segments for which the use of AHS seems unlikely. Based on this information, we then use the taxonomies to estimate the maximum approximate potential size (i.e., numbers of trucks) of the market segment for each AHS , within each of the three representative markets (e.g, liquid petroleum, building materials, and processed foods). 'These market segment numbers are approximated to characterize an order of magnitude relationship not to imply a specific tabulated number.

Because this analysis estimates maximum potential market segments for AHS , the analysis is based on two important simplifying assumptions. First, the analysis assumes that the current technical impediments to the use of certain AHS on trucks will be overcome. For example, although automatic cruise control (ACC) is currently not available on many larger trucks (due to insufficient torque-to-weight ratios and manual transmissions), future technological advances may make ACC viable for all sizes of trucks.

'The second simplifying assumption is that the analysis does not address all of the alternative configurations of each AHS cluster (e.g, shared right-of-way versus exclusive right-of-way, mixed traffic versus trucks only). 'The characteristics of some of these alternative configurations could limit the applicability of certain AHS , and therefore reduce their market segments. 'Thus, the figures that this analysis provides represent the estimated "upper bounds" of the market segments for each AHS .

	AHS Clusters								
Operating Characteristics	Automatic Cruise Control	Automated Lane Holding	Automated Gap Control	Adjacent Lane Changing	Platooning	Exclusive Facility	Automated Facility	“Smart” Vehicle	Automatic Vehicle
Operating Range									
• Local(<5OMiles)	•	O	O	O	•	•	•	O	O
• Regional (50-200 Miles)	O	O	O	O	O	O	•	O	O
• National(200+Miles)	O	O	•	•	O	O	O	O	O
Fleet Size									
• 1-5 trucks	O	•	•	•	•	•	O	•	•
• 6-l9 Trucks	O	•	•	•	•	•	O	•	•
• 20-99 Trucks	O	O	O	O	O	O	O	O	O
• l00-499 Trucks	O	O	O	O	O	O	O	O	O
• 500+ Trucks	O	O	O	O	O	O	O	O	O
Route Varlability									
• Variable	O	•	O	•	•	•	•	O	O
• Fixed	O	O	O	O	O	O	O	O	O
Time Sensitivity									
• TimeSensitive	O	O	O	O	O	O	O	O	O
• Non-TimeSensitive	O	O	O	O	•	•	•	•	•

O Potential Market Segment • Not a Potential Market Segment

Figure 12. Potential Market Segments of AHS Clusters

EVALUATION OF AHS CLUSTERS WITH RESPECT TO OPERATIONAL CHARACTERISTICS

AUTOMATIC CRUISE CONTROL (ACC)

Operating Range

The use of ACC is not practical in congested urban driving where vehicle speeds change frequently and where travel distances between stops are short. The potential market for ACC is therefore limited to regional and national trucking operations (see figure 12). As mentioned earlier, this conclusion is based on the assumption that automatic transmissions will be available for large trucks in the future, thereby permitting the widespread use of ACC at the regional and national levels. It is important to recognize, however, that at present the potential market for ACC is much smaller. 'The majority of trucks operating at the regional and national levels are large (at the national level, for example 90 percent of trucks weigh over 11,804 kilograms [26,000 pounds]). For these large trucks, automatic transmissions generally are not currently available.

Fleet Size

Cruise control is an inexpensive technology. In the future, it should be within the reach of all trucking companies, regardless of size. Thus, all fleet sizes are included in the potential market segment for ACC.

Route Variability

Cruise control is equally applicable to trucks that operate on fixed routes and those whose routing varies.

Time Sensitivity

Cruise control is equally applicable to trucks making time-sensitive deliveries and those whose deliveries are non-time sensitive.

Estimated Maximum Potential Market Segment for Automatic Cruise Control

'The potential market segment for automatic cruise control includes trucks operating regionally and nationally, in all fleet sizes, on fixed and variable routes, and on time-sensitive and non-time-sensitive schedules.

- Liquid Petroleum: Among trucks carrying liquid petroleum, the potential market segment for automatic cruise control is estimated to be approximately 29,500 trucks, or 27 percent of the entire national fleet of such trucks (see figure 13).

AHS Clusters	Representative Market Segments					
	Liquid Petroleum		Building Materials		Processed Foods	
	Number of Trucks	Percent of Fleet*	Number of Trucks	Percent of Fleet	Number of Trucks	Percent of Fleet
Automatic Cruise Control (ACC)	29,500	27%	97,700	20%	150,100	52%
Automated Lane Holding (ALH)	18,500	17%	36,700	7%	125,300	44%
Automated Gap Control (AGE)	23,300	21%	110,800	22%	112,300	39%
Adjacent Lane Changing (ALC)	17,400	16%	27,700	6%	96,500	34%
Platooning	700	<1%	1,500	<1%	3,300	<1%
Exclusive Facility	700	<1%	1,500	<1%	3,300	<1%
Automated Gap Control	400	<1%	4,300	<1%	2,100	<1%
"Smart Vehicle"/Automa tic Vehicle	4,600	4%	80,400	16%	20,000	7%

* Percent of fleet is the percentage of the total number of trucks carrying each commodity.

Figure 13. Estimated Maximum Potential Market Segments for ASH Clusters

- Building Materials: The potential market segment for automatic cruise control among building materials trucks is approximately estimated to be around 97,700 vehicles, or 20 percent of the entire national fleet of such trucks.

- Processed Foods: The potential market segment for automatic cruise control among processed foods trucks is estimated to about 150,100 vehicles, or 52 percent of the entire national fleet of such trucks.

AUTOMATED LANE HOLDING (ALH) Operating Rang.

At the local and regional operating ranges, automatic lane holding (ALH) would increase safety on congested roads by preventing trucks from drifting out of their lanes. For long-haul (i.e., national) operations, ALH could increase truck safety by preventing lane drifting due to driver fatigue on long trips. 'Thus, all operating ranges are potential market segments for ALH.

Fleet Size

All ALH systems would require the installation of some type of automatic steering controls and vehicle position sensors onboard the vehicle. Therefore, ALH technology would add to the cost of each truck, and might be prohibitively expensive for small trucking firms. For the purposes of estimating the potential market segment for ALH, it is assumed that trucks in small fleets (fewer than 20 trucks) will not adopt ALH.

Route Variability

In addition to requiring onboard sensing and control devices, ALH also requires devices within or along the roadway (e.g., imbedded magnetic nails). Consequently, only trucks which operate on fixed routes are likely to be interested in ALH. Therefore, this analysis limits the potential market segment for ALH to fixed-route trucks.

Because it offers safety benefits and potential time-savings benefits, AHS would be of equal benefit to trucks making time-sensitive deliveries and to those whose operating schedules are less stringent This analysis therefore includes both time-sensitive and non-time-sensitive trucks in the potential market segment for AHS .

Estimated Maximum Potential Market Segment for Automated Lane Holding

The potential market segment for automated lane holding includes trucks operating locally, regionally and nationally, in fleets of 20 or more trucks, on fixed routes and on time-sensitive and non-time-sensitive schedules.

- Liquid Petroleum: 'The estimated potential market segment for automated lane holding among liquid petroleum trucks is approximately 18,500 vehicles, or 17 percent of the entire national fleet of such trucks.

- Building Materials: 'The estimated potential market segment for automated lane holding among liquid petroleum trucks is only around 36,600 vehicles, or seven percent of the entire national fleet of such trucks.

- Processed Foods: The estimated potential market segment for automatic lane holding among processed foods trucks is about 125,300 vehicles, or 44 percent of the entire national fleet of such trucks.

AUTOMATED GAP CONTROL (AGC)

Operating Range

Automated gap control would provide safety benefits to individual trucks by preventing rear-end collisions. It would also allow for increased roadway capacity, since trucks could safely follow each other more closely than under present conditions. AGC would be useful to trucks operating locally and regionally, where congested conditions increase the chances of rear-end collisions and where increasing roadway capacity is often a critical concern. At the national level, traffic volumes are generally much lower; neither rear-end collisions nor insufficient capacity are major concerns. This analysis, therefore, limits the potential market segment for AGC to local and regional trucks.

Fleet Size

As with automated lane holding, automated gap control would require onboard control systems. AGC systems would monitor the distance to the preceding vehicle, and would operate the throttle and brakes as needed to maintain a constant, following distance. Because it would add to the coot of each truck~ AGC might be out of reach of small firms. 'Thus, this analysis limits the potential market segment for AGC to trucks in fleets of 20 or more vehicles.

Route Variability

AGC could be implemented using only onboard Systems; no roadway-based devices are required. Because of this, trucks operating on variable routes could make full use of AGC, regardless of the roadways on which they traveled. Therefore, trucks operating on both fixed and variable routes are included in the potential market segment for AGC.

Time sensititvity

AGC is primarily a safety-enhancing system, which would be of equal use to both time-sensitive and non-time-sensitive trucks$_1$ so both are included in the potential market segment of AGC.

Estimated Maximum Potential Market Segment for Automated Gap Control

The potential market segment for AGE includes trucks operating locally and regionally, in fleets of 20 or more vehicles, on fixed and variable routes, and on time-sensitive and non-time-sensitive schedules.

- Liquid Petroleum: 'The estimated potential market segment for AGC among trucks carrying liquid petroleum is approximately 23,300 vehicles, or 21 percent of the total national fleet of such trucks.

- Building Materials: The estimated potential market segment for AGC among trucks carrying building materials is around 110,800 vehicles, or 22 percent of the total national fleet of such trucks.

- Processed Foods: The estimated potential market segment for AGC among trucks carrying processed foods is about 112,300 vehicles, or 39 percent of the total national fleet of such trucks.

ADJACENT LANE CHANGING (ALC)

Operating Range

As is the case for automated lane holding and automated gap control, ALC would be beneficial primarily on local and regional roads, where high traffic volumes make lane changing potentially dangerous for large trucks. 'This analysis excludes national trucks from the potential market segment for ALC.

Fleet Size

ALC would impose per-truck costs due to required onboard sensors and throttle, brake and steering controls. 'These costs are likely to put ALC out of reach of small firms, so trucks operating in fleets of fewer than 20 vehicles are excluded from the potential market segment for ALC.

Route Variability

All ALC systems would require some kind of roadway-based systems to monitor the positions of vehicles in each lane. Because of this, trucks whose operations take them repetitively over the same routes may be more interested in using ALC than would trucks operating on variable routes. 'Therefore, this analysis limits the potential market segment for ALC to fixed-route trucks.

Time-Sensitvity

ALC is primarily a safety-enhancing system, which would be of equal use to both time-sensitive and non-time-sensitive trucks; consequently, both are included in the potential market segment for ALC.

Estimated Maximum Potential Market Segment for Adjacent Lane Changing

The estimated maximum market segment for ALC includes trucks operating locally and regionally, in fleets of 20 or more vehicles, on fixed routes, and on time-sensitive and non-time-sensitive schedules.

- Liquid Petroleum: The estimated maximum potential market segment for ALC among trucks carrying liquid petroleum is approximately 17,400 vehicles, or 16 percent of the total national fleet of such trucks.

- Building Materials: 'The estimated maximum potential market segment for ALC among trucks carrying building materials is only around 27,700 vehicles, or 6 percent of the total national fleet of such trucks.

- Processed Foods: The estimated maximum potential market segment for ALC among trucks carrying processed foods is about 96,500 vehicles, or 34 percent of the total national fleet of such trucks.

PLATOONING

Operating Range

For trucks operating at the local level, the time required to approach and enter a platoon (time which could in some instances include waiting in an acceleration lane while a platoon approached or was being formed) would outweigh the benefits of traveling in the platoon. 'Thus the potential market segment for platooning is limited to trucks operating regionally and nationally.

Fleet Size

Most platooning would require sophisticated onboard sensing and control systems. 'Thus platooning would be too expensive for smaller firms. 'Trucks in fleets of fewer than 20 vehicles are excluded from the market segment for platooning.

Route Variability

All platooning systems would require some kind of roadway-based systems to monitor the positions of vehicles in each lane. Because of this, trucks whose operations take them repetitively over the same routes may be more likely to be able to use platooning. 'Therefore, this analysis limits the potential market segment for platooning to fixed-route trucks.

Time-Sensitivity

For firms whose delivery schedules are not time-sensitive, the cost of installing platooning technology may not be justifiable. For time-sensitive trucks, however, the potential time savings offered by platooning may justify the additional expense. 'This analysis limits the market segment for platooning to time-sensitive trucks.

Estimated Maximum Potential Market Segment for Platooning

'The estimated market segment for platooning includes trucks operating regionally and nationally, in fleets of 20 or more vehicles, on fixed routes, and on time-sensitive schedules.

- Liquid Petroleum: 'The estimated potential market segment for platooning among trucks carrying liquid petroleum is approximately only 700 vehicles, or less than 1 percent of the total national fleet of such trucks.
- Building Materials: 'The estimated potential market segment for platooning among trucks carrying building materials is only around 1,500 vehicles, or less than 1 percent of the total national fleet of such trucks.
- Processed Foods: The estimated potential market segment for platooning among trucks carrying processed foods is only about 3,300 vehicles, or 1 percent of the total national fleet of such trucks.

EXCLUSIVE FACILITY

Operating Range

For trucks operating locally, the time required to access an exclusive facility may outweigh any time savings gained from using the facility'. In addition, these trucks travel more often on local streets rather than on limited-access highways. 'This analysis excludes local trucks from the potential market segment for exclusive AHS facilities.

Fleet Size

The costs associated with using exclusive facilities may make them too expensive for small trucking firms. 'The potential market segment for exclusive facilities is limited to trucks in fleets of 20 or more vehicles.

Route Variability

Variable-route trucks would be far less likely to benefit from exclusive facilities than would trucks whose operations took them repetitively over the same routes. Thus, variable-route trucks are excluded from the potential market segment for exclusive facilities.

Time-Sensitivity

For firms whose delivery schedules are not time-sensitive the additional time and costs associated with the use of exclusive faculties may not be worthwhile. For time-sensitive trucks, however, the potential time savings offered by exclusive facilities may justify the additional expense. 'This analysis limits the market segment for exclusive facilities to time-sensitive trucks.

Estimated Maximum Potential Market Segment for Exclusive Facilities

'The potential market segment for exclusive facilities includes those trucks operating regionally or nationally, in fleets of 20 or more vehicles, on fixed routes and on time-sensitive schedules.

- Liquid Petroleum: The estimated potential market segment for exclusive facilities among trucks carrying liquid petroleum is approximately only 700 vehicles, or less than 1 percent of the total national fleet of such trucks.

- Building Materials: 'The estimated potential market segment for exclusive facilities among trucks carrying building materials is only around 1,500 vehicles, or less than 1 percent of the total national fleet of such trucks.

- Processed Foods: The estimated potential market segment for exclusive facilities among trucks carrying processed foods is only about 3,300 vehicles, or 1 percent of the total national fleet of such trucks.

AUTOMATED FACILITIES

Operating Range

Use of an automated facility would require a truck to unload its contents into a provided vehicle, or to drive onto a “pallet” for transport on the system. Because of the time required for the transfer, automated facilities would only be appropriate for trucks making long-haul trips. 'The potential market segment for automated facilities includes only trucks operating nationally.

Fleet Size

Unlike previous AHS , which require onboard control technologies, automated facilities would use provided vehicles or pallets; individual trucks would not need any onboard AHS technologies to use automated facilities. 'Therefore, the potential market segment for automated facilities includes trucks from all fleet sizes.

Route Variability

Variable-route trucks would be far less likely to benefit from automated facilities than would trucks whose operations took them repetitively over the same routes. 'Thus variable-route trucks are excluded from the potential market segment for automated facilities.

Time-Sensitivity

For firms whose delivery schedules are not time-sensitive the additional time and costs associated with the use of automated faculties may not be worthwhile. For time-sensitive trucks, however, the potential time savings offered by automated facilities may justify the additional expense. This analysis limits the market segment for exclusive facilities to time-sensitive trucks.

Estimated Maximum Potential Market Segment for Automated Facilities

'The estimated market segment for automated facilities includes trucks operating nationally, in all fleet sizes, on fixed routes, and on time-sensitive and noontime-sensitive schedules.

- Liquid Petroleum: The estimated potential market segment for automated facilities among trucks carrying liquid petroleum is approximately only 400 vehicles, or less than 1 percent of the total national fleet of such trucks.
- Building Materials: 'The estimated potential market segment for automated facilities among trucks carrying building materials is around only 4,300 vehicles, or less than 1 percent of the total national fleet of such trucks.
- Processed Foods: 'The estimated potential market segment for automated facilities among trucks carrying processed foods is about only 2,100 vehicles, or less than 1 percent of the total national fleet of such trucks.

"SMART" VEHICLE OR AUTOMATIC VEHICLE

Because "smart" vehicles and automatic vehicles represent two variations of the same AHS , their potential market segments can be assumed to be identical. 'Therefore, this discussion combines the analysis of both smart vehicles and automatic vehicles.

Operating Range

Smart vehicles and automatic vehicles could provide safety and time-savings benefits to trucks operating at the local, regional, and national levels; this analysis includes all three operating ranges in the potential market segment for smart vehicles and automatic vehicles.

Fleet Size

Smart vehicles and automatic vehicles would represent a distinctly different level of technology from standard trucks; they would utilize multiple sensing and control systems, and are likely to be much more expensive than conventional vehicles. For this reason, smart vehicles and automatic vehicles would be prohibitively expensive for small firms. 'This analysis excludes trucks from fleets of under 20 vehicles from the potential market segment for smart vehicles and automatic vehicles.

Route Variability

Because their AHS would be entirely onboard, smart vehicles and automatic vehicles would operate on all roadways, and would therefore be equally beneficial to trucks that use the same routes repetitively and to trucks whose routing varies.

Time-Sensitivity

It is unlikely that firms whose deliveries are non-time sensitive would be able to justify the expense of smart vehicles or automatic vehicles. This analysis includes only time-sensitive trucks in the potential market segment for smart vehicles and automatic vehicles.

Estimated Maximum Potential Market Segment for Automated Facilities

'The estimated potential market segment for smart vehicles or automatic vehicles includes trucks operating locally, regionally and nationally, in fleets of 20 or more vehicles, on fixed and variable routes, and on time-sensitive schedules.

- Liquid Petroleum: 'The estimated potential market segment for smart vehicles or automatic vehicles among trucks carrying liquid petroleum is only approximately 4,600 vehicles, or 4 percent of the total national fleet of such trucks.

- Building Materials: The estimated potential market segment for smart vehicles or automatic vehicles among trucks carrying building materials is around 80,400 vehicles, or 16 percent of the total national fleet of such trucks.

- Processed Foods: The estimated potential market segment for smart vehicles or automatic vehicles among trucks carrying processed foods is about only 20,000 vehicles, or 7 percent of the total national fleet of such trucks.

CHAPTER 5: TRANSIT UTILIZATION OF THE AUTOMATED HIGHWAY

This section of the Commercial and Transit Report presents a review of the possible role of Automated Highway Systems technology in the development of new systems of public transportation. In order the better understand the needs of the transit industry, a historical analysis was undertaken of major research efforts of the past three decades. 'These research efforts focused on the uses and limitations of bus technology in medium and high volume applications.

5.1 THE DEVELOPMENT OF ADVANCED BUS CONCEPTS AND THE IMPLICATIONS FOR AHS TRANSIT

While early work in the 1960's suggested that buses could provide a significant cost advantage over rail systems, the development of busways and HOV-lane strategies occurred slowly over the next two decades. By the 1970's, researchers were examining the possible use of automation in part, but not all, of the bus trip -- a concept which matured as "Dual-mode" technology. In spite of a sudden curtailing of all research in advanced transportation concepts, some of concepts continued to receive attention over the 1960s, including the actual development of guided bus technology in Europe, and the development of the dual-propulsion bus-in-subway project in Seattle, Washington. This section of the Commercial and 'Transit Report reviews some of those developments, and notes their implications for the development of AHS Transit in the 1990s.

5.1.1 Overvlew: Advanced Bus Concepts and the Development of AHS Transit

'The development of AHS systems offers the possibility of a revolutionary improvement in service improvement for the American transit industry. 'The prospect of free flowing guideway segments of the regional AHS network being available to transit vehicles offers many opportunities for high quality services to be routed over major routings in a high volume, high capacity format, with the cost of maintenance of these line segments largely (or entirely) borne by budgets other than the transit operator. (If, for example, it is assumed that on a given roadway link has a possible capacity of 4,000 vehicles per hour. Assuming that link had 60 buses on it which were providing 3,000 seats of capacity, the buses would represent about less than two percent of the vehicles on the system, and might equivalently bear only two percent of system investment costs.)

Buses, unlike trains, provide high levels of capacity by relying on a relatively high number of vehicles. There exist many design and operational issues associated with the operation of systems which provide capacity by providing many smaller vehicles. 'The design of facilities, and routing/operational needs of these vehicles, must be thought through before the AHS system is defined.

This section of the Commercial and Transit Report reviews the history of development and understanding of advanced bus concepts over the past three decades, and seeks to present information which will help in the formation of a work program to develop AHS Transit over the next decade.

Much of this chapter deals with the truth and misinformation on the concept of the capacity of bus systems, and their operating costs relative to rail systems. This review, we believe, is needed for several reasons. First, the subject of capacity of bus systems relates to the very justification of AHS Transit. This chapter will review conditions in which additional capacity of AHS is and is not relevant. A key irony of AHS Transit is that it may (in theory) be able to create levels of line-haul capacity (past a cordon point, not through a station) that are totally not applicable to virtually all American cities (but one). This chapter will explore both the relevance of increasing bus capacity at full speed past a point, and increasing capacity in and out of various station configurations.

The chapter will present a review of historical capacity' needs of various corridors and then a more up to date review of the major investments of the last two decades. Having established some sense of the market niche for advanced bus services (which exists between the 3,000 and 15,000 riders per hour range), we will review a series of historic studies that tried to establish the logical market area for bus service compared to rail. These studies begin to analyze the total costs of systems, in addition to their capacity'.

'The studies of the 1960's can be used to begin asking what role technology could play in creating the optimal mode of urban transportation. In the early studies, there are simple references to the logical implications of certain configurations, such as the ability to operate buses in "train" formation in certain operating conditions, such as in downtown distribution tunnels. By the early 1970's a mature research program had arisen to develop that optimum transit technology, usually referred to as dual mode, or the dual mode bus. In a rare joint public-private effort, both government and private enterprise were pursuing this idea in parallel. By the end of the decade all of the studies had died, for reasons still debated in the profession. 'This chapter seeks to begin the process of documenting the lessons learned from this intense decade of research and development, and to define which research areas were left unresolved. In particular, the chapter discusses which of the lessons learned can be applied to the early development of a national AHS 'Transit work program.

5.1.2 The Implied Needs of the Transit Industry

'The transit industry wants to provide a higher quality' of service, but cost is an overwhelming issue. In cities where the investment is made in rail, the service is very popular. But even in these cities, expansion of the initial lines is a problem because of cost. Solutions are found for the downtown, with careful planning in cities like Portland, Oregon showing the way. But the extension of totally exclusive rights-of-way deep into the suburbs is very expensive. Because of the technology, the rights-of-ways cannot be shared with anyone, and the transit agency must bear the cost of construction and maintenance.

In a way cost becomes the Achilles heel. As city after city seeks the kind of transportation world of a "world class city", the public is seeking something better than the bus service they presently know on the streets. In order to provide the citizens with something better, excessive operating/carrying costs are being experienced, which in the end, may be causing a fixed amount of subsidy to provide less service than would have been provided without the capital intensive projects.

Throughout the literature, it is common to reject bus systems in favor of rail because of the alleged inability of bus services to provide high levels of capacity. In order to understand what market niche seems to exist for AHS 'Transit services, it is worthwhile to review the direct data on the kinds of corridor public transportation volumes actually experienced in American cities outside of the unique example of New York City, New York. 'The data are relevant for two reasons. First, it is important to understand the range of volumes that presently available bus systems can handle, contrary to much popular belief. Second, it is also relevant to the understanding of the upper range capacity levels that could be carried by buses along a given segment of an automated highway.

5.1.3 Estimated Peak Point Loads on Various Systems

'Table 2 has been prepared to show the number of peak hour riders on representative corridors of several American transit systems. While New York shows passenger volumes of over 100,000 riders past selected cordons lines with both express and local services, this kind of realized capacity is essentially not applicable to other American cities. 'Table 2 shows ranges from 5,000 persons per hour in Cleveland, Ohio to 14,000 persons per hour in Chicago, Illinois. It has been often noted in the literature that most of the cities that have corridor volumes in the 5,000 to 14,000 persons per hour range already have major rail facilities. 'Those corridors which are already served by heavy rail systems would not be considered as the logical market for evolving AHS 'Transit technology.

Table 3 has been prepared from recent literature summarizing the results of the light rail projects in major American cities. Selected light rail cities are shown with an estimate of their peak hour ridership. (It is common in the field of transit analysis to assume that the one-way peak hour ridership is about fifteen percent of the 24 hour ridership for an individual corridor.) In the light rail group, peak hour ridership ranges from 2,100 in Sacramento, California to 2,700 for Cleveland's Shaker Heights light rail, to 3,150 for Portland, Oregon. These volumes are similar to Boston Massachusetts' Riverside or Arborway lines, with somewhat under 3,000 riders per peak hour. San Diego, California is reported similar to Pittsburgh (South Hills), Pennsylvania at over 3,000. Writing in 1988, 'Tom Parkinson wrote that:

> "...the remaining North American corridors with potential for capital intensive transit improvements generally will have patronage in the low to middle intermediate capacity range, that is 15,000 to 50,000 passengers per day. [17]

Table 2- Peak Load Point Hourly Volumes on American Rail Systems

City Facility	Peak Hour Load Past Max. Load Point
New York City, New York	
59th Street Cordon (Express and Local)	170,500
Queens Cordon	130,600
PATH Lower Manhattan	29,000
PATH Midtown	10,000
Chicago, Illinois	
North South (North side)	14,000
West-Northwest	14,000
Lake - Ryan	14,000
Philadelphia, Pennsylvania	
Market- Frankfort	12,800
Broad Street	8,500
Lindewold Line	8,000
Cleveland, Ohio	
East west Rapid (East)	5,100
San Francisco, California	
BART Concord	6,200
BART Daly City	6,300

Source: Levinson, Characteristics of Urban 'transportation Demand USDOT, 1978

Table 3. Selected North American Light Rail Hour Volumes

City	Daily Passengers*	Estimated Peak Hourly Volume"
Buffalo, New York	21,000	3,150
Cleveland, Ohio	17,500	2,625
Newark, New Jersey	12,000	1,800
Pittsburgh Pennsylvania	20,000	3,000
Portland, Oregon	21,000	3,150
Sacramento California	21,000	3,150
San Diego, California	23,000	3,450
San Jose, California	40,000	6,000

*Source: Tom Parkinson, Light Rail Transit. TRB Special Report 221, p.76, 1988.
** NOTE: Corresponding Daily Passengers multiplied by Assumed Peak Hour Conversion Factor of 0.15.

Applying our peak hour/daily rule of thumb, 15 percent of those riders will occur at the one-way peak hour, thus between 1,800 and 6,000 persons will need to be carried at the peak hour.

Based on his research for the HUD New Systems Studies in the 1960's, Clark Henderson summarized his conclusion that rail systems:

> "... can carry peak loads of 30,000 passengers per hour in reasonable comfort. 'There is evidence that these huge (rail) investments are highly attractive where a substantial part of the capacity can be utilized during peak hours. However, case studies for a typical U.S. city indicate that passenger loading on most links of an areawide network will not exceed 3,000 passengers per hour.. ~(18)

'The ability of light rail to handle far greater volumes is well established in everyday practice. Concerning the capacity of light rail, Leibbrand reports that a 25 meter (83 loot) non-articulated tram operating at 30 second headway can carry 19,000 riders per hour.[19] This assumes that no station stop takes longer than 30 seconds, at which point, the station dwell time causes the queue backup to begin. As the trains get longer, he recommends a 45 second headway for light rail trains, producing 42,000 per hour. For block signal controlled rapid transit, he reports the use of 90 second headway resulting in a capacity of 45,000 per hour.

In short, the U.S. has a variety of cities which do indeed benefit greatly from the high capacity that rail Systems can provide. But analysts tend to agree that the next market for improvements in cities will tend to occur in corridors whose peak hour volumes lie in a range of under 5,000 or 6,000 persons per hour.

5.2 EXPLORATIONS OF ADVANCED BUS CONCEPTS (1960's)

'The rapid development of AHS requested by IS'TEA suddenly throws the spotlight on the potential role of many buses (and quite possibly small buses) carrying major volumes of passengers. Fortunately, the existing literature of the past three decades has given extensive coverage of the special needs and potentials of buses carrying corridor volumes often associated with guided forms of urban transportation, such as light rail and automated guideway transit (AGT). 'This section of chapter 5 will review some of the major contributions to this literature.

5.2.1 Economic Analysis of the Role of Buses

The Urban Transportation Problem by Meyer Kain and Wohi attempted to apply economic and systems analysis techniques to the question of urban transportation costs. 'The Rand Corporation study served to challenge some of the most fundamental assumptions about the relative costs of bus and rail services at various levels of corridor demand.

The study carefully dissected the urban area transportation trip into three primary' segments: collection, line haul and distribution. 'The study examined the relative cost and performance of bus and rail in each of the three segments. Concerning the role of rail services in downtown distribution tunnels, the study notes the logic of rail in high density situations:

> "In very high density employment districts, especially with little surface street area, the simplest and most economical solution for downtown collection and distribution usually will be rail or bus transit operating either in subways or on elevated structures... If long tunnels are required or deemed desirable, rail transit has a substantial cost advantage for the downtown distribution function in being able to carry larger volumes in a smaller number of vehicles than other modes. ft is in this quality more than any other that rail has a particular or special advantage.[(20)]

The "surprise" in the Rand study turned out to be the conclusion that bus systems which included downtown tunnels - even with large off-line stations and high ventilation costs - would be cheaper than rail systems with the same configuration.([21]) With the design assumption of two miles of downtown subway, the study concluded that "integrated bus in tunnel" would be cheaper than "feeder bus with rapid transit" at volumes as high as 50,000 passengers per hour at the maximum load point. When they assumed 6.4 km (4 mi) of downtown subway construction, "integrated bus in tunnel" was cheaper than "feeder bus with rapid transit" up to about 30,000 persons per hour at the peak load point. Then rail became cheaper over that 30,000 person per hour threshold volume. It should be noted at the outset that these conclusions were very controversial and that most transit operators questioned the ability to get anything near 30,000 riders through stations in a subway configuration.

At the same time they examined the effect of residential density. The above figures are for "medium residential density." When "high residential densities" are assumed, "feeder bus with rapid transit" options offer cheaper service than the "integrated bus in tunnel" options. This, in theory helps us to locate the market niche for guideway bus services -again, away from densely built up areas that may already have rail transit services.

In terms of service provided, the study examined the time characteristics of various modes for downtown distribution and concluded that "integrated bus in tunnel" was markedly faster than "feeder bus with rapid transit1" and would represent the fastest downtown distribution mode. For example, their graph, (attached as figure 14 in this chapter) showed that for a 4-mile downtown route, integrated bus in subway would offer a downtown distribution time of 7 minutes, versus rail at slightly over B minutes; integrated bus on surface would have about 13 minutes of downtown distribution time.

In the RAND analysis, downtown bus tunnels were substantially more expensive than rail tunnels, as they assumed a multi slot configuration connected by a mezzanine, at 39 meters (128 ft) width as opposed to the on-line rail configuration of 15 meters (50 ft) width. Thus, for all volumes and route lengths, the cost of a bus tunnel was more than the cost of a rail tunnel. Later in this chapter, we will explore later concepts (particularly Seattle) where on-line bus stations similar in width to rail stations were implemented. Still later, the question of platooning buses to act "like trains" in the tunnel will be explored. For this point, it is important to note that an early study concluded that the total cost of a bus-in-tunnel system would be cheaper than a similar rail system even with the assumptions of large, unusual downtown stations. It follows, then, that the later inclusion of technology which allows the bus to operate through cheaper tunnel stations would make the conclusions even more favorable to buses.

The question of the role of technology was touched upon at the very end of the study. In the mid 1960's, analysts were already beginning to predict the advent of what we now call AHS Transit:

> "....electronic or other automatic guidance and control on highways used for bus line hauls would permit buses to operate with closer headways and at higher speeds. 'This would increase highway capacity and reduce line haul construction and right of way costs, which run from 13 to 20 percent of total bus costs Buses might be operated in trains with virtually the same advantages as rail transit, while retaining much of the flexibility that allows buses to operate on city streets and in residential areas without passenger transfer.[(22)]

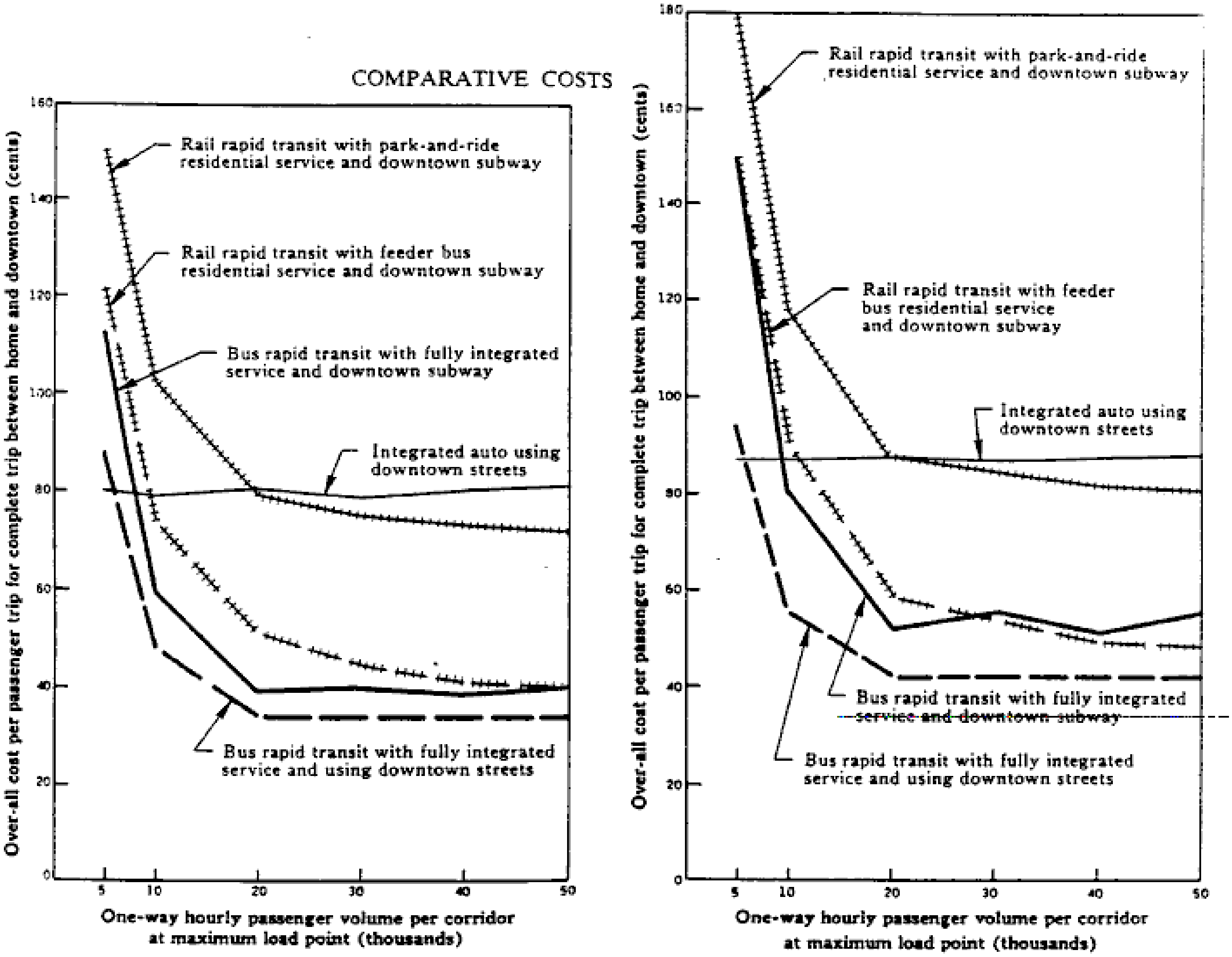


Figure 14. Comparative Costs Between Feeder Bus With Rapid Transit and Integrated Bus in Tunnel Systems

They did also note the logic of what soon would be developed as the concept of Dual-Mode transportation:

> "...it is noteworthy that the more immediate promising innovations usually share a common trait: each combines the best features of two or more modes into one transportation system. There is nothing very new about this concept in transportation: it underlies for example, most of the current thinking and experimentation with piggybacking and containerization in intercity freight

shipping."[(23)]

5.2.2 Other Studies of Bus Efficiency

At the end of the 1 960s other studies were beginning to examine the potential of buses in better operating configurations. In terms of line capacity, R. H. Pratt noted the observation of 573 buses per hour, and based on the performance in the five minute peak segments, hypothesized a level of 817 buses per hour. At 52 seats per bus, this allows a peak load point volume of 42,000 passengers per hour.[(24)]

In 1969, 'Tom Deen published one of the first articles to call into the question the economics of rail systems in corridors where buses could easily be configured.([25]) His article in 'Traffic Quarterly joined the chorus of those who were questioning the concept that at certain volumes, rail is necessarily cheaper to operate than bus. An early attempt to put this concept in Atlanta was rejected by local leaders when proposed by its systems planning consultant. In place of the proposed busway, Atlanta, Georgia built the east-west rail line of the MARTA system.

5.2.3 GM Explores Bus Platoons

During this same period, General Motors was examining the potential of bus rapid transit systems at far higher volumes than previously contemplated. Table 4 shows the results of GM's theoretical research into the potential operations of bus platoons. GM concluded that with 40 second dwell times, 55 platoons could get through per hour (resulting in a 1.1 minute headway).

In terms of number of buses moving past a given point, GM actually ran 1,450 buses per hour, (at 2.5 second headway) resulting in a theoretical capacity of 72,000 persons per hour. 'This experiment served to support the general concept that bus systems can carry volumes past a given point vastly higher than most American cities could use. Having dealt with the logical upper limits of line haul volume, GM began exploring the capacity of a given loading platform under various assumptions of bus platoon length. 'Table 4 shows their conclusion that one four-berth platform, handling a four bus platoon [slowing from a maximum speed of 48 kilometers per hour (30 mi/h)] could board 6,080 persons with a 20 second dwell time. It should be noted that this is the number of passengers boarding at one station, not the total of riders on the platoon at its peak load point, which is about 15,000 passenger's/hour under these assumptions. If this particular platform were located off-line, and other buses were by-passing the platoon at the platform, that peak line number would be far higher.

Number of Buses in Platoon				
Maximum Speed of Bus Platoon (mph)	Dwell Time (seconds)	4(1)	8(2)	12(3)
		Bus Service Volume (Seated Passengers Per Hour)		
30	20	304(6080)	464(9280)	552(11040)
	40	220(8800)	360(14400)	456(18240)
60	20	240(4800)	360(7200)	456(9120)
	40	184(7360)	288(11520)	360(14400)

(1) Assumes four buses per platoon capable of boarding one rider per second.
(2) Assumes eight buses per platoon capable of boarding one rider per second.
(3) Assumes twelve buses per platoon capable of boarding one rider per second.

Note: A platoon of buses is a vehicle formation which assumes similar acceleration, deceleration and cruise speed characteristics which help minimize delay due to vehicle friction. Usually potential bus passenger are aware of where to stand at the platform and are encouraged to form waiting lines which minimize boarding delay.

Table 4 (for rail transit) is analogous to the above Table; bus capacity, when on-line stops are included, is restrained by the boarding time if loading occurs through a normal size door; rail capacity is constrained by on-line conditions such as station spacing, acceleration, maximum speed, etc.

Source: General Motors Research Laboratories, Bus Operations in Single Lane Platoons and their Ventilating Needs for Operations in Tunnels, GMR-808, Warren, Michigan, 1968.

Table 4. Volume of a Bus Loading Platform Under Platoon Operation

5.2.4 **Other Station Capacity Calculations**

Over this period, Herb Levinson, then at Wilbur Smith and Associates, began publishing a series of studies on the potential of bus systems.([26]) Because the GM studies had assumed that every berth at every part of the peak hour was feeding passengers at an equal rate (one passenger per second) Levinson undertook empirical calculations based on the observed unevenness of flow of passengers arriving at the platform.

Assuming a modem style bus with two double doors, he concluded that the first berth could board about 2,000 prepaid persons. But, he concluded that the second berth would only be about 75 percent as efficient as the first berth. Similarly, he concluded that the third berth would be only about 50 percent as efficient as the first berth. Disparaging the fifth berth as useless, he judged the fourth berth would have about 25 percent efficiency. Thus, the maximum boarders from a four-berth platform would be 5,000 passengers/hour. In short, Levinson calculated that a four bus platoon platform would board at a rate of 1.8 seconds per person, rather than the 1.0 seconds per person assumed by GM in their input assumption. A variety of these assumptions are explored in the following table 5.

5.2.5 Implications of the Early Bus Transit Studies for Later Research

This brief review of recent fixed route systems suggests that for the American transit industry, a technology to increase capacity is most often not the issue. For most American cities, there is a pressing need for a technology which can better fit the origins and destinations of the passenger.

Meyer Kain and Wohi concluded that, except in the case of highest residential densities, the total cost of an integrated system with a downtown distribution bus tunnel would be less than the total cost of a rail tunnel system. And this assumed a separate 16 kilometers (10 mi) line-haul guideway for the bus, born entirely by the transit sector budget. If a technology could exist that would allow the expensive line haul segment to be operated in a mode shared with other services, significantly lower costs would be allocated to the transit budget. 'The challenge remaining is to lower the cost of the full system.

Given the densities involved, many cities would benefit from a grade separated downtown distribution system for the transit system. And some segments of the linehaul trip also would benefit from a separate right of way. But in many cases, the volumes of transit operations in the line-haul segment of the trip allow for operations to be shared with other services in the corridor such as commercial trucking, thereby lowering the total cost to the transit budget. 'The challenge facing the transit industry is to lower the capital cost of providing the high quality service that recent light rail projects are offering.

fype of Fare Payment	Bus (1) Loading Condition	Cumulative Total Passengers Per Hour Hour				Cumulative Total Buses Per			
		Number of Berths (2)				Number of Berths~[3]			
		1		2	34		2	3	4
Pay upon boarding - 1 door available	On-Line	650	1140	1460	1620	13	23	30	33
	Off-Line	650	1200	1750	2240	13	24	35	45
Prepaymet - 1 door available	On-Line	950	1660	2140	2380	19	34	43	48
	Off-Line	950	1760	2570	3280	19	36	52	66
Prepayment - 2 doors avdil~b1e	On-Line	1550	2710	3490	3830	31	54	70	77
	Off-Line	1550	2870	4190	5350	31	58	84	107
Prepayment - (4) 4 doors available	On-Line	2050	3590	4610	5120	41	72	93	103
	Off-Line	2050	3790	5530	7070	41	76	111	142

(1) On-line loading is the condition where the passengers board buses roadway; off-line assumes particular bus berths located off of the main loaded$_1$ can pull out and into the traffic stream. whi1e the buses are still in the main roadway and where a bus, once

(2) Passenger rates account for expected internal impedances, peak 20-minute demand, inefficiencies in berth loading capabilities.

(3) Based on 50 passengers per bus.

(4) Presently not being manufactured but technically operational.

Source: Wilbur Smith and Associates, "Design and Analysis of Bus and Truck Roadway Systems in Urban Areas," Draft Report, New Haven, Connecticut, November, 1973

The studies of the 1960's implied that an as-yet-undeveloped advanced system could offer use of uncongested streets for the suburban residential collection function, with at-grade signal priority as appropriate, followed by HOV lanes shared with carpools and emergency vehicles for most of the line-haul segment of the trip. But that same vehicle could be operated in areas of tight physical tolerance, perhaps utilizing advanced control mechanisms to form "platoons" of tightly spaced vehicles. The interest in this subject would soon surface as a national research effort in so-called Dual-Mode technology.

5.3 DEVELOPMENT OF THE DUAL-MODE BUS CONCEPT

By the early 1970's, transportation researchers had begun to focus in on the concept of the Dual-Mode Bus, which operated in manual mode oft of the guideway, then operated in guided mode along with other vehicles on the automated guideway. In a remarkable partnership, both public and private researchers were pointing to a new direction for public transportation development. The results of those studies set an informative precedent on which to base the development of AHS Transit in the 1990's.

5.3.1 HUD's New Systems Study

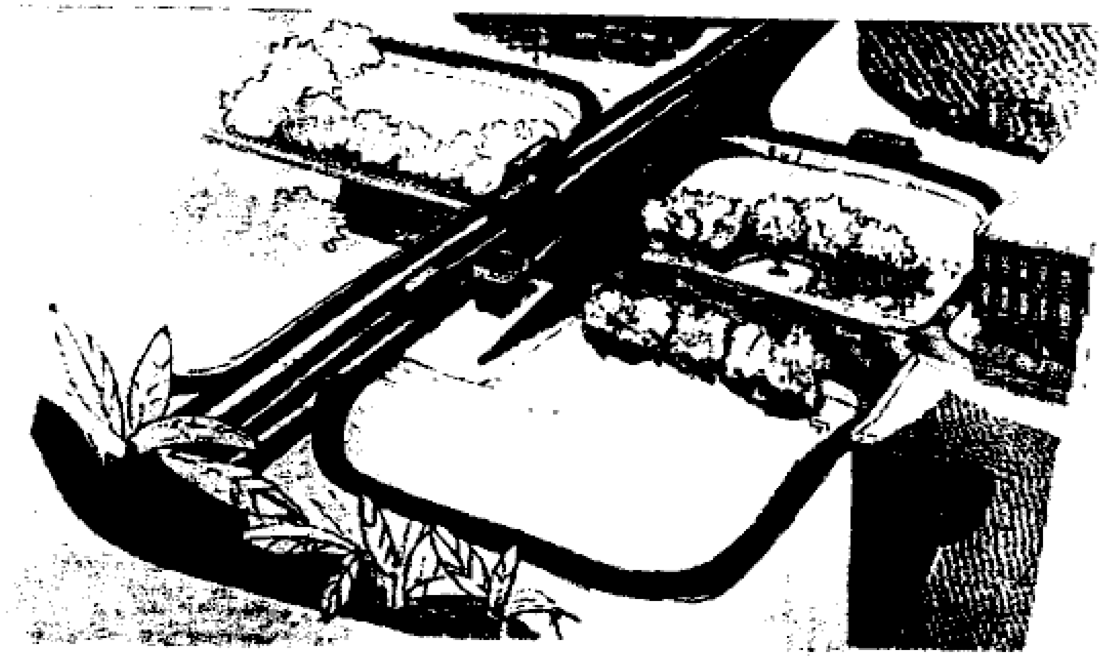
More than any other single event, dual mode studies arose Out of the New Systems Study undertaken by HUD in the late 1960's, and published in 1968. That study developed the dual mode concept, which is presented in "cartoon" form as figure 15. 'The 1968 report concluded that "the automated dual mode bus could be developed and its feasibility demonstrated very likely within five years at a possible cost of less than $15 million.[27]

Eugene Canty of General Motors described the results of two Dual-Mode studies undertaken in 1967, examining the cities of Boston, Massachusetts and Houston, Texas. He summarizes that:

> “.... prominent among the most advanced developments .. .. is the automatic, electrified guideway .... Utilization by both public and private modes of a single guideway system is clearly desirable for efficiency and economy. 'The resultant dual mode ... system would provide personal rapid transit for transit uses; at the same time it would accommodate privately owned automobiles designed far either conventional manual operation on city streets or automatic operation on the guideway.[28]

5.3.2 MIT Urban Systems Lab

By the beginning of the new decade, the subject was being explored by independent researchers across the country. For example, in June of 1970, Mitt’s Urban Systems Laboratory issued a report entitled *Dual Mode Transportation Systems: Analysis of Demands and Benefits in Urban Areas and Development of Performance Requirements.*[29] That study concluded that conventional technology



SOURCE: Department of Housing and Urban Development (HUD), New Systems Study Summary Report, Washington, D.C. 1968, p.69.

Figure 15. The Dual Mode Bus Concept in HUD's New Systems Study

would not be able to serve new user groups, "...showing conventional transit service improvement to be of not much benefit to other than existing transit riders.... Accordingly, transit improvements show little potential for reducing substantially the demand for urban expressway capacity."

The study concluded:

"...In summary, therefore, only dual mode and demand activated-ubiquitous Systems (automated highways) appear to offer the kind of service which is compatible with and satisfies the requirements stemming from the major travel demand and metropolitan development issues.[30]

5.3.3 TRB's 1974 Conference

In May of 1974, 'The Urban Mass Transportation Administration sponsored an international 'TRE conference on Dual-Mode 'Transportation. This conference was a major opportunity for public and private sector research programs to be discussed and compared.

Conference Chairman Eugene Canty of General Motors accepted the following definition of dual mode (and dual-mode transit) in his conference summary:

"Dual mode transportation is that broad category of systems wherein vehicles may be operated in both of two modes: (a) manually controlled and self propelled on ordinary streets and roadways and (b) automatically controlled or externally propelled (or both) or powered on special gads. In general dual mode transportation systems can include both common carrier and private vehicles and provide for the transport of both persons and freight over a common guideway facility.

"Dual Mode 'Transit is a special case of dual mode transportation. Service is provided only by common carrier vehicles for passenger transportation. Such service may be on a personalized or group transit basis.[(31)]

5.3.4 Early Dual Mode Studies

The Conference on Dual-Mode Transportation included summaries of major public and private research efforts. Based on its 1971 study of Milwaukee, Wisconsin by Allis Chalmers, UMTA concluded that:

"....the high level of service of DM'TS (Dual Mode Transit Systems) resulted from its convenient passenger access on manually operated collection and distribution routes, its short vehicle headways (during peak periods headways are typically 5 to 10 minutes on the collection and distribution routes and 5 to 10 minutes on the guideways), the persuasiveness of its region wide network of guideways and shorter passenger trip times because of the high vehicle speeds on the exclusive guideways and the coordination passenger-vehicle-driver movements provided by its central management system.'•~~

Based on these studies DeMarco concluded "a useful criterion of market potential for DMTS is any area with a population of more than 750,000 and a population density in the central city of more that 6,000 per square mile" (2,300 per square km).~~ In September of 1973, UMTA chose GM, Rohr, and 'Transportation Technology Inc. to develop dual mode transit.

In 1971 the first study of Milwaukee, Wisconsin, Barton-Asch man Associates concluded emphatically that:

"Dual mode transit systems offer higher service quality (ability to attract riders), higher labor productivity, competitive fares, benefits exceeding costs, greater attainment of regional development goals and objectives, a high degree of operational flexibility to meet carrying transportation needs, and possibly most important, growth potential with good cause to expect a long term trend of increasing utilization, total benefits, and economic operating margins."[(34)]

After Barton~Aschman's study of Milwaukee, Ueb (of Mitre Corporation) focused on more comparisons within the rubber tired mode. Dual mode is compared with exclusive busway bus, exclusive busway with small feeders, expressway bus, and conventional bus. The study concluded that small bus dual mode was most comparable with large bus exclusive busway systems. In that comparison, annual cost of busway is 21 percent less, but ridership is 17 percent less. Perceived travel time for dual mode is 27 percent less. The abstract notes that "small buses allow for shorter headways But small bus operations are not economical unless automated operations are used.[35] It is interesting to observe that at this early point in the analysis of automated operations, that hypothesized cost savings over regular busway operations were not being found. This was the case even when it was assumed that the bus drivers would get off the bus on the automated segments.

Other studies began to question the cost savings of automated buses on rights of way whose costs were solely allocated to the transit sector. Canty notes the importance of sharing the guideway costs with private vehicles, thereby reducing the portion of the guideway costs assigned to transit. GM undertook studies, published in 1968 and 1969, using Rochester New York as a case study. The GM research examined an option in which the guideway was not shared with other vehicles.

> "'The estimated savings in driver labor costs through automatic operation were small in comparison to the estimated annual costs of the automated facility. 'The conclusion was that the dual mode system, using its own automated guideway facility, did not appear to offer potential performance and cost advantages over manually controlled bus rapid transit on exclusive busway facilities."[36]

'The DOT's 'Transportation Systems Center [now Volpe National 'Transportation Systems Center(VNTSC)I undertook a follow-up study published in 1973 that noted:

> “.... an effective first step might be to install a limited network of Dual Mode minibus system with capacity for ultimate growth to a longer guideway network with personal vehicles and buses.[37]

In the meanwhile, UMTA planned to focus on strategies to get more capacity out of the guideway, and suggested that "platooning" or "training" of smaller vehicles might be necessary: "we have a program goal to increase the capacity of 10,000 passengers/h/single lane to 25,000 passengers/h/single lane. 'This can be accomplished by training vehicles, using larger vehicles, or decreasing headways from a 5 to 10 second range to a 2 to 4 second range."[38]

5.3.5 GM's CONCEPT

General Motors had developed and elaborated the Dual Mode 'Transit concept, based around a 8 meters (27 ft) bus with 17 seats, as shown in figure 16. Having established a concept of relatively small vehicles, GM proposed some innovative guideway and station concepts to maximize system capacity. Their strategy called for oft-line stations, operated in a manner designed not to constrain the throughput capacity of the guideway. In this strategy:

> "No more than every other vehicle may enter a particular station. This allows a station with three or four berths to handle more than 300 vehicles per hour

depending on the efficiency of the vehicle-processing time through the station. In this typical design the mode interchange including entering diagnostics and departure landings and ramps, is located in the lower level."[39]

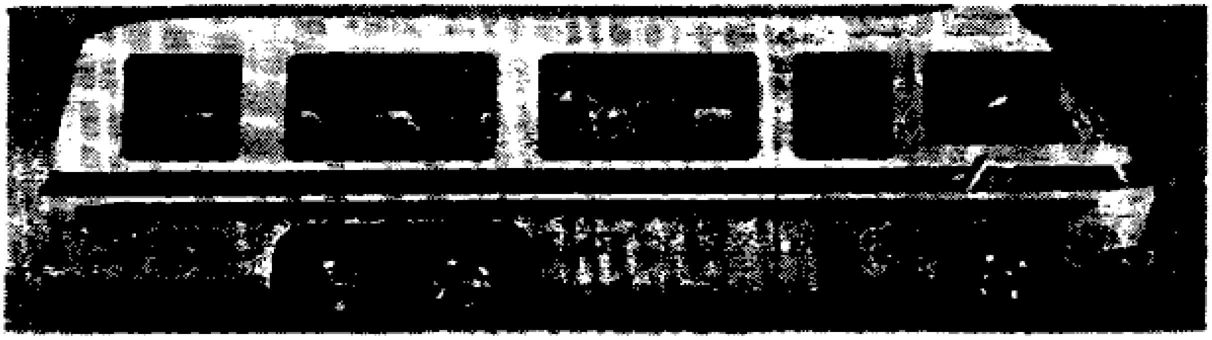
In its published work, GM came up with an interesting alternative to the concept of bus training and bus platooning. Platooning through stations assumes that most (if not all) of the buses in the transit formation are going to the same set of stations. GM proposed an interesting off-line station concept, in which the basic concept is of three oft-line, bypassable slots, as illustrated in figure 17. In order the minimize the width of the main guideway, GM designers suggested allowing some of the deceleration to occur at the station, placing a loop around the platform area. GM designers present us with a classic prototype of a small bus, off-line station concept. Conceptually, the oft-line multi-slot station should have much higher capacity than on line stations; if any one berth is having a longer than expected dwell time, the arriving bus is shuttled to a different slot. 'This will, however, increase the dwell time of that vehicle, as passengers queued in Berth X will now have to run to Berth Y. 'This could cause a cascading effect until rectified. In theory, however, sending the bus to whatever berth is most available at that instant should considerably improve total throughput capacity.

5.3.6 Pathways to AHS - The 1970's

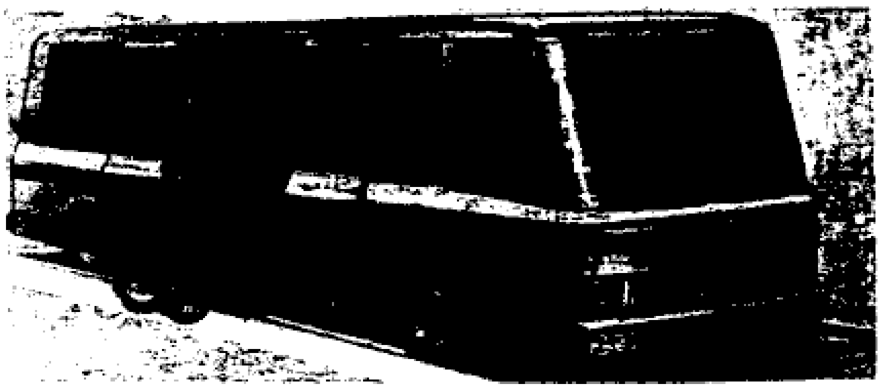
At the present time, FHWA's program of Precursor Studies is developing a logical path for the development of dual mode transportation, in which vehicles utilize both an unguided mode and a guided mode in a single journey. 'The strategy for implementation of such a system has been debated over the last 25 years. In the 1970's there were two major theories:

1. 'That private vehicles should only be part of the program after the resolution of technology issues which would occur with the operation of publicly controlled transit vehicles.

2. 'That the economics of shared guideway operation mandated an early introduction of private vehicles onto the guideway.

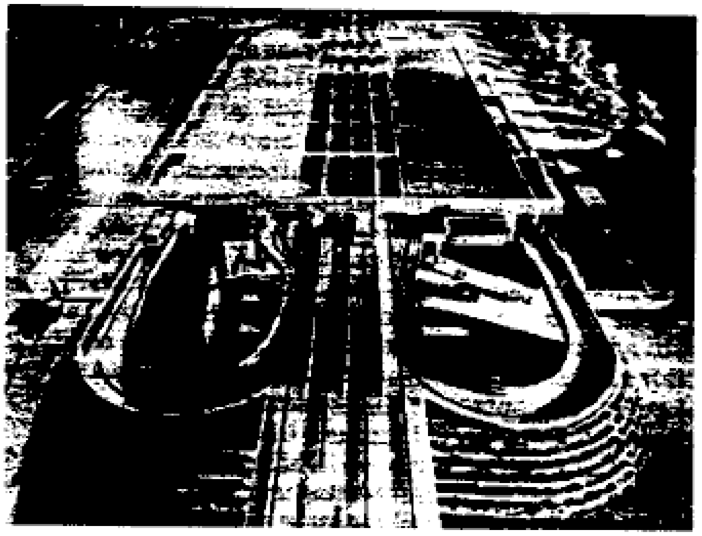


A 17 Passenger Bus Proposed by General Motors



An Early Design from Rohr Industries

Figure 16. Early Designs far the Dual Mode Bus



A study model of a multi-slot, off-line station.

Three berths are shown to the right of the platform, while a bus decelerates to the left of the platform.

Figure 17. GM's Off-Line, Multi-Slot Station Concept

5.3.6.1 *UMTA's View*

Many strategists focused on the task of incrementally building up the technology of dual mode transit. UMTA's view follows a somewhat different path than the AHS strategies now under consideration. Vincent DeMarco of UMTA described one strategy, in which no mention is made of parallel development for private vehicles:

> "The implementation of Dual-Mode Transit Systems (DMTS) in these urban areas might follow a logical technology evolution from conventional bus to dial a ride bus, bus priority traffic signal control$_1$ freeway access ramp metering, freeway-dedicated bus lanes$_1$ central vehicle~river-passenger management, guideway automatic vehicle control and DM'TS.~~

In his role as Conference chairman, Canty summarized the view of those who would postpone development of the private aspects of dual mode:

> "....although to achieve adequate reliability and performance in dual mode automobiles may not be possible, to do so for publicly owned and maintained vehicles including small buses and public service vehicles should be. 'Those who take this viewpoint are thus of the belief that dual mode transit may be technically feasible, but more general dual mode transportation systems are not."[(41)]

In his work, Hamilton had come to the conclusion that the automated highway presented too much of a challenge for the beginning of the dual mode implementation plan:

> ".... though lull (highway) automation could provide both personal and dual mode service, its achievement appears far away because the existing multi-lane freeway poses more complex technical problems in automation than the single lane guideway, wherein lane changing would be unnecessary and manually operated vehicles would be excluded from the beginning.[(42)]

5.3.6.2 *Ford Motor Company's Pathway to the AHS*

In the early 1970's an implementation strategy for private auto guideway was examined that is considerably different from the path being explored now in AHS . Richard Shackson, of the corporate planing staff of Ford Motor Company, created a chart entitled "Dual Mode Vehicle System Evolution," reproduced as figure 18 in this report. Shackson discusses several possible strategies to evolve to the end state in which private vehicles operate over a region wide system, represented by the bottom right cell of his matrix. In his article, he argues that the first users of the guideway would be single mode captive vehicles, thereby postponing the issue of implementing both the entrance check-in function and the exiting check-out function. In the first years of operation, issues of single mode captive guideway (i.e., longitudinal and latitudinal control mechanisms) would be addressed and solved.

> "....first of all we are dealing with a simple linear system rather than a network, we've eliminated the need for vehicle inspection and registration, we have avoided the liability and indemnification questions raised by the operation of privately owned vehicles on a public guideway, and we have substituted simple single mode electric propulsion for the dual propulsion system simplified in the final configuration.([43])

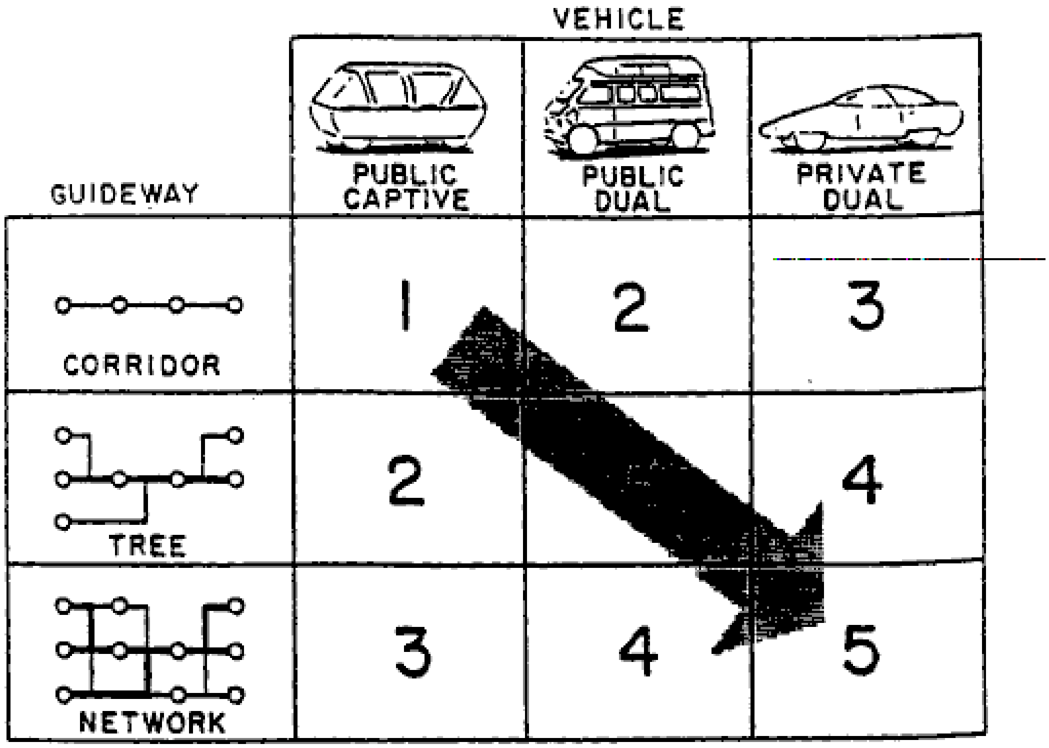
Shackson's concept for a second level of complexity moves from "corridor"' to "tree," which introduces the signal and control issues of merging separate flows between segments and into networks. In that phase, he would introduce the publicly owned dual-mode vehicle, and begin to address the issues of check-in and check-out. In this diagram, publicly owned dual-mode is introduced as the "corridor" becomes a "tree."

Then, having dealt with the network interconnection issues at the "tree" level, the system is expanded into a "network." It is at this point that this model introduces the privately owned vehicles to the system, in a phase after the resolution of entrance and exit have been resolved with the publicly owned vehicle, and after issues of network interconnection have been resolved. "'The point is that there are multiple paths, and the choice of paths can be made on the basis of individual installations." In this case, Shackson illustrated an implementation process that implements "corridor captive" first, dual mode second, and private use of the network third.

5.3.6.3 GM's View of the Importance of Including Private Vehicles on the Guideway

While there seemed to be a general consensus on the concept of commencing dual mode operation with larger, publicly owned (or controlled) vehicles, Canty emphasizes the importance of designing for the inclusion of privately owned vehicles.

> "'There is a clear consensus in the analytical case studies that implementation of dual mode transportation systems accommodating both privately owned vehicles and public transit vehicles would yield greater overall benefits and would be more cost effective than alternative transportation system investments in the areas studied   Dual mode transit, as an integral part of a more general dual mode transportation system and sharing a guideway facility with privately owned vehicles, is a more attractive and more economical solution to urban transit needs than are various forms of bus rapid transit and conventional transit systems.([44])



SOURCE: "Dual-Mode Vehicle System Evolution", Shackson, Richard, circa 1970.

Figure 18. Dual Mode Vehicle System Evolution

5.3.7 Some Observations about the 1970's: What the Transit Industry Sought

In the 1960's, the theoretical desirability of a new mode which acted like a bus on the street, but like a train in the tunnel was explored. In the 1970's major corporations began developing the dual mode bus. From the benefit of hindsight, we can make several observations about the conditions affecting the development of a new transit technology:

- The transit industry has few corridors that need the capacity offered by rail.
- The transit industry would like to offer a higher quality product (i.e., world class city, etc.).
- In the downtown distribution function, bus operations have been feared.
- In the line-haul segment, buses operating over dedicated and shared rights of way have operating advantages over rail, including
    - ability to skip stops.
    - ability to originate where the volumes originate thereby lowering operating costs.
- In lower volume segments, exclusive systems have to justify full costs for reasons other than capacity.
- A one-seat-ride for collection, line-haul, and distribution is desirable.

From these observations we can note certain of the attributes sought for a new mode of urban transportation that the research sought to create:

- A vehicle that can do collection services.
- A vehicle that can perform light and medium density line-haul services on rights of way which are shared with others.
- A vehicle that can perform in higher density conditions on its own right-of-way (such as a downtown distribution tunnel).

This discussion does not imply that dual mode rubber-tired buses were the only mode being pursued to meet these desired attributes. in tact, during this period many American cities tried to emulate (with some success) European light rail operations, which delivered the one-seat-ride on whatever right of way was available, often shared with other traffic, often on exclusive right of way. And, perhaps most importantly, the early 1970's saw a sudden increase in the development of one-seat-ride express bus services, which themselves sometimes operated in shared environments, and sometimes over reserved lanes and facilities. Indeed, the noted transportation critic Martin Wachs wrote "tO the extent to which expressway bus operations constitute a prototype of future dual mode operations, these results are most encouraging." (Wachs, "Anticipated Attitudinal Responses to Dual-Mode Transit Systems and Their Effects on Mode Choice," TRB Report 170, p.65)

5.4 THE SEATTLE EXPERIENCE IN ADVANCED BUS TRANSIT

As research in advanced transportation nearly came to a halt in the early 1980s, interest in using buses in cost effective strategies remained strong. The Municipality of Seattle, Washington undertook a series of studies of possible ways to develop a downtown bus tunnel; several of these studies reviewed recent advances in Europe towards the development of the dual mode bus. Although Seattle did not select the option of guided buses in the tunnel, the work that was undertaken provides a good model for the kind of research now needed in the development of AHS Transit.

5.4.1 Context

Of all the advanced bus operations in the world, the Seattle system offers us the most precedent for understanding what the AHS 'Transit can, and perhaps cannot, accomplish. A close study of the operating plan for Seattle gives a good case study for the application of the principles governing advanced bus operation. Whatever form it ultimately takes, AHS 'Transit would be characterized by the management of many bus-size vehicles each with relatively small amounts of capacity, when compared against the operation of rapid transit-type train capacity. In this section, we will explore the results of Seattle's research which compared certain operations under an AHS -like set of operating conditions and examine the implications of those projected operations. In particular we will explore the relationship between guided operations that can utilize high platform loading areas and the capacity increases which result from the lowered station dwell time attained by those platform assumptions.

It is important to note from the outset that this discussion will focus on the operating plan developed for the phase in which a full set of dual-propulsion buses were in operation through the downtown tunnel. At the present time Seattle is operating with a partial fleet of special vehicles, whose present tunnel frequency does not require nor mandate the kind of managed (platooned) operations discussed in the following section of this chapter.

5.4.2 Seattle's Studies in the 1980's

By the 1980's, research efforts on developing advanced bus concepts had virtually come to a standstill. A major breakthrough occurred in June of 1983 when UMTA awarded the Municipality of Seattle a research grant to study guided bus technology. Some of the results of that research effort, which were prepared by Metro in March of 1984 ("Evaluation of European Guided Bus 'Technology," 'Task 2 'Technical Memo, Prepared by Daniel Dunoye of Lea, Elliott McGean & Company, Washington, D.C., and Metro Staff, Prepared for The Municipality of Metropolitan Seattle, March 1984), have profound implications for the development of AHS technology.

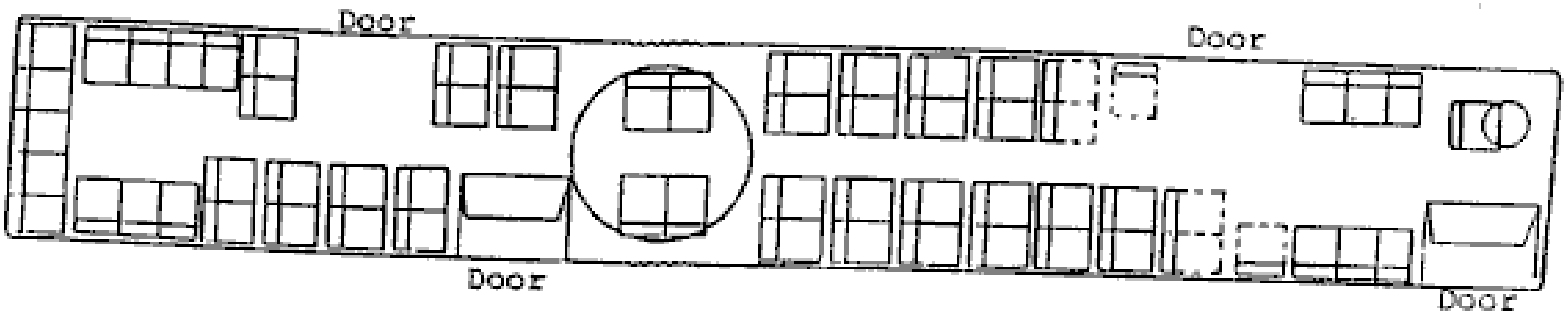
5.4.3 Development of the High Platform Bus

Seattle's research team developed the concept of a dual propulsion articulated bus with precise guidance features that allowed it to utilize a "rapid transit type" high platform. As shown in figure 19 taken from the March 1984 Task 2 'Technical Memo, the proposed configuration of the bus assumed two normal ground level doors on the right hand side of the vehicle, and two high level platform doors of the left side of the vehicle. All use of the left hand doors assumed prepayment, with whatever stations needing on-board fare collection to utilize the low level right hand doors.

5.4.3.1 Guided High Platform vs. Low Platoon

In the operation of any on-line, or platoon type station, minimization of station dwell time is a critical element in maximizing capacity. At a typical downtown station, the study calculated a dwell time of 22 seconds for the high platform operation, and 38 seconds for the low platform operation. Based on the total performance, the study calculated a total on-guideway cycle time for the high platform vehicle of 1,808 seconds per trip, vs. the conventional platform vehicle at 2,104 seconds. More important than this difference of equipment efficiency is the projected capacity of 14,500 passengers per lane on the high platform service, versus 10,920 passengers per lane for the two platform ~

In terms of design, the high platform system assumed a common center platform for both directions, while the low platform used the normal configuration of two platforms on the right side of the lane. Within the tunnel itself, the emergency egress walkway (of varying widths based on different assumptions of wheel chair requirements) was located on a common raised platform in the center, served by the left hand door. For the other services, egress onto two walkways on the right side of each vehicle was assumed. This assumption of one common center egress facility



SOURCE: Metro Transit

Figure 19. Seating Configuration of dual Power Tunnel Coach

resulted in somewhat reduced width for the two directional guideway, at about 6.7 meters (23 ft) in width compared with a common assumption of 8.5 meters (28 ft) for conventional busways. The Seattle study stands as the first prototype of an examination of what guidance/control mechanisms can provide above and beyond what can be performed by highly disciplined manual controls of buses.

Importantly, decision makers in Seattle did choose to pursue and develop the dual propulsion bus system in the downtown tunnel, but did not choose guided bus operations at this time.

5.4.3.2 Seattle's Station Design and Operations Plan

The layout of Seattle's downtown stations are shown in figures 20 and 21, reproduced here.(46) In a given direction, the platform area is divided into two primary waiting/boarding areas - one at the head of the station, and one at the back. In the diagram, they are labeled A and B in one direction, C and D in the other. At a waiting/boarding area there are berths for two buses, labeled Al, ~, etc. Between the two waiting areas, a berth exists which allows the use of a fifth bus when needed.

The operation calls for a major staging and platoon formation area at each end of the tunnel. From these platoon formation areas, the Seattle operations plan calls for about 145 buses to be sent through the tunnel in about 50 platoons per hour. The actual length of each platoon will vary from one bus to five buses, depending on the readiness of the buses in the platoon formation facility. A sketch of the platoon formation area is shown as figure 22. The operation of 145 buses, each with 61 seats will provide about 8,800 seats per hour. A common rule of thumb to calculate peak load capacity is seats x 1.3, which would result in about 11,000 persons per hour potential capacity.

The station design with the right hand platforms allows the existence of a center lane for passing delayed vehicles in extraordinary conditions. Because the buses operate from an overhead catenary, there is a basic operating assumption that buses do not pass each other, and remain in their fixed configuration, unless passing is needed.

The decision to go 'without guidance was based on several operational considerations and assumptions. First of all, it was not clear that Seattle's demand volumes would need the extra capacity that high level platforms would bring. Consistent with this was the idea that guidance could in fact be added, if a later decade of operations demanded the additional capacity.

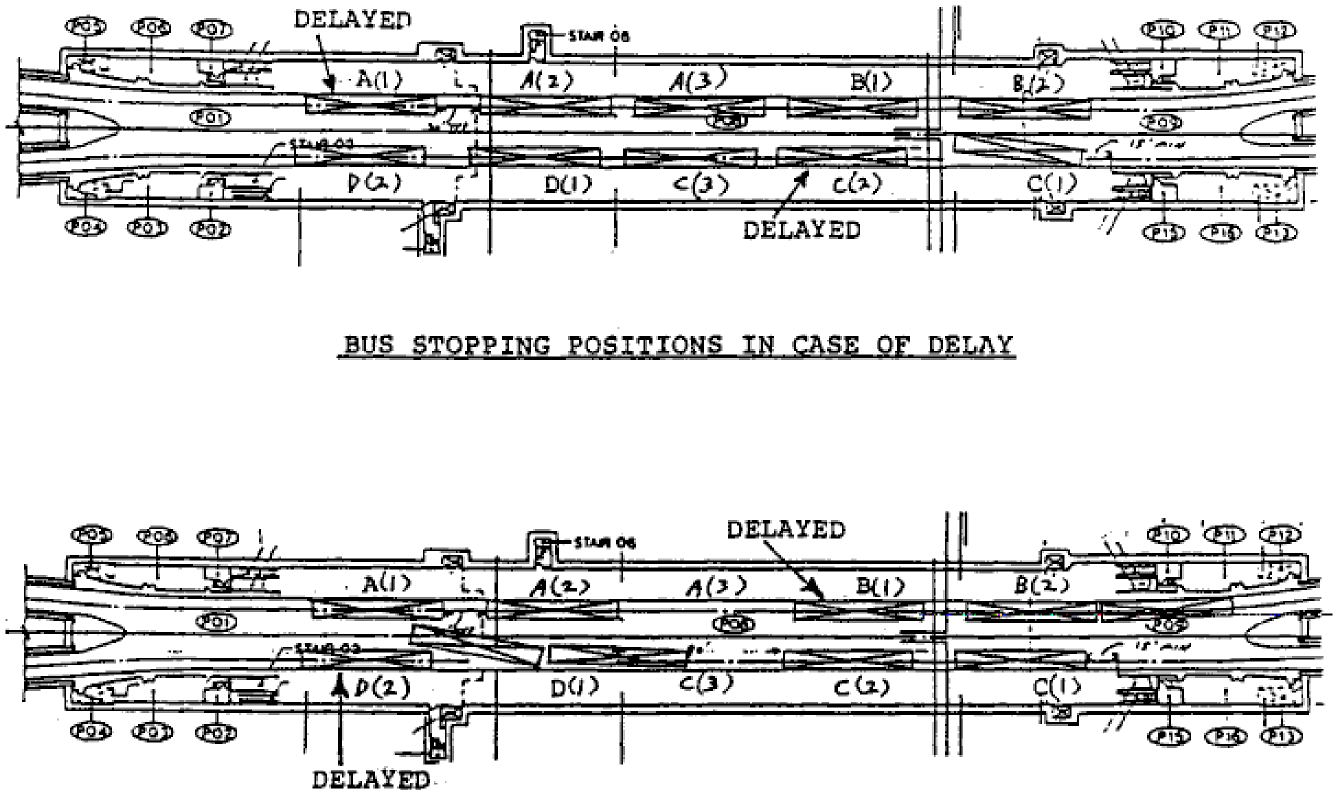


Figure 20. Concept Diagram for Seattle Station Operations

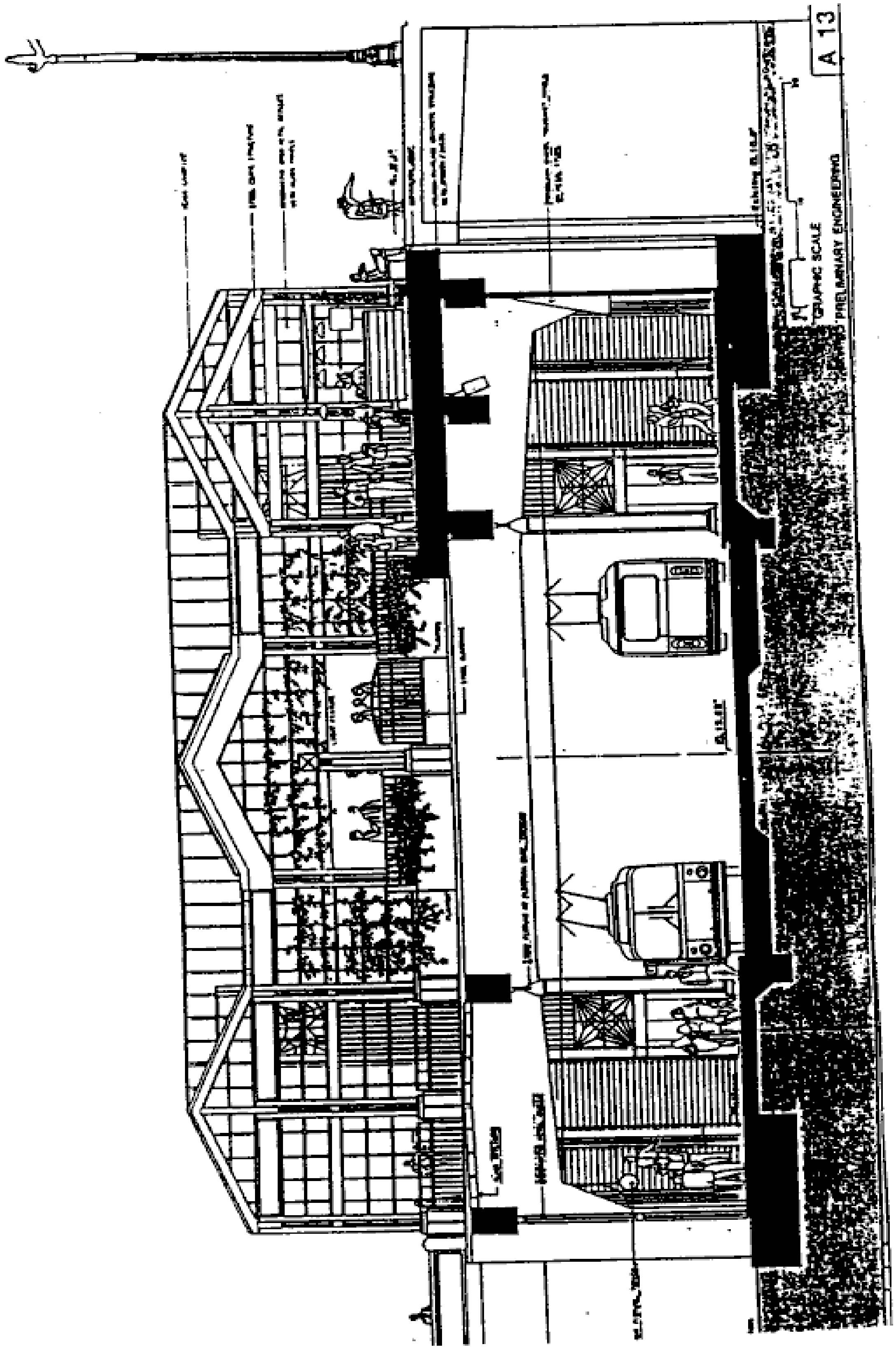


Figure 21. Station Cross Section Showing Passing Lane

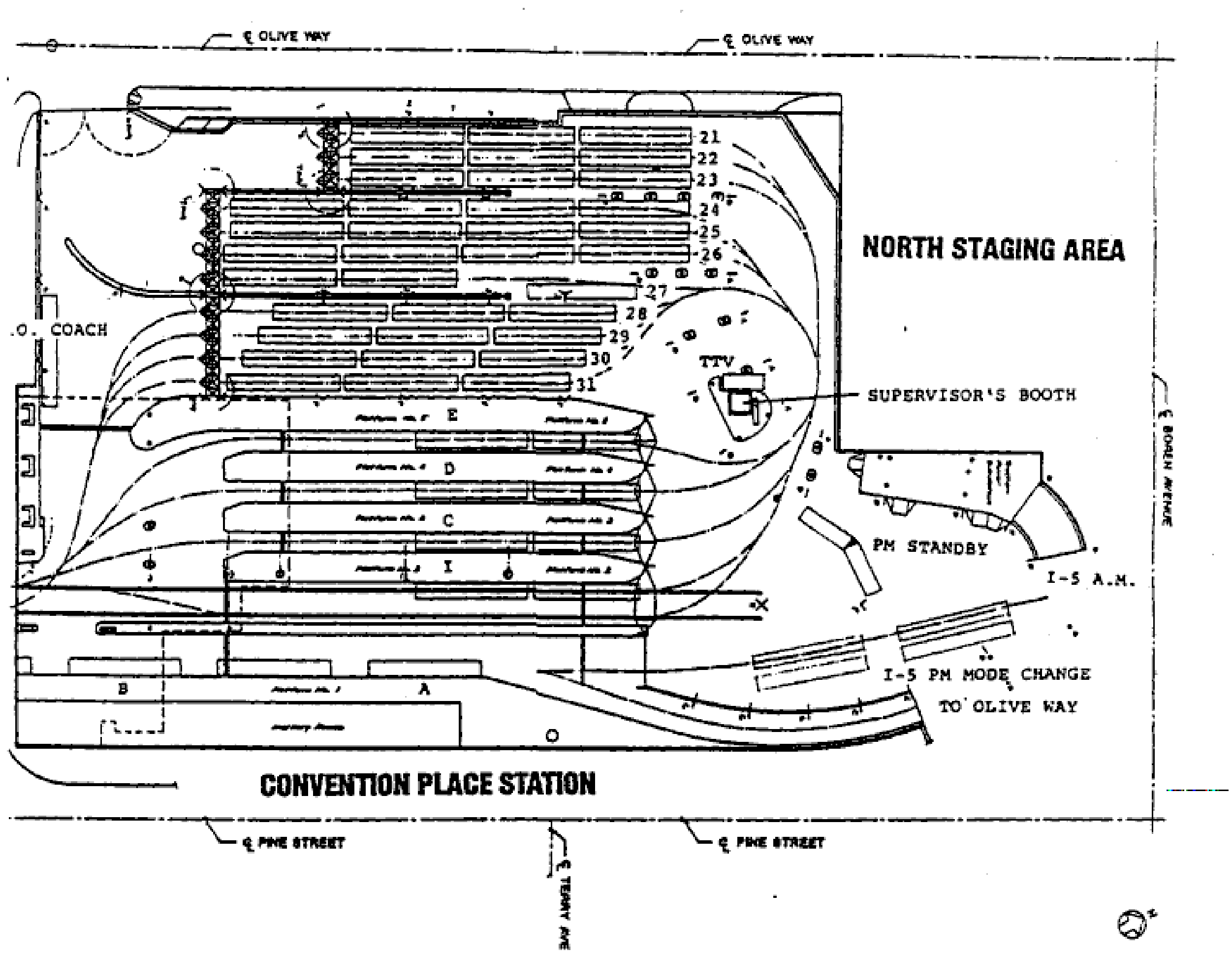


Figure 22. Seattle's Bus Platoon Formation Area

Second, there are two fundamentally different approaches to operations between the guided and unguided mode. In high platform guided mode, it is not possible for the bus to pass another bus while it is located next to a platform because the back of the bus swings into the platform. Thus, the high platform guided mode assumes that the platoon will stay together, in formation. While in low platform mode the largest source of on-platform delay will be the need to use wheelchair lifts for these platforms; high platform service can load the wheelchair in a matter of seconds, waiting only for tie down operations.

The selected operations plan will allow the bypassing of buses delayed for wheelchair lift operations. When a wheelchair lift is needed, the driver will bring down the trolley poles, and the following buses will pass the stalled bus using the emergency passing lane which lies between the two operating lanes. This same lane allows operational flexibility for other reasons, such as equipment failure in the station.

5.4.3.3 The Seattle Operations Plan - Implications for AHS

The present Seattle configuration, is in fact an interesting evolution from the dual mode studies of the 1970's. It is essentially an on-line platoon concept until something difficult happens. Then the delayed vehicle pulls down his trolley poles, and the trolley is used by the following vehicle which pulls out into the emergency passing lane, then returns to the single lane in the tunnel. Thus, it reflects the on-line "platoon" concept for operations, and the by pass capability of off-line concepts in times of operational problems.

The Seattle on-line station can be contrasted with the original off-line multi-slot concept from the RAND study. Figure 23, reproduced from Meyer Kain and WohI shows a five-berth concept.[(47)] To make this work each would have to be equipped with an escalator, and a strategy to get each wheelchair safely up to the mezzanine level. This concept assumes a wide two level station, with a mezzanine where people actually wait until it is dear which slot berth their bus is coming through. The reader can compare this five berth concept with the relatively straightforward Seattle on-line station design.

The question can be raised whether the extra capacity from the multi-slot off-line platform concept would be needed. If Seattle were to operate their tunnel with five bus platoons, for example, at 70 second headways, per hour potential capacity would exceed 19,000 which is comparable to the highest U.S. rapid transit volumes outside New York.

The other aspect of the Seattle system which must be studied by AHS Transit designers is the concept of a holding-staging-platooning area lying between the high capacity line-haul facility and the lower capacity distribution facility. The AHS line-haul roadway will be capable of producing extremely high volumes of buses which may or may not be bunched, badly ordered, or just experiencing normal surges in the peak hour. It is crucially important for the AHS designer to include some form of buffer facility between the high volume operations of the guideway to the more difficult

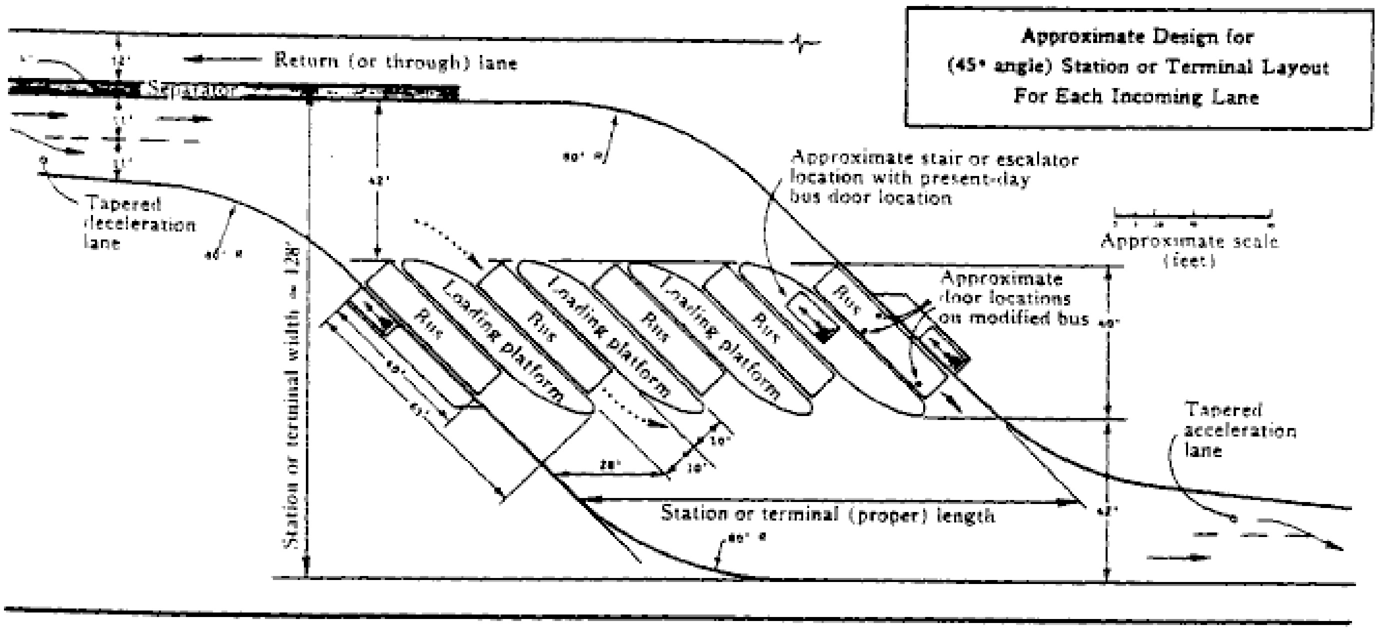


Figure 23. A Multi Slot Station Concept

demands of the lower volume distribution facility. The Seattle case study is a testing ground for various physical and operational concepts essential to AHS Transit. Simply marrying the enormous capacity of the guideway with the limited capacity of the online distribution loop could result in serious backup, queues, and significant problems with reliability.

5.4.3.4 Policy Implications for AHS

Seattle is now in a major process of determining the future of the downtown tunnel. Within the region there is a major debate about the future ability of the tunnel to deal with future transit volumes. The extent to which this concern about capacity is real or perceived cannot be resolved in this report. But it is valuable to speculate on the possible role of AHS Transit technology to increase the capacity and quality of service over the next decade as it evolves in the AHS research and development effort.

Specifically, AHS technology may be able to contribute to the reliability of the on-line platoon operation, with the result that the operational flexibility to break the platoon and bypass other buses may become less important. With this higher level of reliability, facility operators could move to high platform operations. A significant capacity increase could result first from the lowered standard dwell time, and second from the elimination of the wheelchair lift incidents from the operations plan.

These AHS-based improvements could be followed by the resolution of the so-called "train-like platoon" issue. All the calculations about capacity in the above section assume that buses are controlled by individual drivers, making quick decisions about the safe stopping distance of the bus in front of them. If indeed AHS technology does invent a longitudinal control mechanism in which the acceleration, deceleration and braking of all buses in a platoon is controlled as one unit, then true "train-like platoon" operations could result.

This area remains a high priority for the development of AHS Transit concepts. In order to understand the importance of this concept we can draw an analogy from light rail operations. Leibbrand reports that two articulated vehicles operating through a tunnel WITHOUT coupling can provide about 28,000 units of capacity. The same two units operating With coupling provide 42,000 units of capacity.([48]) Of course, this is just an analogy from another mode, with different performance assumptions. But it does suggest a possible major role for eventual "train-like platooning" for AHS buses operating in a constrained, on-line environment.

5.5 COPENHAGEN'S STUDY AND NEW COST DATA

The Seattle bus tunnel represents a major breakthrough in the development of high volume bus distribution facilities. With a present operations plan calling for more than 8,000 seats per hour, the Seattle work can be used to challenge earlier assumptions about the capacity limitations of bus facilities. Various new studies around the world are providing new data concerning the relative efficiency of advanced bus operations. In this section, we will review these studies for the possible impact of AHS Transit technology on their conclusions.

5.5.1 Copenhagen’s Cost Study of Comparative Modes

In a most important study reported in 1988, a Danish engineering firm undertook a comparison of Automated Guideway Transit (AGT)[1] Light Rail Transit (LRT) and guided bus schemes for a corridor from Copenhagen, Denmark's capital to several suburban corridors, including connections to their international airport. The study assumed several miles of downtown tunnel, similar in many ways to Seattle's downtown distribution tunnel. In the suburbs, light rail and guided bus were assumed to be at-grade, with signal pre-emption at intersections. The Automated People Mover (APM) was assumed to be grade separated throughout. The demand was fixed at 5,800 passengers per hour at the peak load point, and the facilities (station length, for example) was scaled for each modal alternative.

The key results of the comparison are shown on the attached table 6.

Table 6. Modal Comparison Study, from Copenhagen, Denkark

System Data	LRT	APM	Guided bus	Units
Peak Hour Ridership (Control)	5,800	5,800	5,800	Passengers/Hour
Tunnel	4.2	4.6	3.9	Km
Elevated	0.6	15.9	0.4	Km
Total	20.6	20.5	18.9	Km
Stations	24	24	21	
Control System	Manual	Auto	Manual	
Min Headway in Tunnel	3	1.7	1.5	Minutes
Max Headway on Branch	9	3	3	Minutes
Ave Speed	35	40	35	Km/Hour
Max Capacity/Hour/Direction	10,200	20,400	7,800	Passengers/Hour
Capital Costs				
Infrastructure	272	432	233	Million US $
Track Signals and Controls	135	347	88	"
Rolling Stock	88	46	38	"
Total Investment	495	825	359	"
Operating Costs				
Staffing	9	5	10	Million US $/Year
Other	7	8	6	"
Total Operating Costs	16	13	16	"
implied Debt Burden	43	67	33	"
Total Annual Costs (capital and operating)	59	8Q	49	"
Fares	30	30	30	"
Subsidy	29	50	19	"

Metric Conversion Table : Km x 0.621 = miles

5.5.2 The Role of Costs in the Copenhagen Study

This is a very important supply-side study. A central theme in the investment in capital intensive systems is that the initial investment in capital facilities will result in an overall savings when lowered operating costs are taken into consideration. But the Copenhagen study casts some doubt on that premise. In order to buy the full guideway solution for this system, a yearly debt burden of $67 million is implied. Thus, in order to bring about a year's savings in operating costs of $23 million over the guided bus, an additional carrying cost of $44 million must be born.(49)

The interpretation of the results of this study were interesting, and reflect a deep concern about the potential of bus operations. Having undertaken this analysis, in which automated guideway came out the clear loser, the consultant recommended implementation of the automated guideway. This was based on a concern that the guided bus concept did not have the capability to expand over time to provide for more capacity that its hypothesized design called for. The authors concluded that the guided bus "attracts the fewest passengers, and it is at the limit of ultimate capacity." In their study, they hypothesized an hourly demand of 5,800 riders at the peak load point. They further concluded that the ultimate maximum capacity of the guided bus was 7,800 riders per hour. By contrast the Seattle study suggested a maximum capacity of 14,000 riders per hour for the same calculation.

A key observation here is that the advanced bus was not rejected because of its proposed capacity, but out of a fear that over time it would not be able to grow in its potential capacity. In many ways this is similar to the Seattle situation described in the previous paragraphs. Before we turn to the possible role of AHS Transit technology in dealing with that perceived problem, it is worthwhile to check for other international data on the relative costs of modes, specifically automated vs. manual, and LRT vs. buses.

5.5.2.1 Recent International Cost and Operating Data

In the Copenhagen study, it was determined that automated systems would need $1.67 subsidy per ride, while LRT would need $.97 per ride, and the advanced bus would need $.63 per ride. Some confirmation of this relative performance comes from other recent studies.

5.5.2.1.1 AGT vs. Light Rail. The question of the economics of full automation has been under examination for years. Several recent studies have begun to challenge some of the earlier assumptions about the inherent savings in eliminating the driver. A recent study took the operations of the Vancouver Skytrain and applied the operating cost data of the Portland LRT to them. In this analysis, the with-driver LRT was concluded to provide service at 6.9 cents a passenger kilometer (11.1 cents per mile) versus 10 cents per passenger km (16.1 cents per passenger mile) with the automated driverless system.([50]) A recent French study compared the operating costs per passenger kilometer between the new Nantes LRT, and the automated VAL system in Lillie.[(51)] In this study the at grade with-driver LRT system was reported to cost 5.6 cents per passenger km, (9.01 cents per passenger mile) while the automated driver-less AGT system cost 12 cents per passenger kilometer, (19.31 cents per passenger mile.)

5.5.2.1.2 Light Rail vs Busway. Just as the Meyer Kain and Wohl study challenged the efficiency of rail operating cost assumptions, so do the studies continuing in the 1990's. Biehler has compared recent LRV operating costs with the operations over the Pittsburgh busway. Pittsburgh's East busway is currently carrying about 29,000 riders a day[1] which compares with 19,000 for Portland LRT, 27,000 in San Diego, and 30,000 in Buffalo, for example. Using a standard 15 percent conversion factor, these peak hour volumes can be estimated at between 2,800 and 4,500 passengers per hour. Biehier compares reported operating costs of five American new light rail facilities with the average of two busway costs in Pittsburgh. He reports an average per rider cost of $2.21 for the LRV option vs. an average cost per rider of $0.50 for the bus option.[(52)]

Both of these recent studies tend to support the logic of the conclusions of the Copenhagen study, which found the automated system the most expensive and the guided bus system the least expensive.

5.5.3 Implications of the Copenhagen Study for AHS Transit

In a situation not unlike Seattle, the Copenhagen decision questions the long term ability of the bus mode to increase in efficiency over time. While it is unclear whether or not a capacity issue really exists, it is clear that it is perceived to be a problem. Again, the promise of major AHS technology breakthrough could have a significant impact on the decision concerning the long term future of buses in distribution tunnels. As noted above concerning Seattle, AHS technology, with its focus on the immediate diagnostics in the "check" in function, could improve the reliability of the on-line guided services, allowing efficient high platform loading from simple on-line platform formats. Second, the later existence of "train-like platooning" capabilities could improve overall capacity and allow for the use of smaller less efficient buses into the platoon.

If the AHS Transit program could offer this promise in a decade, near term decisions to proceed with more basic bus investments could be made now with greater certainty about perceived long term futures.

5.5.4 Other Considerations in Automation

The conclusions reached in both Copenhagen and Portland concerning the operating cost implications of removing the driver from the vehicle may or may not remain valid as development of automated systems makes them cheaper. In reviewing the potential of dual mode bus systems to provide significant savings by removing the driver, the comprehensive German vOv study concluded:

> "Automatic longitudinal guidance results in a material benefit only if the driver does not accompany the bus onto the fully automated segment. However, the driver's roster will seldom allow this. The proportion of the automatic line segments of the entire line network would have to be very great to make this possible, but this is not the case for cost reasons."(53)

Thus, one of the most basic assumptions in the development of small bus dual mode automated guideway concepts in the 1970's is now being seriously reconsidered. This seems to be the case above and beyond the present interest in security of the riders, and the present tendency to add attendants for security reasons.

5.6 A PROTOTYPICAL INTERMODAL CORRIDOR EXERCISE

The concept of a "prototypical corridor" has been used to test the applicability of various modes under a variety of hypothesized conditions. A prototypical corridor was created, for example, in both the Seattle research and the Copenhagen study. In order to test the concept of AHS Transit in a variety of service functions, we have created a "Prototypical Intermodal Corridor" which includes, a major airport (with an internal circulation system), a commenced (but not completed) HOV network, a downtown Intermodal Terminal, and a downtown needing improved distribution services. Realistically, we can imagine that the airport authority is looking at improved internal circulation within the airport, the state highway department is examining the possibility of more HOV lanes on the state highway, and the transit authority is looking at their options for improved downtown distribution. For the first time in Federal legislation, the Intermodal Surface Transportation Efficiency Act of 1991 (ISTEA) now mandates:

1. That all of these separate components now be looked as a unified Intermodal System.
2. That IVHS, and other advanced technologies, be considered in that planning process.

The following section of the Commercial and Transit Report presents an examination of such a process, and its implications for the development of AHS Transit.

5.6.1 Purpose of the exercise

In the previous two sections, this report has reviewed the studies leading to the choice of technology in Seattle and Copenhagen, focusing largely on the issue of capacity of advanced bus systems to handle the possible increases in demand. In each of those case studies, existing available bus technology was found to provide the most effective service for the demands forecast. However, in each case the issue is raised about the potential of AHS technologies to extend that capacity as they come into existence over time. Both of these examples consider a light-rail like formation of dispersed feeder lines assembling at a downtown gateway, with several miles of downtown distribution tunnel.

In this section of chapter 5, we will examine a different kind of application, exploring the possible role of AHS Transit services between a major airport and major downtown activity centers. In this exercise, we will examine a context in which capacity is not the relevant issue. Indeed, it is shown that the actual number of air passengers needing transit service in a peak hour would not require any advanced technology. Rather than focusing on the issue of capacity this exercise seeks to illuminate the role of AHS in providing highly specialized intermodal connections of the kind now being demanded by airline passengers for their ground access needs.

The following corridor has been hypothesized. The reader should be cautioned that this corridor is NOT a description of any given city[1] but is intended to illustrate issues experienced in many cities.

5.6.2 Description of the Present Corridor Conditions

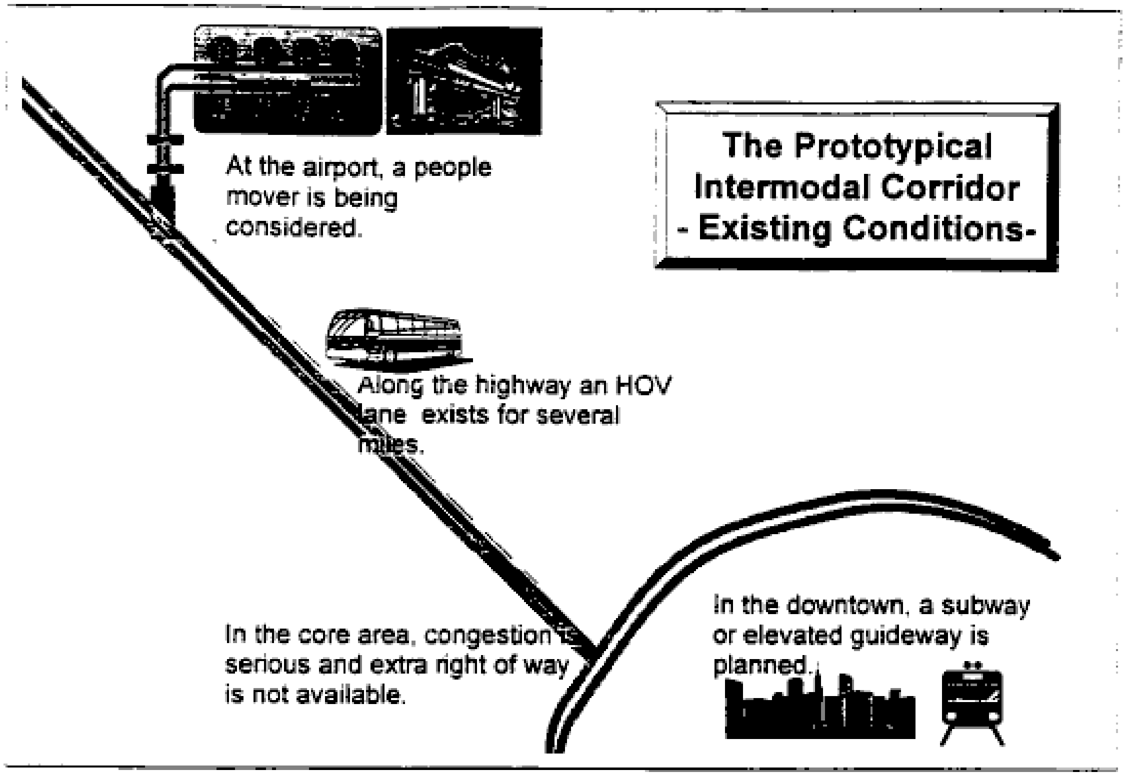
As illustrated in figure 24, the airport is located about 16 kilometers (10 mi) from the city center. The city has a partial, but not complete HOV system,. including much of the main radial highway used to access the airport. At the intown end of the HOV system, a seriously congested segment exists, in which it has not been possible to build an HOV system and will not be possible to build an HOV system.

Figure 25 shows the airport, which has four separate unit terminal buildings. During peak hour, the buses get caught in the airport roads congestion. To alleviate this, the airport is planning to build a new people mover. The airport contemplates building a new people mover system to connect the four separate terminals, a rent a car area, and several long duration parking locations. The airport is planning to invest in the terminal/people mover interlace, to provide for a high quality of architectural integration between the two.

In the downtown area, a loop distributor is being discussed for the longer term, modeled after the downtown people mover in Detroit, Michigan. In the shorter term, the city is considering using bus lanes through the major CBD sub districts.

In our hypothetical corridor, three options are being considered to give better service between the airport and the core area.

1. The AGT transit proposal proposes to extend automated service from the airport to the downtown on its own private right of way. In this option, the people mover stations to be built at the four unit terminals will be used for direct service to downtown. There a new terminal will be just a taxi ride away from the hotel district, the convention center and the financial district. In the long run, some of these airport vehicles would proceed onto the downtown distribution loop that is under consideration.



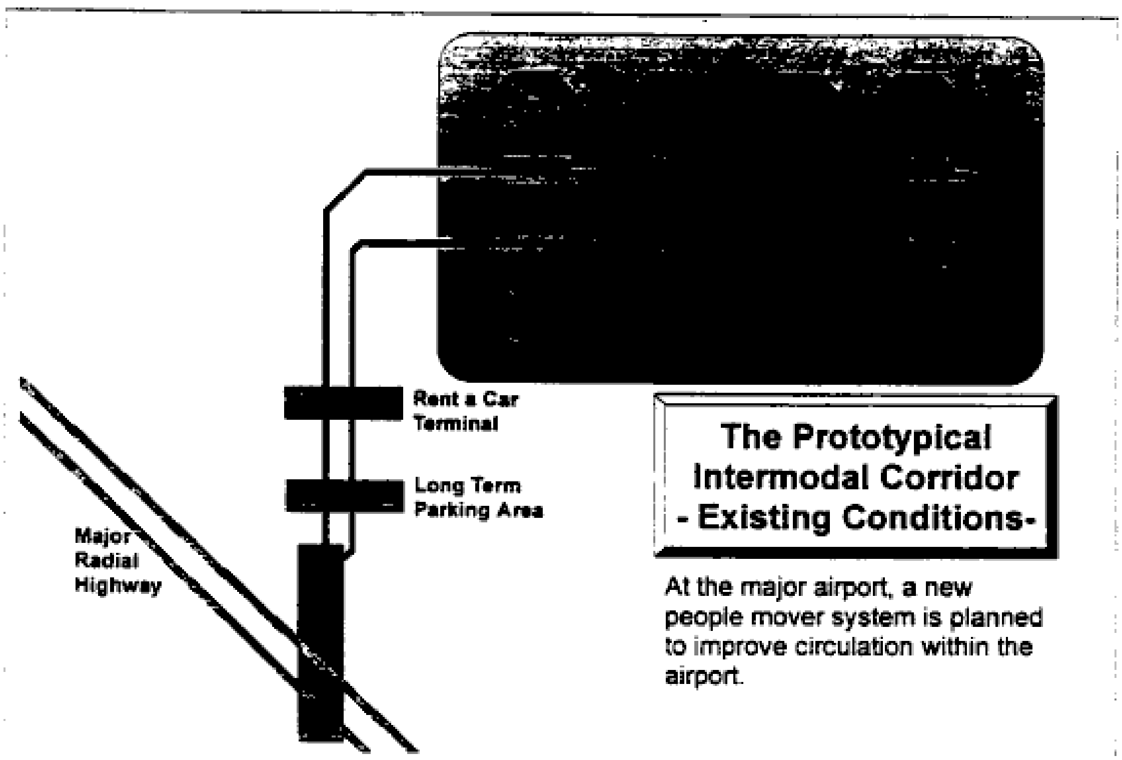
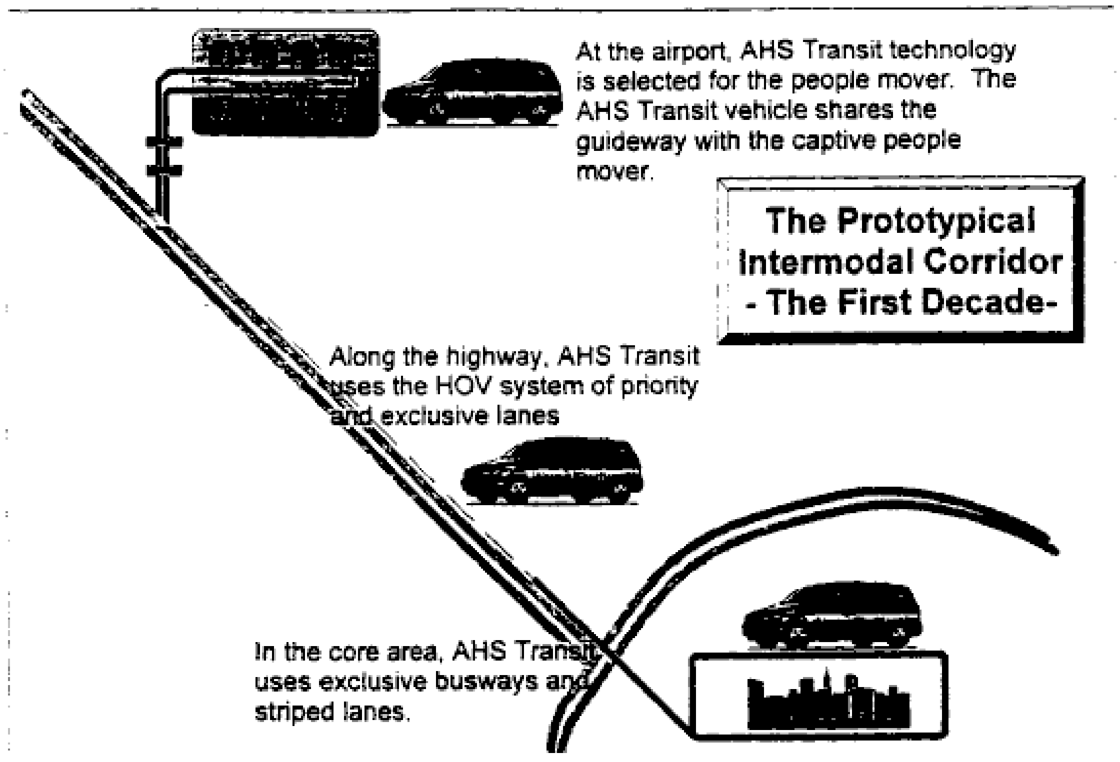


Figure 24. AHS Prototypical Intermodal Corridor Existing Conditions



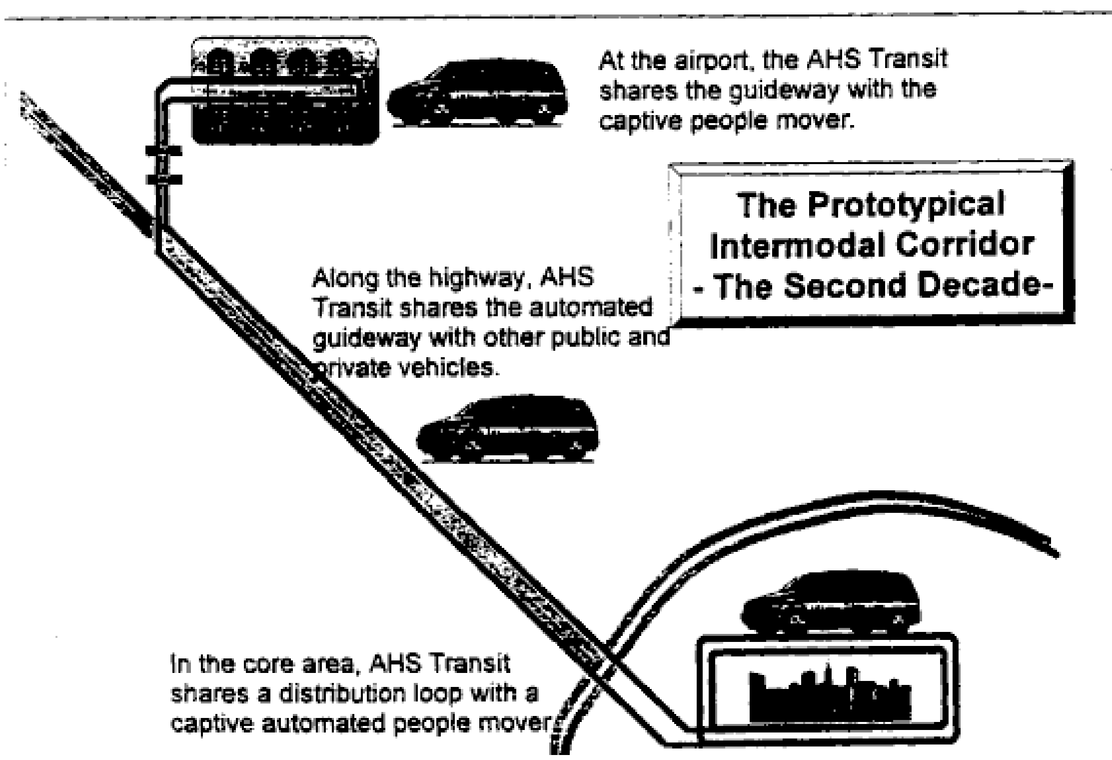


Figure 25. AHS Prototypical Intermodal Corridor - Future Conditions

2. The second option is an express busway. In this option, the bus uses the existing airport circulation road, competing for curb space with the other modes. New elevated structures are contemplated to connect with the existing structures.

3. In the third option, light rail is considered to replace the HOV lane. A new rail right of way would be constructed from the center of the city to the airport 16 kilometers (10 mi) away. The light rail would serve the whole corridor, and have about six stops between the airport and the downtown.

5.6.3 An Illustrative Example of AHS Transit - Long Term

To use this exercise to illustrate the possible role of AHS Transit, we will first look at the very long term potential for the corridor, and then work backwards to look at steps of implementation. In this future Prototypical Intermodal Corridor, AHS technology has been selected for a wide variety of separate network segments.

In the airport itself AHS technology has been selected to provide so-called "people-mover" services within the airport, and connecting to rent a car, long term parking, and a convention complex. Service along this segment of the network is provided by automated vehicles which are "captive"" to the guideway; they cannot be driven off the guideway onto any roads.

Throughout the region, AHS technology has been selected for the major highways. In our corridor, the early HOV lane has been replaced by an AHS guideway, on which our publicly owned transit vehicle shares the right of way with thousands of privately owned vehicles. From the end of the airport guideway to the beginning of the downtown distribution area, our airport access vehicle utilizes the common dual mode guideway.

Just before the major merging system with the inner core expressways, our vehicle leaves the radial highway guideway and proceeds onto a guideway which is for transit and other specialty vehicles only. This guideway leads to a downtown intermodal terminal for some of the buses, and to the downtown distribution loop for vehicles which are specially configured for these distribution services, as illustrated in figure 26. On that loop, our AHS airport access vehicle proceeds in electric mode through a variety of major activity areas which have grown up around the downtown distributor. The driver of the airport access vehicle is now serving as an attendant, helping people with their baggage and explaining the system to the riders. AHS Transit technology is operating the vehicle on a guideway which is mainly used by automated vehicles which are captive to the system.

Each element of the network -- the airport guideway, the automated highway segment, the busway connector, and the distributor loop -- has been designed to utilize the same signal, control and guidance technology, based on electronic control of rubber tired vehicles.

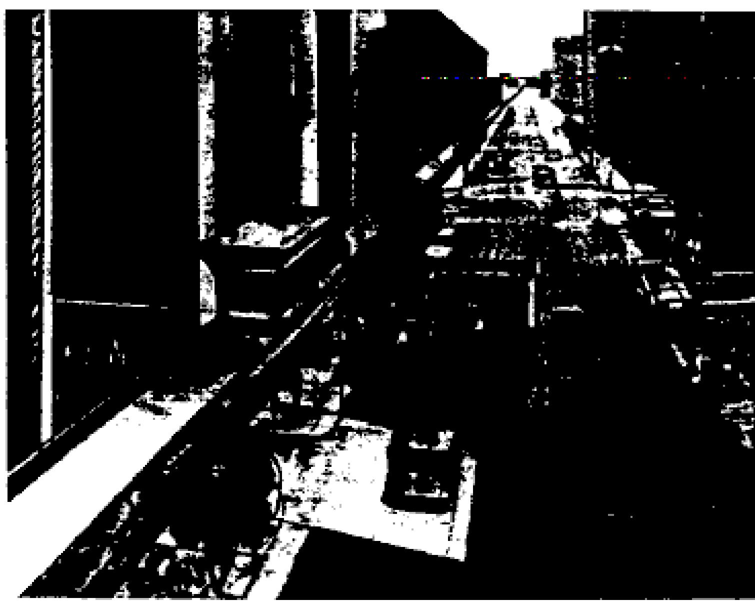


Figure 26. Dual Mode Station Concepts

5.6.3.1 A Qualitative Comparison with Other Modes: Long Term

There is little question that --once installed as total system-- AHS technology could provide benefits to the community of users of public transportation. The tougher questions concern the difficulty of reaching the fully installed system, which will be noted below.)

5.6.3.1.1 Cost Comparisons- Guideway. In terms of capital costs, the advantage to the transit sector may be most robust. For most of the line-segment [perhaps 13 kilometers

(8 mi)], the cost of construction of a guaranteed free-flowing right of way has been almost entirely born by other sector budgets. Transit capital investment savings compared to an AGT or LRT exclusive right-of-way would be in the nature of $400,000,000, conservatively estimated at $80.5 million per kilometer ($50 million per mile).

Savings from the busway connector segment are harder to calculate. A conservatively designed busway would have about a 12.2 meter (40 ft) width, based on the assumption that reliability problems from some of the vacuoles suggest the need for breakdown lanes in both directions. The combination of AHS technology's lateral guidance mechanisms, and (perhaps more importantly) AHS entrance-procedure improvements in vehicle reliability could allow for a 6.7 meter (23 ft) width. Structurally, such an AHS Transit guideway could fit in demanding situations currently favoring AGT technology. It may be that the ability of the AHS Transit guideway to fit into tight geometric conditions will be more important than its lowered costs.

In terms of the capital costs for downtown distributor, the guideway for an AHS transit one way loop should be indistinguishable from the costs of an AGT guideway in the same formation. However, if the AHS guideway at some point allows entrances and exits, some routes could operate partially on the guideway, and partially off of the guideway. Theoretically, this could allow the opportunity for staged implementation of a full system over time.

5.6.3.1.2 Cost Considerations - Vehicle Oriented. In the AHS Transit scenario, the standardization of technological components has helped the operators of segments of the total system to control costs. First in terms of the initial capital costs of the vehicles, standardization of component parts allows the "people-mover" to be purchased as a variation of the standardized AHS bus, rather than as a piece of equipment that is almost literally built to order.

Second, in terms of the ongoing maintenance function, the airport authority now buys component parts for its guidance mechanisms from corporations that make literally millions of similar components for the private car market which uses AHS facilities. For a specialized maintenance problem, the airport authority may ask help from a specialized technician employed by the transit authority; this is no problem because the mechanisms of guidance and control have been standardized over the systems.

5.6.3.1.3 Service considerations. Once the lull, mature AHS system is in operation, the transit user has, at last, attained a truly seamless form of transportation in our hypothetical case of airport ground access. The user found a "people mover"' at his/her air terminal baggage claim area, benefiting from the kind of close architectural integration people movers have attained at major US airports. With no change of vehicle, that user(with his/her baggage) has been sent non-stop to many of the major destinations of the region. In some cases, that destination is reached via a distribution loop guideway, in most cases that destination is final reached by the use of local streets and driveways. The transit user has literally by-passed all sources of congestion still experienced by the private user, with the various combination of guideway facilities not all of which were available to the private auto user.

5.6.4 Incrementally Attaining the Long Term System - First steps The long term

system described above was the end result of several decades of incremental project decisions, each of which had payoff before the ultimate integration of the elements into a mature system:

- Airport decisions. As the airport chose its people mover technology, it selected an electronically guided technology, not dissimilar from the technology now used for service vehicles in the English Channel Project. In the short term, that vehicle may or may not be outfitted with some form of physical guidance to ensure a perfect alignment at the high platform station. In the early years, this people mover is operated with no sharing of the guideway with dual mode vehicles.

- Expressway decisions. Over time, a flexible strategy is selected for cost-effective HOV priority service. Near the airport, no exclusive lanes may be needed. Simple paint striping may be used on other segments, leading to the totally exclusive right of way portion of the highway.

- Busway connector decisions. Within the dense urban core it may not be possible to find any more width for the roadway to accommodate a desired HOV system. For a short segment of two miles, it may be best to build an elevated busway segment between the HOV lane and the downtown intermodal terminal.

- Downtown distribution decisions. Having looked at the budget, a decision is made to start the long term project with some carefully enforced bus lanes, and hold a right of way envelope for a later elevated loop.

5.6.4.1 Introduction of AHS Transit to the Network

In early phase AHS Transit is introduced to provide a one seat ride from each airport terminal to specific subareas of the core with no stop from the airport to the destination. The vehicle has been designed to utilize the "people mover"' guideway through the airport, benefiting from the high quality architectural integration with each of the separate terminals. Using the airport guideway for the first kilometer (mi), the vehicles is driven onto the HOV system already in place on the radial highway. In this stage of incremental implementation no attempt is made to remove the HOV system and replace it with AHS technology. The strategy at this stage is to increase the amount of right of way dedicated to exclusive HOV lanes, which later will be converted.

At the commencement of the elevated busway segment, the AHS Transit vehicle, with its precise lateral guidance, could utilize a relatively narrow elevated structure of about 6.7 meters (23 ft) in width -- as narrow or narrower than LRT or AGT options. Alternatively, the busway segment could be designed for regular bus Operations at a width of about 9 meters (28-30 ft) with no breakdown lanes, or about 13 meters (40-44 ft) with breakdown lanes. Either width elevated busway could be chosen in this long term AHS implementation strategy.

At the downtown entrance, our airport access vehicle bypasses the terminal completely, and drives down the bus lanes to deliver passengers to each of their separate activity centers downtown.

5.6.4.1.1 A Qualitative Comparison with other Modal Strategies: Short Term. At this phase of implementation there is little or no value to the AHS Transit system in converting the line haul segment from HOV to AHS technology, provided that the HOV lanes can guarantee a free flowing right of way. However, there may be significant benefit from the busway connector between the radial highway and the downtown terminal. On the positive side, highly reliable operations could be established on a narrow guideway[1] whether elevated or in tunnel. On the negative side, the investment in this narrow guideway would not give benefit to the majority of HOV and special purpose vehicles, which by this point in the implementation process would not yet have AHS guidance capability.

From the user perspective, the interim service would provide the high quality, seamless transit service desired. Unlike a concept which sends AGT just to the airport, advanced buses throughout the corridor would share the new AHS/busway facilities. Incremental addition of many bus lines would be easy at this phase. The key policy question for this phase concerns the cost effectiveness of a guided AHS strategy vs. a pure HOV investment strategy.

5.6.4.2 Capacity Considerations at the Airport

The concept that the regional shuttle would utilize the airport people mover guideway can be explored in terms of capacity. The Intermodal Corridor exercise can be used help understand that in many cases, the problem of designing high quality public transportation system is not one of capacity, but rather with the need to provide a large number of highly specialized services. AHS Transit may have a particularly important role for this reason, rather than for the reason of capacity itself.

In order to set a scale and context for the issue of airport passenger access, we have hypothesized the existence of large international airport, with a predominance of origin/destination traffic, rather than connecting traffic. This hypothetical airport has about 45 million passengers per year, making it similar in scale the largest of US airports at the present. We have further assumed that 90 percent of the users are not connecting other flights and need ground transportation services. Based on calculations based on similar assumptions, we can note that in the peak hour (4-5 pm) some 6,300 passengers arrive by air, of which 5,700 need ground transportation services.

Taking an average of airport mode split data from Boston, San Francisco and

Chicago, we can note that at present, somewhat less than 25 percent will choose all forms of public transportation combined. This produces a volume of about 1,500 air passengers per peak hour currently seeking all public services in the peak direction In terms of the volumes discussed throughout this chapter, this is a distinctly low number of public transportation users. Given that existing street bus operations record as much as 6,000 riders per peak hour, discussion of the need for new technology *to increase* capacity would seem somewhat out of place. By way of example, one articulated bus on a simple on-line collector loop operating every 90 seconds would provide about 2,400 seats per hour. The assumption of a two bus platoon on that loop would increase the capacity to about 4,800 seats per hour. Thus, a three berth simple platoon operation over an airport guideway (at 7.200 seats per hour) would have no problem in carrying both airport demand and all present users of ground transport services.

The problem -- and the opportunity for AHS technology -- stems from the fact that most airport ground access demand cannot be serviced by large 60 seat buses. Rather, at the present time the trend is overwhelmingly toward exactly the kind of dial-a-ride size minibuses hypothesized in the early days of dual mode transit research in the 1970's. Thus the logistic problem comes in the management of literally hundreds of small vehicles per hour in order to provide the capacity in the range of 2,000 to 3,000 seats per hour.

5.6.4.3 The Airport Challenge to AHS Transit

The management of hundreds of small vehicles simultaneously seeking access to separate unit terminal curb boarding areas is currently vexing airport managers around the country. Curb area frontages designed to board 50 person buses with grace are now being used by a wide variety of shared and non-share limousine services -- often with anarchic results.

AHS Transit technology might be utilized in terms of disciplined platoons of smaller vehicles operating over narrow guideway loops, allowing a high level of architectural integration with the terminals themselves. Conversely, it may be the disciplined dispatching to many off-line platforms - exactly as GM had predicted in the 1970's-- that makes the most sense. Alternatively, it may be that smaller vehicles -- particularly those that operate on demand, and with no predictable schedule, should not operate to the separate terminals at all, and that some other mode should bring passengers to them. In any event, the challenge to AHS Transit for airport access does not lie in the issue of maximizing capacity -- that seems to be irrelevant in traditional terms. Rather, the kind of dispatching and control technology currently under consideration for PRT (Personal Rapid Transit) systems may have to be incorporated into AHS systems for reasons having nothing to do with airports. If this occurs, AHS Transit could play a major role in organizing multi-terminal origins to multi-location destinations in support of Intermodal Access strategies.

These considerations suggest that AHS transit technology could play a significant role the management of transit vehicles through highly constrained geometry at existing mufti-terminal airports. These benefits could be gained relatively early in the development of an ultimate region-wide system. The airport can logically be seen as subsystem which needs early analytical attention, with potential for near term pay-offs.

5.6.4.4 Later Conversion to Full AHS Network

When the regional decision is made for implementing the full AHS automated highway network, the highway line-haul segment is converted from HOV facility to an AHS facility. The airport bus uses a guideway independent from the AHS within the airport boundaries, and uses a separate guideway in the densely developed core area. The implementation of the automated highway segments complete the system. The primary benefits of this automation would fall to others than the previous users of the HOV system, assuming that it still could guarantee free flowing conditions.

In the downtown, development envelopes have been established for the downtown distributor loop over the previous decade. The downtown bus lane system is now augmented by the elevated distribution loop, which has been designed to integrate with the busway connector and intermodal terminal projects.

5.6.5 Lessons from the Prototypical intermodal Corridor Exercise

AHS Transit will not be able to meet its potential as long as it is seen as a mechanism to have buses make use of the highway segment. It will make its most impact when the technology of the shared highway segment is matched with the needs for exclusive segments, all of which integrate into one system. Similarly, its benefits may stem from contributions that have little if anything to do with increasing capacity of what exists without it. Indeed its most powerful impact may have more to do with maximizing reliability than maximizing capacity. The corridor exercise was designed to demonstrate how diverse those contributions may be.

5.7 RIGHT OF WAY REQUIREMENTS

This section defines the right-of-way requirements necessary to accommodate the AHS Transit concept for guideway and stations.

The guideway section reviews needs for design vehicles$_{1}$ lane widths, emergency egress, and walkways.

5.7.1.1 Design Vehicle

Automated guidance can have an impact on the size of the guideway; and this in turn will affect the cost and environmental impacts (e.g. land taking, shadow, aesthetics) of the transitway. Generally, automated guidance allows a narrower guideway than would be practical for manually-driven buses under similar conditions.

The size and design of the transit vehicles will also affect the guideway width. The comparisons in this section will consider buses which are commonly in use in North America. The typical commuter or urban bus used in high-density corridors is 12.2

meters (40 feet) long, and either 2,440 mm (96 inches) or 2,590 mm (102 inches) in width. Mirrors and mounting assemblies will add another 250 mm *(10* inches) to each side of the bus. A study by Lea, Elliott and McGean ("Evaluation of European Guided Bus Technology, Municipality of Metropolitan Seattle, March 1984) indicates that collapsible mirrors can reduce the additional side clearance required to 90 mm (3.5 inches) on each side. Also common are articulated buses, which are typically 18.3 meters (60 feet) in length, with similar widths to the 12-meter buses.

5.7.1.2 Lane Widths

Figure 27 illustrates typical guideway cross sections for conventional (manually driven) and automated guidance transitways. For conventional buses, a lane width of 4.0 meters (13 feet) is shown. This will be adequate under most operating conditions for transitway speeds up to freeway speeds of 90 km/h (55 mVh) for a two-way transitway. For lower speeds, or where multiple lanes move in the same direction, a lane width of 3.4 to 3.6 meters (11 to 12 feet) may be adequate; for heavy volumes at higher speeds, lane widths of up to 4.6 meters (15 feet) may be indicated.

With the 4-meter lane width, plus additional allowances for barriers or curb overhang on each side, the conventional transitway width would 9.2 to 10 meters (30 to 33 feet).

With automated guidance, the minimum lane width would be 3.0 meters (10 feet), assuming collapsible mirrors, and allowing 110 mm of dynamic clearance (for rocking and bouncing) on each side. At higher speeds, the space between lanes would have to be increased by up to 1.5 meters (5 feet) to reduce the interference from the air pressure differentials created by passing buses. Providing 600 mm (24 inches) each side for side barriers, and allowing right side mirrors to overhang the barriers, the minimum right of way required with automated guidance would be 7 meters (23 feet), with 8 meters (26 feet) a more typical width.

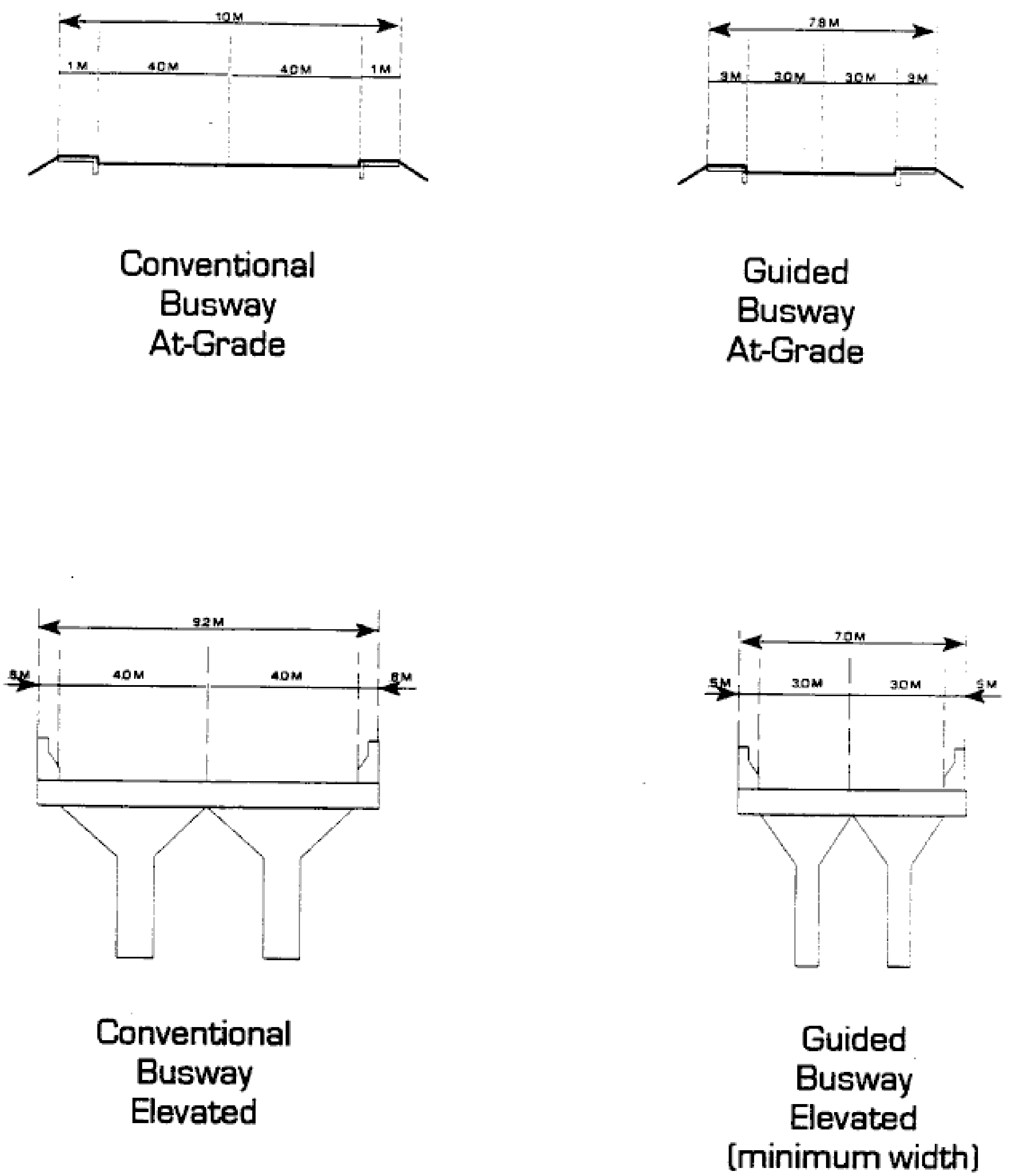


Figure 27. Typical Bus Guideway Cross Section

5.7.1.3 *Emergency Egress, Walkways*

With conventional transitways, the lane width is generally sufficient to allow passengers to exit the vehicle onto the travel pavement when the vehicle is disabled or for other emergencies. That is, a disabled vehicle could stop within the lane with at least 900 mm (36 inches) on the right side for passengers to exit the bus, while allowing room for other vehicles to pass.

With automated guidance, vehicles operating on an elevated or depressed guideway with minimum clearances would not be able to stop within the lane and allow passengers to exit the vehicle on the right side. In such cases, the vehicle would have to pull away from the right wall or barrier, and thus block the other lane, preventing vehicles from passing in either direction. Providing a .9-meter (3-foot) exit/walkway on the right side of each lane would bring the total guideway width with automated guidance to 8.6 meters (28 feet), slightly less width than a conventional transitway.

In either case, there may be circumstances where exit from the right side of the vehicle is impossible. For example, a tire or axle failure or collision may leave the vehicle disabled and resting against the right wall or barrier. In this event, passengers would have to exit the vehicle through emergency window exits on the left side.

Maintenance or access walkways or pedestrian sidewalks may be desired so that authorized persons can walk along the guideway. When such a walkway is provided, it will generally be separated from the travel lanes by a barrier or substantial curb, and it will add to the width of the overall guideway.

5.7.1.4 Guideway, Summary

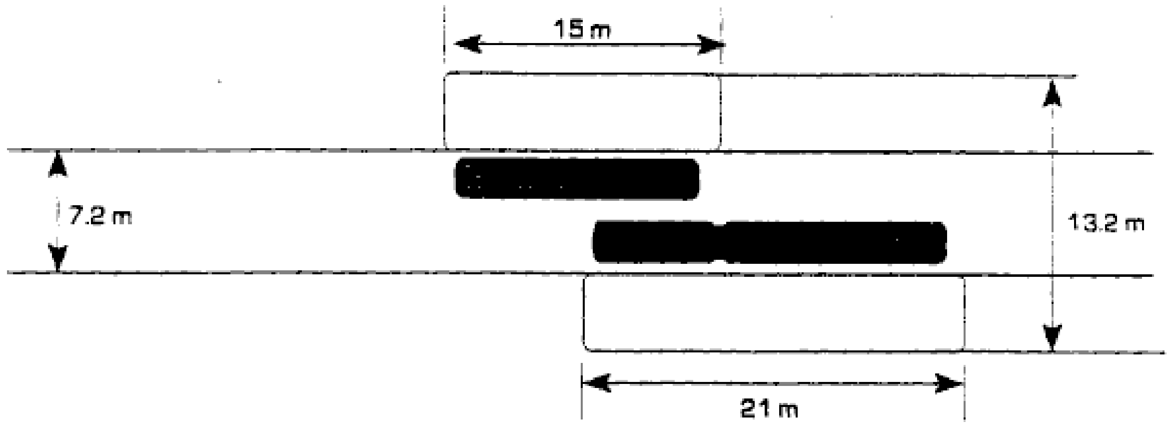
There are some circumstances where a guideway for automated guidance vehicles can built with a narrower cross-section, and thus with reduced costs and other impacts. These circumstances generally include lower-speed operation where the impacts of a wider guideway are great compared to the potential impact of disabled vehicles on operations.

5.7.2 Stations

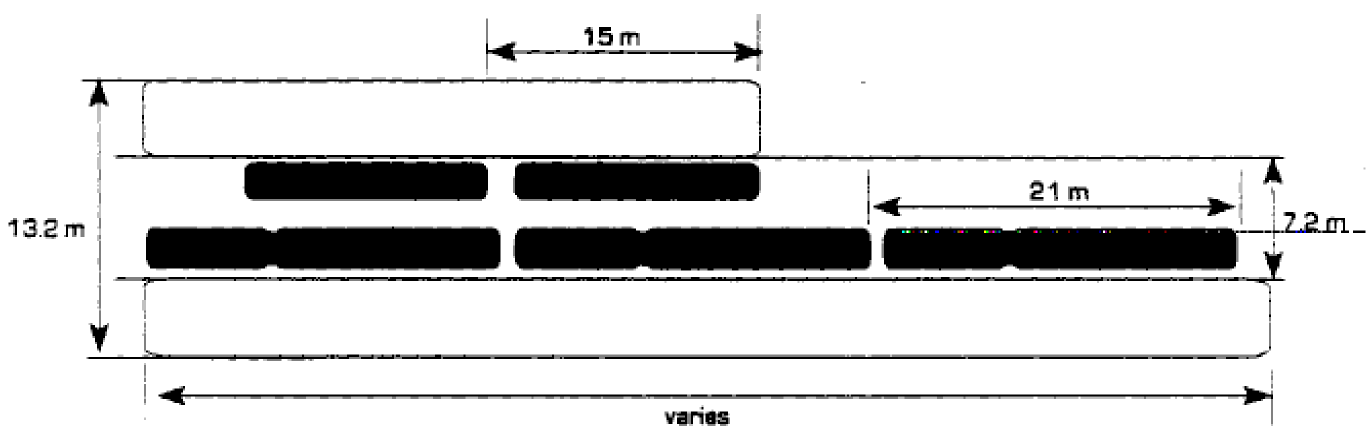
The design parameters at the stations vary for on-line versus off-line stations. Both types were investigated.

5.7.2.1 On-Line Stations

On-line stations (where the bus stops in the travel lane to discharge and pick up passengers) will generally have the smallest requirements for real estate. Figure 28 shows typical arrangements for on-line stations. The top figure shows a single bay at each stop (with articulated and 12-meter buses shown). The minimum platform width for passengers is 3 meters (10 feet), with a length equal to the length of the bus,



Single Bay



Multi Bay

Figure 28. On-Line Stations

plus 3 meters (10 feet) in beyond the front of the bus. For a conventional bus, this would result in a waiting and circulation area of 45 square meters (480 square feet). The total width of station and guideway would be 11.8 to 13.2 meters (39 to 43 feet).

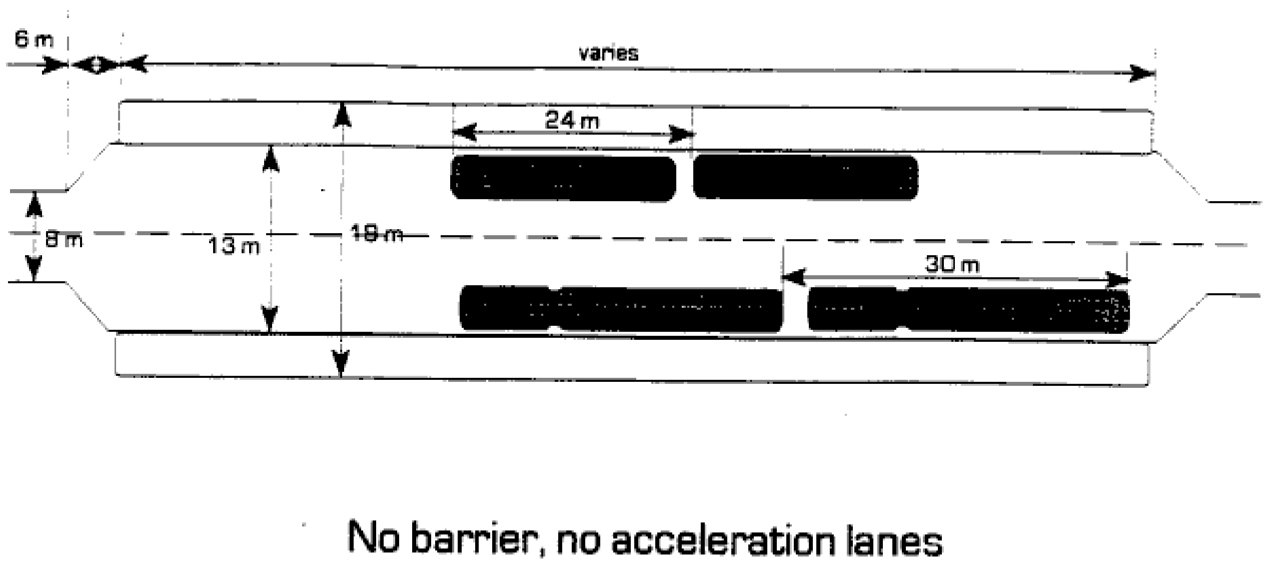
At a single-berth on-line station following buses cannot be serviced until the bus in the station completes its boarding process, limiting the headway between buses to the dwell time (total time for discharging and boarding passengers) at the busiest station on the line. Prior studies (quoted in "Characteristics of Urban Transportation Systems," for example) suggest that the maximum throughput at a typical high-activity station is 15 to 30 buses per hour. This would limit the headway for on-line, single-berth operations to approximately 2 to 4 minutes. (Seattle experience suggests that tighter headways are possible where boardings are spread over several stations so that the dwell time at each station can be held under a minute.

Providing multiple berths allows platoons of buses to operate into on-line stations. With platoons arranged with buses in the order of berth positions at the stations, each berth could handle between 15 and 30 buses per hour, with total throughput limited by the practical length of each station. Multiple berths may be indicated at lower bus volumes in order to provide separate waiting areas for buses with different destinations. Spacing between berths for an on-line station can be as little as the bus length, but providing space between buses of up to 3 meters (10 feet) will improve through times by not requiring drivers to hit an exact spot.

5.72.2 Off-Line Stations

Off-line stations provide increased operating flexibility, at a significant cost in terms of right-of-way requirements. Figure 29 illustrates two possible arrangements for off-line stations. The station at the top of figure 29 would be appropriate where all buses on the line are scheduled to stop at the station, so that one bus slowing to access the station will not interfere with a through bus. Where such interference may occur (that is, express buses on the transitway will bypass the station), a curb or barrier separation, with deceleration and acceleration lanes, may be required.

The off-line station offers a number of advantages over on-line stations. The ability to pull into and out of a berth independently of other buses means that throughput of the line is not driven by a single route. This also provides more operating flexibility, by not requiring a staging area to form ordered platoons. Off-line stations can accommodate many more berths than an on-line station, by provide multiple lanes serving separate platforms. These station designs, however, require significantly more space than on-line station, and may not be practical in tunnel or on viaducts. For trolley bus operations, off-line stations are significantly more complex, and may not be practical.



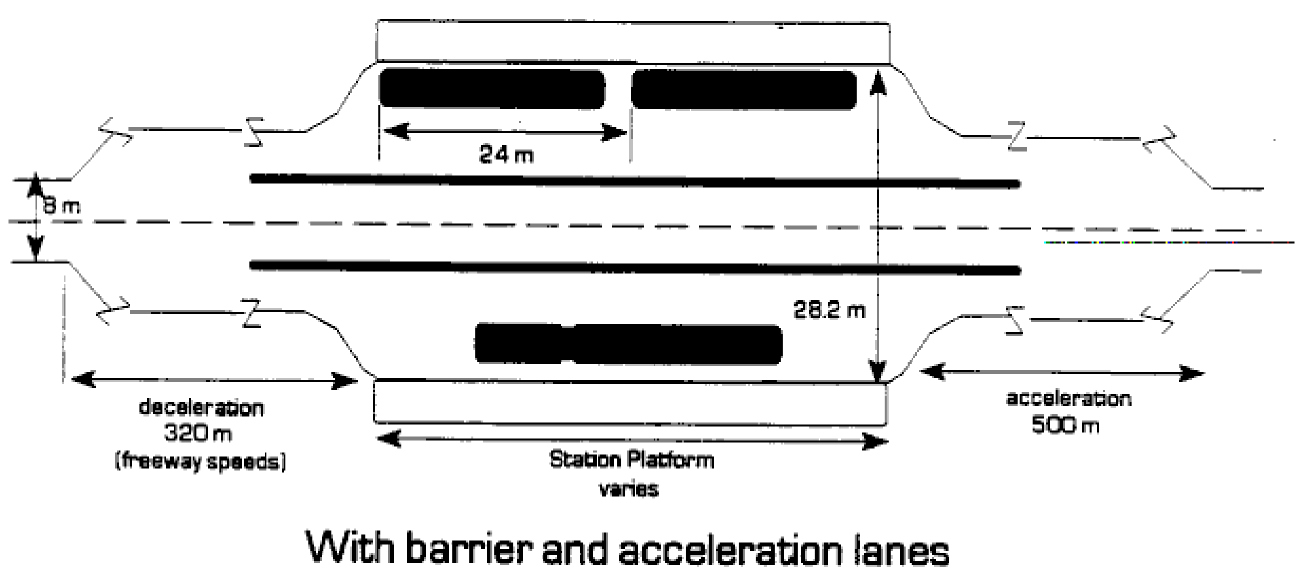


Figure 29. Off-Line Stations

5.8 CONCLUSIONS

Through the extensive research into past transit technologies, current passenger carrying capabilities, and the anticipated AHS technologies several research observations and implications for program development were noted.

5.8.1 Observations From Research

Observation # I. The transit industry has been working for decades on the task of providing high quality service at reasonable cost. Innovative light-rail strategies have been developed to attain shared use of right of way on key segments where capital costs for total grade separation would have been excessive. Still$_{1}$ the cost of building and maintaining many miles of facilities has stifled the development of higher quality transit services across the country. If major high speed segments of the AHS network could be provided which guarantee high performance operations, with the cost of those segments born by budgets beyond the transit sector, significant cost savings could result compared with presently available technology.

Observation # 2. The transit industry will not turn to the automated AHS for reasons of line capacity. The potential scale of capacity stemming from existing bus technology (as expressed both in the theoretical literature and in practice) far exceeds what most American cities will be able to utilize. The transit industry may, on the other hand, turn to AHS technology for a series of issues involving the management and control of large number of vehicles operating in extremely demanding conditions, such as the accessing of complex, multi-platform stations. AHS Transit should be seen as a family of key improvements that deal as much with reliability as with capacity; in turn, those reliability improvements may generate valuable dividends in terms of tighter, narrower geometric requirements.

Observation #3. Our examination of possible use of AHS transit in our "Prototypical Intermodal Corridor" suggests that AHS Transit may play its most important role off of the automated highway segment, and in such unique configurations as the on-line one-way loop, or in the automated dispatching through series of multi-slot off line stations.

5.8.2 Implications for Program Development

In an effort to define pathways to AHS, our team has examined a variety strategies for the development of AHS Transit, ranging from ignoring it to redesigning the entire AHS work program to allow AHS Transit to be developed to the exclusion of private vehicles. Based on this policy review, we are now focusing on the following concept for review by USDOT: allow AHS Transit to be developed on a parallel path, while, at the same time, ensuring that its technology development program be a subset of the larger AHS research effort.

The use of “train-like” platooning of many vans and buses in the entering and exiting of transit stations at 40 kilometers per hour (25 mi/h) may pose significantly different technological challenges from the issues of vehicles entering and exiting from platoons at 97 kilometers per hour (60 mi/h). Similarly$_1$ the problem of increasing throughput capacity through the Express Bus Lane of the Lincoln tunnel may largely lie in the problem of reliably sending more buses through a complex multi-platform system within the bus terminal at the end of the lane. These issues - the use of AHS technology in trip segments other than the automated highway segment-- may seem somewhat peripheral to the primary research effort of the AHS program. It is important that a research management structure be established which deals with those transit oriented issues that need to be resolved in order for AHS Transit to gain full benefit of the automated highway systems being developed. At the same time, it is critical that the technological components designed to deal with these transit-oriented issues be developed to integrate back into the larger AHS system technology. Thus, we are proposing for discussion purposes is a parallel development effort for AHS transit, which remains a subset of the larger AHS research and development program.

Twenty years ago Eugene Canty, of General Motors, wrote "Dual mode transit possibly is not the best choice all on its own but is an attractive component of an overall dual-mode transportation system." In our examination of a Prototypical Intermodal Corridor, we explored a staged process of implementing an ultimate system that could provide high quality, truly "seamless" transportation services under highly demanding conditions. The long term advantages of such a system were clear; what remains for further analysis is how much advantage is gained by AHS Transit over the interim phases of high investment in HOVI busway systems, which offer exceptional levels of benefit.

Eugene Canty may have been right; AHS Transit must be analyzed in terms of its role in an ultimate system where the both benefits and the costs are distributed over a wide cross section of transportation users. A national research program must now be designed which at once acknowledges the uniqueness of the AHS Transit potential, while remaining true to the long term need to keep it a part of larger system.

CHAPTER 6: SUMMARY OF EUROPEAN BUS TECHNOLOGY

The development of guided buses in Europe goes back to the middle of the 1970's. The decisive aim of the development of this completely new bus system has been an increase in the attractiveness of the bus transport system as well as a reduction of costs in comparison to the construction of expensive rail transport systems. In order to achieve the system's readiness to go into production and collect proven operational experience, guided bus projects have been supported by government subsidies in several European countries (e.g. Germany and Sweden).

Within this development, two entirely different guided bus technologies have evolved: mechanical and electronic guidance. SNV has been substantially involved in the scientific research and evaluation of the respective projects for both lines of development. Because electronic guidance offers the most advantages for the present AHS project, this technology is discussed in detail.

This report describes the most important electronic track guidance systems for buses which have evolved in Europe with regard to their technical characteristics and their current state of development. It also contains the findings and the experience which were gained from the various practical applications on test tracks as well as form regular public transport. Here, it has to be taken into account that there are no active systems currently operating in Europe. The track guidance system in the Channel tunnel will be the first purely commercial application.

6.1 BUS TRANSPORT SYSTEM

Buses carry the main burden of public transportation in most European countries. To increase attractiveness as well as improve the efficiency of bus transportation a series of innovative technologies in the bus sector have been promoted in Europe since the 1970's - among them especially alternative drive systems and track guidance technologies. The development of track-guided buses was intended to create a technology enabling the setting up of separate bus lanes at reduced width and the joint use of the available infrastructure for rail vehicles.

6.1.1 Historic Precedent

The bus holds a pre-eminent position among the various public transit systems. In most European countries, buses account for over 50 percent of public transportation provided. This is about the same as in most other countries. The bus offers great advantages, be it for the regional coverage of country areas, in small towns, in the peripheral areas of large cities or for serving the main streams on arterials in large urban areas.

There are some characteristics of bus operation that will assure its important position in future as well. Among these are flexibility in operation, adaptability in various demands, relatively low investments for infrastructural requirements and the cost savings that can be obtained.

However, present day operation of conventional buses is not free of problems. Transport demand/traffic density are increasing steadily and the overloading of roads particularly in cities hinders bus transportation capacity. The bus is subject to the same delays as other types of road traffic: traffic jams, traffic light signals, and other hindrances slow the bus down.

In order to eliminate the disadvantages mentioned, public transit research programs were initiated in some European countries during the seventies and eighties. Dual-mode bus Systems are among directions of research that have attracted the main interest. Keeping in mind that the goal is to improve bus transport capability, the main step was to go from the bus to a bus transport system.

A true bus transport system means that the main components of the system (vehicle, roadway, stops, and operation) are taken as integrated parts of the whole transport system. Such a bus transport system can be implemented with existing technology taking advantage of new technological innovations and can be enlarged step by step.

6.1.2 The Development of Track Guidance Systems for Buses

One of the primary elements for an improved bus transport system is a right-of-way separated from individual traffic. The attractiveness of the transit system can be greatly improved with special lanes for buses: travel comfort can be increased and travel times can be shortened. Depending on local conditions, there are several possibilities for creating separate lanes for buses. On the surface, a bus lane or bus street can be provided for, or elevated or underground structures can be constructed. To what degree such right-of-ways improve the attractiveness of the transit system depends very much on the extent to which they are misused by individual traffic. The effectiveness of separate tracks can only be achieved with constructional separation, requiring additional space often not available in dense urban areas. The space required for separate tracks can be minimized with track-guided bus systems and this is often the only method available for creating separate bus lanes. Track guidance can assure effective, reliable, and punctual bus operation. It offers decisive advantages in those segments of the network where shortage of space does not permit a separate conventional bus lane such as at single narrow points, at intersections and at crossings with very heavy traffic. Bus stops and especially station platforms can be negotiated very precisely without damaging the tires.

Mainly two technologies have been developed: Mechanically guided buses that need fixed infrastructure such as guide-curbs alongside the track, and electronically guided buses that follow a cable embedded in the roadway.

On electronically guided buses, steering is effected by means of a hydraulic actuator linked to an electronic control system. The nominal course of the bus is normally marked by cables embedded in the surface of the bus lane. The antenna mounted beneath the bus measures the deviation of the vehicle from its true course, the electronic control system calculates the necessary correction and transmits the data to the actuator which operates the steering.

When planning guided bus routes, one has to consider that the routes must be very carefully integrated into the existing traffic infrastructure and that they have to be connected with the other modes of transportation. Keeping this in mind, one can distinguish between the integration of the guided bus route into the whole transportation system - paying particular attention to the interaction of guided bus and individual traffic -- and the connection of a guided bus system with other modes of public transport (i.e. underground, light rail transit, tram).

A large number of guidance systems were examined and evaluated in the initial stages of the development of this technological innovation in Germany. The following concepts of electronically controlled guidance systems appears to be the most realistic and worthy of further development:

- The M.A.N. System.
- The Breda System.
- The Mercedes-Benz System.
- The Channel Tunnel System of Mercedes-Benz.
- The Volvo low cost system for bus stops.

In Germany, the development of guidance systems for buses was started along with other technological innovations for buses in the early seventies. After some theoretical work demonstrating the feasibility and applicability of this bus system component, M.A.N. and Mercedes-Benz began to develop guidance systems with aid from the German Federal Ministry of Research and Technology. The systems developed within the promotion programs also form the basis for the Breda system which is a licensed further development of the M.A.N. system and for the Channel tunnel system which has evolved on the basis of experience gained with the original Mercedes-Benz system.

In Sweden, Volvo developed an electronic guidance system that permits buses to drive up to bus stops with elevated platforms and to stop there with great precision. The system went into operation in the town of Halmstad[1] Sweden in 1979 with eight buses as part of an improved transit system. The electronic guidance system has been taken out of the buses later because the drivers felt that such a guidance system was not necessary only for bus stop areas.

The testing of the German guidance systems took place on testing circuits in Munich (M.A.N.), Germany and Rastatt (Mercedes-Benz), Germany. The first passenger operation took place in Munich in 1978 with an electronic guidance system during the '78 Transport Fair. The first public transit demonstration was conducted in the city of Furth, Germany with electronically guided buses between May 1984 and December 1985.

The track guidance system for the Channel tunnel provides electronic track guidance of service vehicles enabling them to reach any location in the tunnel quickly and reliably. At present, the system is in the phase of final inspection. With full operation of the

Channel tunnel there will be a regular application for electronic track guidance in Europe.

6.2 ELECTRONIC TRACK GUIDANCE

The electronic track guidance technologies developed for bus transportation in Europe are all based on the concept of guide cable sin the transport way and receivers as well as control units to convert the transmitted impulses into steering movements in the vehicles. For security reasons all systems necessary for track guidance have to be designed to be mutually redundant. How this has to be implemented is not clearly defined, however, the design has to comply with state-of-the-art technology.

6.2.1 Fundamental design of electronic Truck guidance Systems

Electronic track guidance systems are a subset of vehicle guidance systems operating with frictionally transmitted forces. Lateral guidance forces are subject to the coefficient of friction between the roadway surface and the vehicle tires, as is the case for conventional power-steered buses. Weather conditions, dirty road surfaces etc. therefore influence the driving characteristics of the track-guided buses or trucks to a similar degree as they do in case of conventional buses or trucks.

The following basic concept underlies electronic track guidance: with the aid of an electro-hydraulic steering unit, the vehicle (bus or truck) follows an electronic track which is formed by a cable carrying audio-frequency AC current in the roadway.

The electronic track, the so-called "true course track", is defined by the guide cable embedded in the surface of the roadway. If an AC current flows through this guide cable, a concentric electromagnetic field is set up. Voltages are induced in coils with open cores in this field. If a vehicle is located over the guide line, tensions are induced in the receiving unit (an antenna fixed underneath the vehicle) forming part of the steering system in the vehicle. The magnitude of these tensions depends upon the position of the antenna relative to the guide line; the corresponding values are transmitted to the steering system.

The steering system of the vehicle comprises an electronic and a hydraulic component. In the electronic component the signals received from the roadway are processed to obtain steering adjustment values and transmitted to the hydraulic component which then makes the corresponding corrective steering adjustments.

The technology involved in electronic track guidance systems is of much greater complexity than is the case for mechanically controlled ones. However, these systems can fulfill reliability requirements to the same degree as can mechanically controlled systems. The advantage of electronic guidance in that you don't need physical guiding curbs (steel or concrete) alongside the track.

Currently, there are no specific regulations and guidelines referring to the employment of electronic equipment for track guidance.

From a safety engineering standpoint, the operation of electronically track-guided buses or trucks is comparable with that of non-monitored systems: due to local marginal conditions (short distance from obstacles etc.) it is impossible for the driver to take action to avoid collisions, etc. The driver, therefore does not constitute a safety reservoir. An immediate danger would thus accrue for the passengers of the vehicle as well as for persons in the immediate vicinity of the roadway in the event of a failure of the track guidance system. This is to be prevented by taking additional measures, such as redundancy of special components.

The safety concept underlying the electronic track guidance system is that of fail-safe technology, i.e. failures within the technical system may only produce conditions which consequently convey the entire system into a safe state. Simple subsystems are designed in such a manner that they are functionally safe: breakdowns will not occur. Included among these non-redundant systems is the conventional bus-steering system comprising wheels, stub axle, tie bar, elbow levers, and steering connecting rod.

The redundancy of highly complex systems ensures their functional safety, i.e. more than the necessary technical means to fulfill a given function are available, ready to operate at any time.

The idea behind the redundant components is that even if random isolated errors occur, the whole system will nevertheless remain functional (double errors are regarded as non-existent). To this end, the subsystems may be divided into two partial systems of which each is fall-safe in the event of a fault. Redundancy has been designed into both the electronic and hydraulic supplementary systems of the track guidance system.

This design ensures that:

- Error conditions are quickly recognized.
- Faulty systems are shut off.
- Error messages are conveyed to the driver.
- Sure control of the vehicle is ensured until a safe state (i.e. standstill of the vehicle) is attained.

6.2.2 Design Principles

Electronic track guidance is laid out on the safety principle of functionally non participating redundancy in the vehicle, i.e. the supplementary technical installations do not begin to operate until there is a fault in, or failure of[1] the corresponding function.

6.2.2.1 Principle of the Vehicle Components

Vehicles fitted for electronic track guidance have available two steering Systems which are independent of each other: a conventional steering system as well as an electronic steering system. The inertia of the conventional power steering system does not influence functional efficiency of the electronic track guidance system. The conventional power steering system$_1$ manually operated by the driver, is the system being used on standard buses nowadays.

The guiding fixture in the roadway interacting with the control elements in the vehicle are meant to ensure that the vehicle will remain on track. The following exemplified numerical values relate to the M.A.N., Mercedes-Benz, and Breda systems. For the Channel tunnel system such values are not yet available.

The alternating current flowing through the guide cable has fixed frequencies of 9 and 10 kilohertz (kHz) and an amperage of 0.2 Amp (A); a cylinder-symmetrical magnetic field is set up around the cable. A cross sectional view of the system (see figure 30) will illustrate -- starkly simplified -- the physical interrelationships. There are a total of four available frequencies (7, 8, 9, and 10 kHz). Two frequencies are required for the normal guideway and two frequencies for switches.

The distance "a" represents the horizontal distance of the vehicle's receiving antenna away from the guide line; the distance "h" represents the vertical distance of the vehicle's receiving antenna over the roadway. The bus is exactly on track when the distance "a" is equal to zero.

The operational range of the electronic track guidance system is dependent on the controllable range of the electronic equipment$_1$ on the amperage in the guide cable as well as on the shielding of the field by the vehicle body. An operational range of j 350 mm (13.8 in) in which regulated antenna voltages are linear is available with present system designs, i.e. within this range the vehicle receives unequivocal information in respect to its lateral deviations.

In the vehicle, the two voltages U_d and U_s are received with frequencies discriminated (9 and 10 kHz). A measure of the horizontal deviation "Antenna from guide line" (distance "a" in figure 30) is derived from the quotient of the two values from which a steering angle correction signal, dependent on speed, is then worked out in the processor: this correction signal is transformed into a control signal for the steering elements. The processor does not take into account the actual vehicle passenger load.

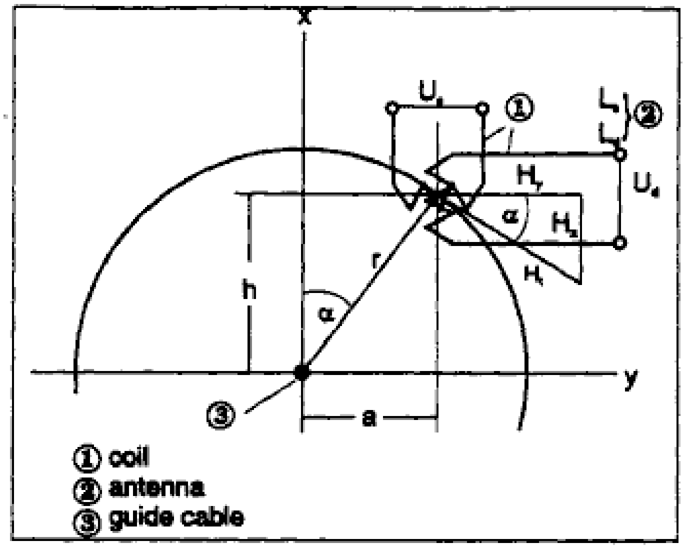


Figure 30. Cross Section of the Magnetic Field

6.2.2.2 Principle of the M.A.N. Bus Electronic Guidance System

The steering system of the electronic track guidance system has two active subsystems with auxiliary power sources which operate alternately in a 60 second rhythm. The two systems are safeguarded with an additional electronic component: a triple-channel microprocessor recognizes errors and induces the switching to the remaining intact unit.

Each of the two functional groups of the active system of electronic steering unit can steer the vehicle independently. Each unit operates alternately for 60 seconds as either the control or standby unit, the rhythm being regulated by the electronic switching unit. The control unit fulfills the task of steering. The standby unit performs the some functions, but it does not participate in the steering process: the steering correction signals are worked out but not transferred to the steering hydraulic components. Every 8 mili-seconds (ms) [approximately every 130 mm at 60 km/h, (5.1 in at 37 mi/h)], the measured values (lateral deviation/actual steering angle/speed) are registered by the sensors and then processed to obtain the corresponding steering correction signals. The steering angle correction value is compared with the actual value of the steering angle: if there is a difference between the two angles, a corresponding correction is then made in the steering hydraulic unit.

The two steering systems are different in respect to their track-guiding hydraulic Systems:

- Steering System 1: Power source is an eccentric rotary vane pump driven by the vehicle engine, hence delivering performance even when idling or at a standstill of the vehicle.
- Steering System 2: Power source is a radial piston pump[1] driven by the vehicle

drive shaft via a cardan shaft. The pump delivery necessary for steering is not attained until a certain minimum speed [about 4 km/h (2.5 mi/h)].

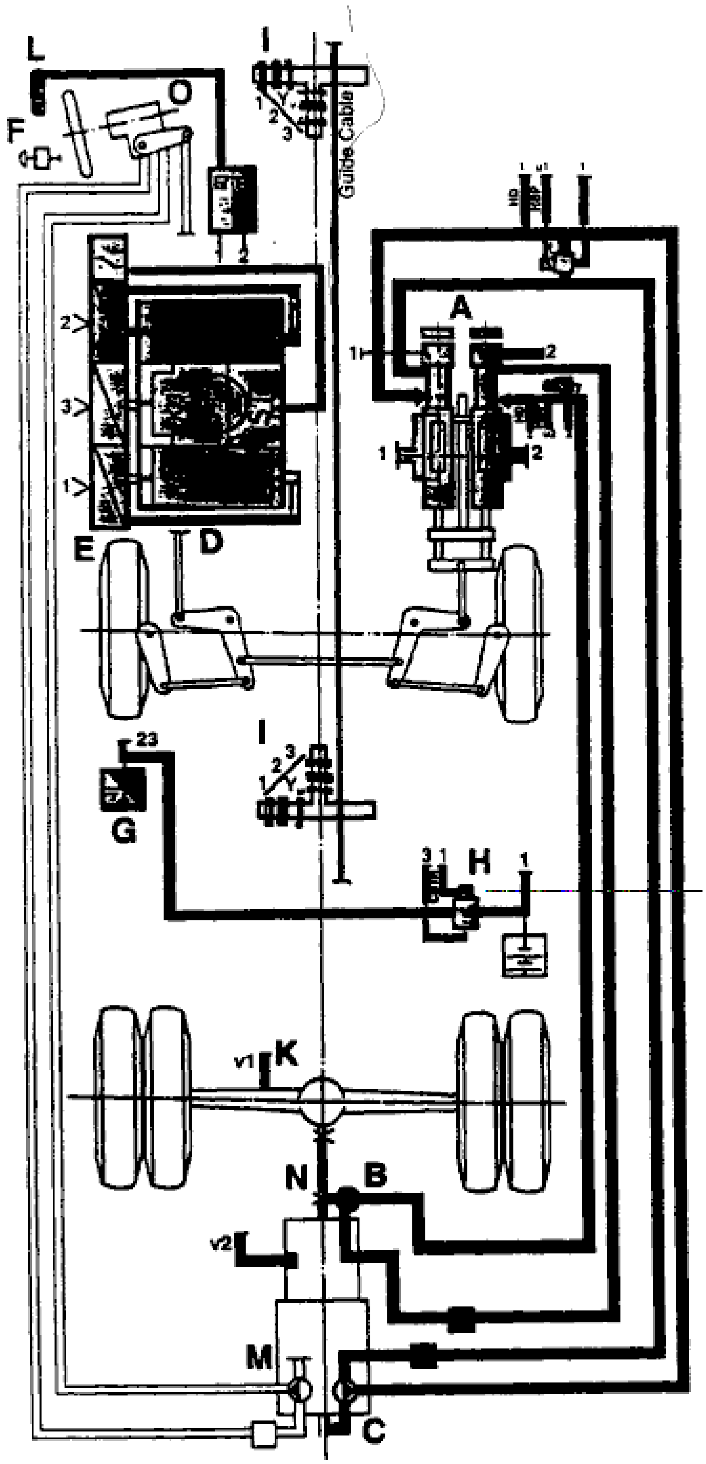
Each of the steering circuits has its own double-acting operating cylinder. The piston rods of the two cylinders are mechanically connected. This mechanical connection is considered to be fail-sale. The maximum pressure in the operating cylinder is 100 bar: a pressure safety valve prevents pressures from exceeding this amount.

A constant pressure is delivered via the respective pump of the two steering circuits. The power steering system functions totally independent of the automatic track guidance system if the electronics of the latter system are shut off. A separate eccentric rotary vane pump supplies the power steering with the necessary power. Figure 31 gives a diagrammatic presentation of the entire steering system of M.A.N.

6.2.2.3 Principle of the Breda Bus Electronic Guidance System

The Breda track guidance system is not an independent new development, but a further development of the M.A.N. system. For this Breda acquired the license from M.A.N. and still available vehicle equipment. The technical description of the system is therefore superfluous, because it is identical with the equipment described under section 6.2.22).

At present one Breda bus is equipped with electronic track guidance and undergoes comprehensive tests on a small testing circuit of Breda close to Bologna, Italy. The testing circuit has been equipped with corresponding track components, guide cables and transmitter. After conclusion of the test, the decision on further development will be hold. Development work still has to be accomplished on a larger scale before the system can be used operationally.



A Automatic Power Steering

B Hydraulic Supply 2

C Hydraulic Supply 1

D Electronic Control Unit

E Switch Box

F On/Off Switch

G Add. Battery

H Circuit Breaker

K Speed Sensor

L Alarm, Display

M Engine

N Gear Box

O Conventional Power Steering

ST Supervision in Channel 3

Figure 31. diagrammatic Presentation of the Entire Steering System

6.2.2.4 Principle of the Mercedes-Benz Electronic Guidance System

The Mercedes-Benz system functions on the principle of active redundancy:
two subsystems independent of each other simultaneously function to operate the

steering system of the vehicle.

Each subsystem in the vehicle comprises:

- The receiving equipment for signals coming from the roadway systems.
- The control equipment to generate control signals for corrections of deviations.
- The steering equipment to execute steering adjustments.
- The supervision system to prevent dangerous situations.
- The operating and error-state signaling systems.

Figure 32 shows the interaction of the individual components of the Mercedes-Benz electronic track guidance design.

The control equipment can function only if data about the position or movement of the vehicle in respect of the guide cable and the momentary steering angle have been transmitted. The position of the vehicle relative to the guide cable is determined at any one time by *one* sensor (antenna) in the vehicle. By applying modern control engineering theories, one need not make measurements, with sensors, of the deviation of the rear section of the vehicle or of the steering angle.

The antennae are centered at the front of the bus immediately behind the bumper. They are situated so that the gradient of the vehicle is not affected. In this manner one obtains a quantified digital system in 20 mm (0.8 in) steps for the deviation from the track.

In track guidance operations[1] the control equipment assumes the function of the driver. It must take into account the specific characteristics of the vehicle to be controlled, of the hydraulic steering system, of the sensors (antenna and steering angle indicator) as well as of the nominal true course of the electronic track.

A microprocessor is employed for the control loop of the electronic track guidance system. A model of the controlled system, i.e. of the bus, which is presumed to be controlled, operates in this unit at the same time as the controlled vehicle. The deviation of the front part of the vehicle from the guide track is the input measured value. Adjustment values required can be calculated from the model: the rear vehicle deviation, deviation speed and steering angle.

The hydraulic steering equipment is also subdivided into two identical subsystems. Both hydraulic circuits are fed by electronically driven pressure oil pumps The control cylinders necessary for steering correction are mounted directly on the front axle between the track rod and the axle. The diagram in figure 33 shows the plan of a hydraulic circuit.

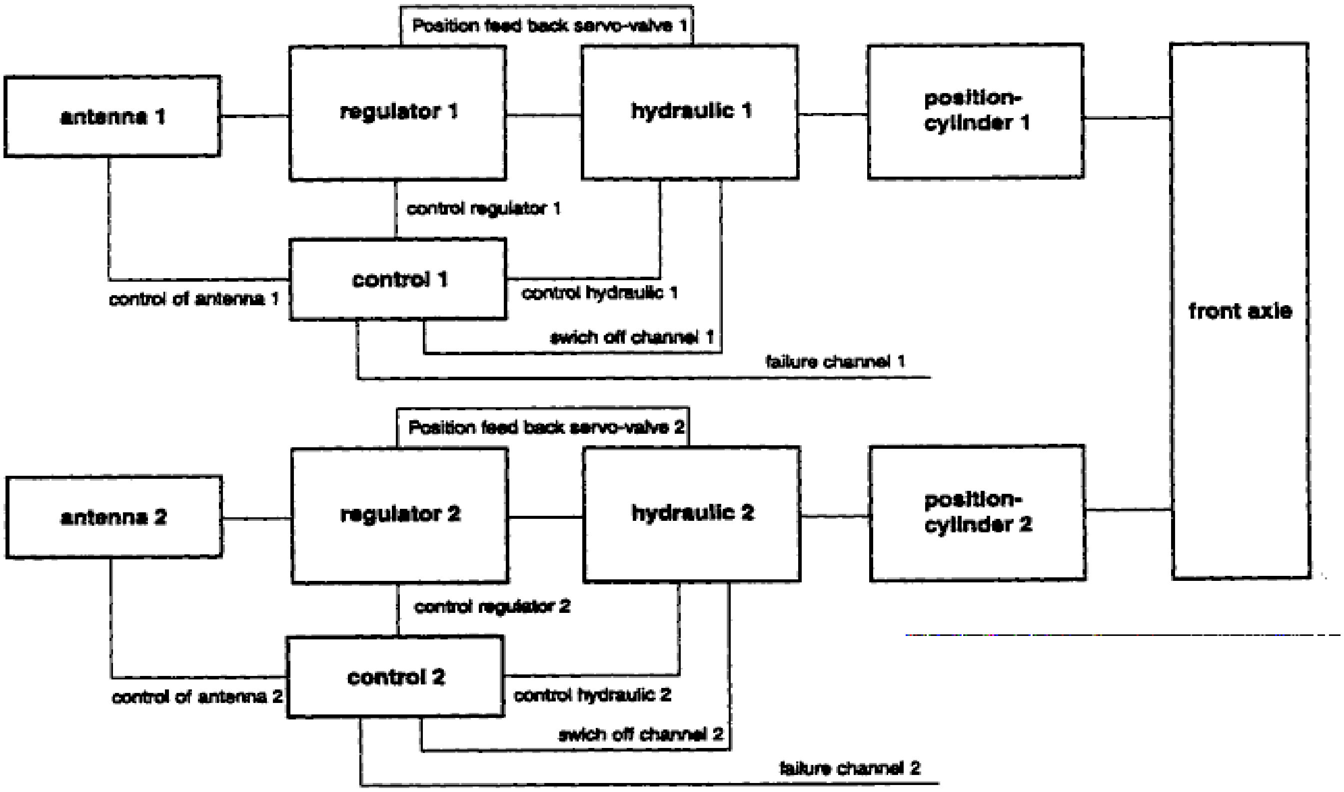


Figure 32. Interaction of the Components of the Mercedes-Benz Truck Guidance Design

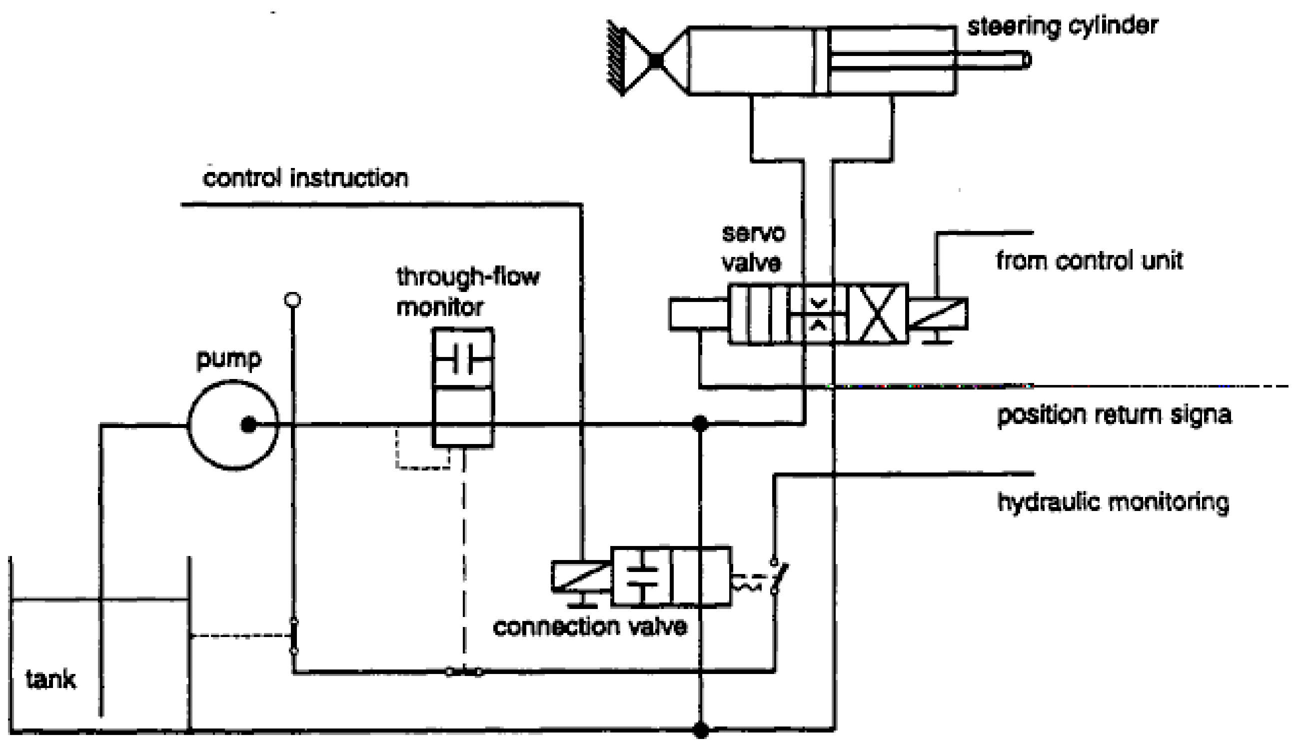


Figure 33. Diagram of the Hydraulic Circuit of the Mercedes-Benz System

Each of the subsystems has a monitoring system relegated to it. The monitoring Systems can recognize errors as they occur, switch off faulty subsystems, and relay optical and acoustic alarm signals to the driver. The monitoring system consists of two component systems: first, a processor which checks whether the incoming signal contains correct values and then processes these values correspondingly (e.g. correct control of the oil flow in the steering cylinders); secondly, a unit to monitor or, as the case may be, to report reliably faults in the sensors, the hydraulic circuits and in the processor. The monitoring of the processor is effected by means of a control signal sent in a scanning pulse of 10 ms. If the signal falls to appear, an alarm signal is relayed.

6.2.2.5 Mercedes-Benz Truck Electronic Guidance System for the Channel Tunnel (Eurotunnel)

The application (shown in figure 34) of track-guided service truck vehicles in the Channel tunnel shows some specific requirements having effects on the design of the truck guidance system.

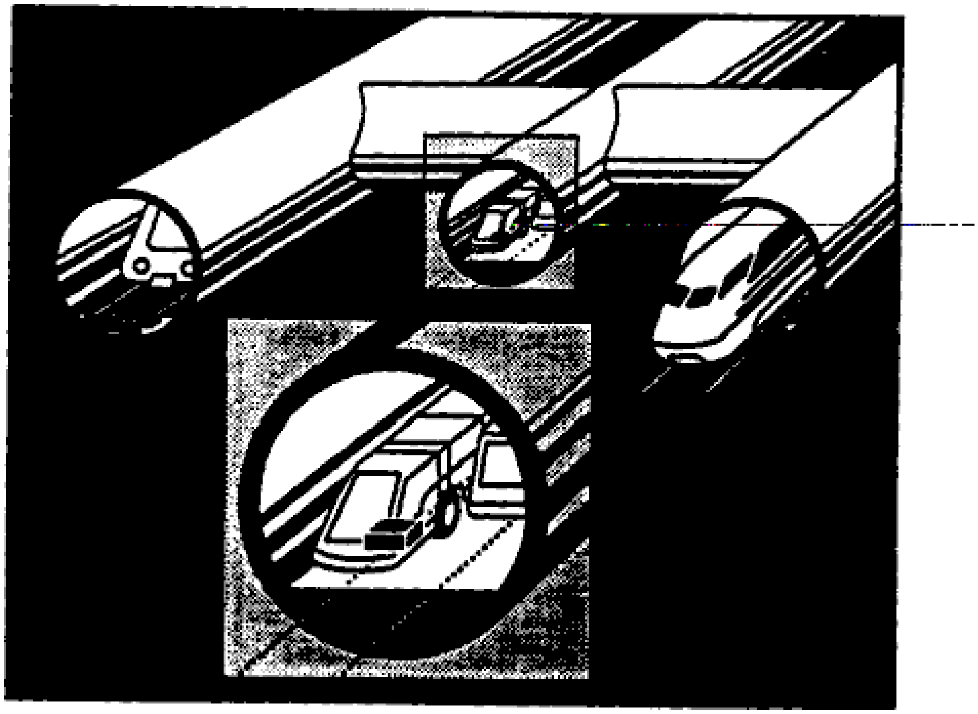


Figure 34. Layout of the Channel Tunnel Principle)

Some of the primary requirements for the Channel tunnel design are:

- Turning of the vehicles in the tunnel is not possible so that the vehicles are designed as two-directional vehicles.
- The necessary width of the service tube has direct impact on its constructional costs. Therefore a higher investment for smaller tolerances of track guidance can be made, provided the cross section of the tunnel tube can be reduced.
- On the one hand, the service tube will be free of obstacles (e.g. other means of transport), on the other hand, in emergency cases there is the risk of smoke obstructing view. Consequently, a driver-independent location of vehicles is indispensable.

The electronic track guidance system itself is a further development of the Mercedes-Benz system which was developed for public transport as discussed previously. In accordance with the philosophy of designing all control and drive systems of two-directional vehicles in duplicate, also the track guidance system is available twice. The respective system which is located facing the engine is applied with a change to manual steering possible at any time.

6.2.3 **Track Components for the Electronic Guidance Systems**

Electronic guidance for automated transit systems are defined in several general component areas. The guiding fixtures for the cable system detail the current operational standards. At switches/crossings both the active and passive technologies can be negotiated. The control instruments bring together all the technical control functions integrating the drivers abilities for "control" and supervision.

6.2.3.1 Guiding Fixtures

Guide cable and accompanying guide cable sender constitute the track guidance components of the roadway. The guide cable as depicted in figure 6-6, which is cast integral with the surface of the roadway in a groove about 30 to 50 mm (1.2 to 2 in) deep, marks out the ideal track for the vehicle. The three-core guide cable is flexible and waterproof. M audio-frequency signal is injected into each of the cores. In the case of the design at hand, two frequencies are sufficient; the third core is kept in reserve. An electric cable of standard production is used to serve as guide cable: a specially manufactured cable is not required.

The guide cable is fed via a guide cable sender which is currently designed to cover a sector of 2 kilometers (1.2 mi). A sector of 10 kilometers (6.2 mi) is possible although the length of the sector depends largely on the network configuration. The sender is of a redundancy type, i.e. two equal and independent sender units monitor each other: the intact sender automatically takes over if a fault or defect arises in the other sender. Figure 34 shows the fundamental design of the feed system for the guide cable track. Each of the senders disposes over two separate channels which feed their respective sending frequencies into the guide cable: frequencies of 9 kHz and 10 kHz are being used with the present system designs. Both senders are completely autonomous and could also be spatially separated. The two senders are both acting on the guide cable. Precautionary provision has also been made for the event that the general power supply from the city works is disrupted: one sender unit disposes over a battery buffer so that safe track guidance will be ensured with the battery as a power source even if there is a power disruption in the network The power requirement of the guide cable amounts to 5 to 10 watt per km of track (8 to 16 watt per mile).

Each sender regulates the guide cable current automatically. The system as a whole reacts very insensitively to complete cut-off points in the line because of the high dynamic range. In the case of lasting cut-off, the vehicle is technically able to stay on track until 10 m (33 ft) before the out-off point. As per agreement, however, an error message which sets off an alarm in the vehicle is sent when the vehicle is about 200 m (660 ft) ahead of a cut-off point.

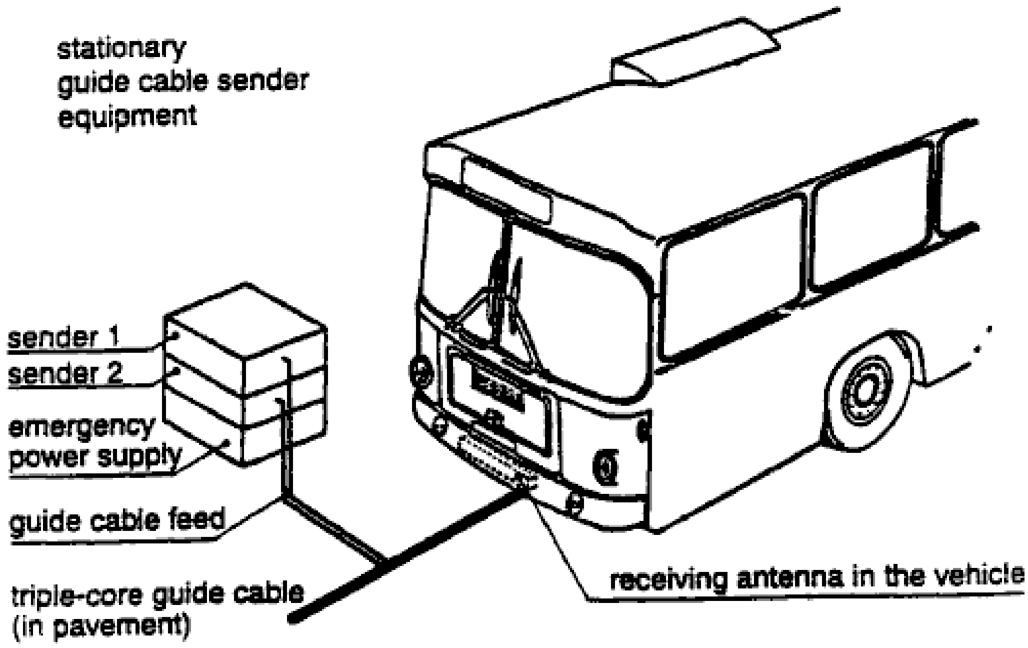


Figure 35. Guide Cable Supply for Guided Bus

8.2.3.2 Switches, Crossings

Both active and passive switch points can be negotiated. The regulative function of the active switch is exercised by a switching station incorporated in the roadway, in which the current is switched from one guide track to another. For passive switches the traffic lane is fitted with guide cables having different frequencies (two frequencies per travel direction). The receiving frequency in the vehicle is switched over from one frequency to the other, depending on the direction of travel, by either the driver or via data transmission from the operational master station.

6.2.3.3 Control Instruments

The facilities for the operation of the electronic track guidance system must be located in vicinity of the driver and have thus been accordingly integrated into the instrument panel. The following instruments have been incorporated in the familiar instrument panel arrangement:

- Selector switch "electronic track guidance" On/Off.
- Two track entry lamps (position of the guide cable: right/left).
- Signal lamp "On Track".
- Acoustic alarms for speed, operational state and for faults in the system.
- Frequency signal for location of the vehicle relative to the guide cable (Channel tunnel guidance system).

According to one rule, the correct designing of the instrument panel requires that one bear in mind that the instrument panel is a structural component located in the driver's field of vision in which the instruments necessary for the control and supervision of the operation of the vehicle are brought together and systematically arranged. The activities to be performed by the bus driver ensuing from the lateral guidance electronic equipment are to be subsumed in the categories "Control" and "Supervision".

A control activity is meant if the employee's task at an operating position (workplace) consists of directly or indirectly coordinating the course of operation with a previously established program.

A supervisory activity is always deemed to exist if the employee's task at an operating position (workplace) consists of constantly checking (monitoring) the functioning of a piece of equipment and taking corrective action where and when necessary.

The control activity consists of switching the track guidance system on and off, and the supervisory activity consists of determining the operational state of the equipment. The least possible utilization of the capital goods (the bus) presupposes that the relayed information (data) can be definitively brought to the driver's attention and that all manipulative elements are located within grasp of the driver. To ensure that the control switches are in easy reach of the driver (i.e. being able to reach the control switches without having to stretch chest and arm unduly), the selector switch was installed left of the instrument panel within easy reach of the driver's left arm. The lamps were mounted at the instrument panel in the driver's field of vision, and green was the color used (signals "information").

However, care must be taken to prevent the lever and switch from being accidentally activated, which is why the movement of control fixtures should be possible only in the direction from where the chance occurrence of forces is improbable.

The proposals for the control instruments are only of a preliminary nature as yet, and a thorough investigation would have to find evidence in favor of the statements made. It has been proposed that instrument be designed as a push button. The implementation of track guidance systems in the regular passenger transport services of a transit authority could lead to modifications here, as in other points also. Whether the inclusion of the control element "emergency shut off" (contained in the test vehicles but not in the series vehicles with track guidance systems), is justified ought to be decided in the course of passenger transport operations.

6.2.4 Principle. on which the electronic Track Guidance System of the Volvo Concept Is Based

Volvo has developed a concept for employment in bus transit systems which, using an electro-magnetic transmission system, makes possible the automatic longitudinal as well as the automatic lateral guidance of the vehicle. The goal in developing this system was not a completely independent system of vehicle control as in the case of the M.A.N. and Mercedes-Benz designs, rather, the main aim was to aid the driver in carrying out steering and braking maneuvers on roadway sections where driving conditions are difficult - especially in the vicinity of bus stops. The main emphasis was therefore on facilitating the drivers work. The supporting guidance systems are designed in such a manner that -- should this be required -- the driver can steer and brake the bus in all situations without having to take special measures (e.g. manual switching off of the automatic guidance system).

In contrast with the designs of M.A.N. and Mercedes-Benz, systems of this kind are not suitable for automatic operations where the responsibility for the track guidance must be transferred to a technical system. This is, however, the prerequisite for operations in the total network system or in large parts of a line network. That means, an option for manual or automatic operation cannot be provided in such cases.

The aggregate system of the Volvo electronic track guidance system comprises both roadway sender apparatuses as well as receiver and control components in the vehicle. Because until now, this design has been exclusively employed in bus stop sections, the following information refers exclusively to this application

6.2.4.1 Roadway Components

The roadway guide track installation consists essentially of the guide cable and the guide cable senders. In contrast with the M.A.N. and Mercedes-Benz systems, where the guide cable is installed in the middle of the lane, the Volvo system guide cable encloses the activating area of the trackguided vehicle. A multiple-core, standard electric cable is used as guide cable; each core has a diameter of 2.5 mm (0.1 in). The figure 36 shows the location of the guide cable in the area of the bus stop.

In the usual case, the cable is laid at a depth of 30 mm (1.2 in) in the surface of the roadway. The length of the guide cable section amounts to a total of 90 m (295 ft). The entry width of 2 m (6.6 ft) narrows down over a stretch of 30 m (98 ft) to the final space of 1 m (3.3 ft) between the cables, which is then maintained for a further 60 m (196 ft). A guide cable sender installed at the bus stop platform and having a battery buffer provides the power supply for the guide cable. The battery buffering is necessary in order to maintain safe track guidance even in the case of interruption of the power supply from the public power mains.

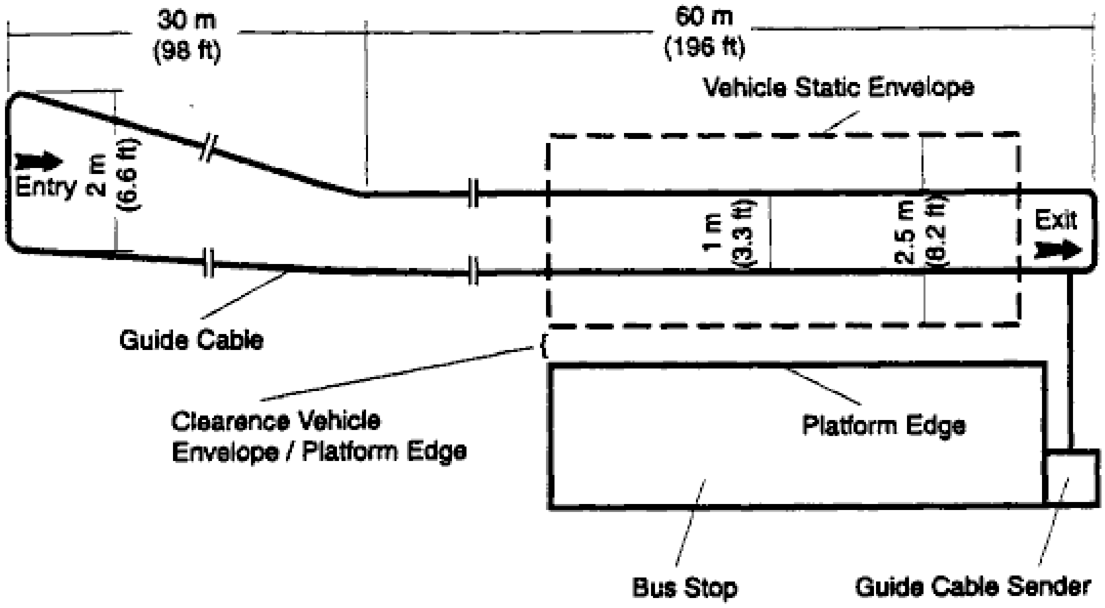


Figure 36. Layout of Track guidance Section In the Volvo System

The battery is connected in circuit with a battery charger which is coupled with the bus stop lighting, providing sufficient energy density for the battery. The battery is capable of supplying energy to the guide cable sender for a period of 4 days without being recharged. An oscillator, in which the required frequency for the guide cable is generated, is built into the circuit after the battery. ft is possible to supply several sectors within the activating area with the sender - e.g. in the direction of the bus stop and in the opposite direction. In this case a different frequency is generated for each direction -- in practice frequencies of 8 kHz and 15 kHz were used.

6.2.42 Vehicle Components

The entire equipment was installed in a Volvo bus. This signifies that the vehicle *does not* have auxiliary hydraulic steering.

The guidance equipment in the vehicle consists of a receiving unit, an amplifier, an electronic control component and a steering actuator.

The receiving unit (an antenna constructed on the principle of crossed coils) is located underneath the vehicle: it receives the signals from the roadway and relays them to the electronic control component. The control unit processes the signals to a desired steering angle signal, comparing this value with the actual steering angles, which are measured by a wheel-angle indicator (potentiometer) mounted on the axle, and then relays the required steering instruction to the electric motor powered steering unit.

6.2.4.3 Electronically Guided Entry into the Area of the Bus Stop

The vehicle is manually steered when it crosses the entry markings of the area of the bus stop. On crossing the guide cable, which is located approximately 90 m (295 ft) in front of the platform end, the proper functioning of the system is checked: a green light signals proper functioning of the system to the driver; a red light indicates a malfunction in the system.

Because driving with the electronic guidance system takes place only in the area of the bus stop, the vehicle guidance was designed only as an aid to relieve the driver. This operational application thus also did not require a safety system designed on the redundancy principle. Full responsibility for driving - including in the electronically controlled area of the bus stop - continues to remain with the driver. This means that when driving in the electronic control loop, the driver must always be prepared to take over the steering function (hands on the steering wheel, etc.). In the event of a failure of the system, indicated by the lighting up of the red warning lamp, the driver must immediately take over the steering of the vehicle.

If the green light turns on when crossing the guide cable$_1$ the automatic system controls the approaching to the bus stop. The track channel, which is 2 m (6.6 ft) wide at the beginning, narrows down to a width of I m (3.3 ft) (guide track width) after a distance of 30 m (98 ft). Where no adverse external influences affect operations, the automatic steering system will position the vehicle laterally with an accuracy of + 10 mm (0.4 in) operating on the principle of minimum value registration (minimum voltages).

In the actual case of implementation at Halmstad, a distance of 0.4 m (16 in) was provided for because of safety engineering considerations: it is therefore ensured within the system that the driver can maintain the same distance when manually steering into a bus stop.

A guide cable can be laid in the approach area of very narrow bus stop exits. The exact guidance of the vehicle may become necessary in order to prevent the stern of the vehicle from coming into contact with the edge of the platform when veering out (entry into the street area).

In addition to the electronic lateral guidance, the Volvo design also has electronic longitudinal control relegated to it. The lateral guidance and the longitudinal guidance systems employ the same components in some aspects, as, for example, the speedometer equipment. The longitudinal guidance is activated on crossing the guide cable, as is the case with the lateral guidance: however, the vehicle must approach the~section directly over the entry channel - driving in from the side will not trigger the automatic track guidance system. The proper functioning of the longitudinal guidance system is indicated by one optical signal only: if the green indicator lamp lights up, the system is ready to function - if the light goes out, the driver must continue steering the vehicle manually.

With the guide cable layout presented here, the vehicle can enter the area of the bus stop at a speed of about 55 km/h (34 mi/h); with the given technology, speeds of up to 70 *km/h (43* mi/h) are possible. Before the entry to the bus stop, the driver preselects a desired deceleration; there is a choice between two rates, 1.2 m/s^2 and 1.6 m/s^2 (3.9 $ft/^2$

and 5.2 ft/s^2). The vehicle determines its speed and with the deceleration curves via the electronic control system, it reduces its speed down to zero. The stopping accuracy of the vehicle is I 100 mm (3.9 in) with the longitudinal guidance system.

The aggregate system assumes the nature of a quasi-ABS system with the combination of lateral guidance and longitudinal guidance, i.e. steering actions on the part of the vehicle due to varying braking forces are compensated for by the lateral guidance. However, the reaction speed of a combination as described here is slower than in the case of a conventional Anti-blocking system (ABS).

As is the case for lateral guidance, the driver can disengage the automatic longitudinal guidance at any time he chooses: as soon as he activates the brake pedal, the automatic longitudinal guidance is inactivated. The driver can superimpose manual steering on the electronic system for lateral guidance (i.e. the electric motor force can be overcome by the driver), or he can simply switch off the system.

6.3 TRACK

For electronic track guidance a guide cable prescribing the true course track of the vehicles has to be embedded into the road surface. From this true course track the necessary width for the lane can be derived. The maximum possible deviation due to the prevailing peripheral conditions is added to the width requirements when driving in the true course track.

6.3.1 Line Design of the Truck

Electronic track guidance is technically possible on existing streets as well as on specially designed tracks. For operation in conventional urban street systems in the German Federal Republic, bus width requirements are generally taken at 3.5 m (11.5 ft). Due to the precise steering characteristics of vehicles using electronic track guidance, these width requirements can be reduced.

In order to determine the vehicle dynamic characteristics, a considerable number of tests have been carried out, taking into account both disturbed and undisturbed operation; actual required vehicle clearance is determined as a composite result of the following individual factors:

- Inaccuracies in vehicle construction (skew, superstructure etc.).
- Side sway of entire vehicle caused by cross winds or laterally slopIng tracks.
- Deviations caused by the vehicle dynamics (curves, loading etc.).
- routine switching.
- Deviations resulting from malfunctions in the vehicle or on the track (brakes pulling unevenly$_1$ malfunctions in the magnetic field, etc.).
- Shifting caused by a defect in the auxiliary power steering unit.

The following points must be noted when assessing the individual factors:

- The first two factors mainly affect the rear of the vehicle due to the effect of the regulating control unit.
- The other malfunctions have a greater effect on the front of the vehicle than on the rear (traction curve).
- Disturbances of every kind$_1$ including gusting, only have a momentary effect.

In the following$_1$ individual tests carried out to investigate the main influencing factors are briefly summarized and measured deviations are given. All conceivable malfunctions were investigated, split according to malfunctions within the electronic guide track and outside the guide track. All tests were carried out on the test tracks of the manufacturer (see figure 37). Note: The effects of disturbances described below do not refer to the track guidance system in the Channel tunnel. For this system no statements on effects of disturbances and failures of components are available.

Lateral deviation caused by malfunction within the guide track.

- Ferro-magnetic elements near the guide cable disturb the electromagnetic field around the guide cable. The positioning of the receiving antenna leads to slight deviations from the set track. When driving over a metal plate 500 x 300 x 10 mm (20 x 12 x 0.4 in), which lay directly along the guide cable, a maximum deviation of 25 mm (1 in) was recorded.

- Breakdowns in power supply in the guide cable of up to 50 percent of the cable current have no effect on the function. Fluctuations of more than 50 percent of the power rating lead to an alarm signal being set off in the vehicle. No dependence could be determined on the frequency of the guide cable.

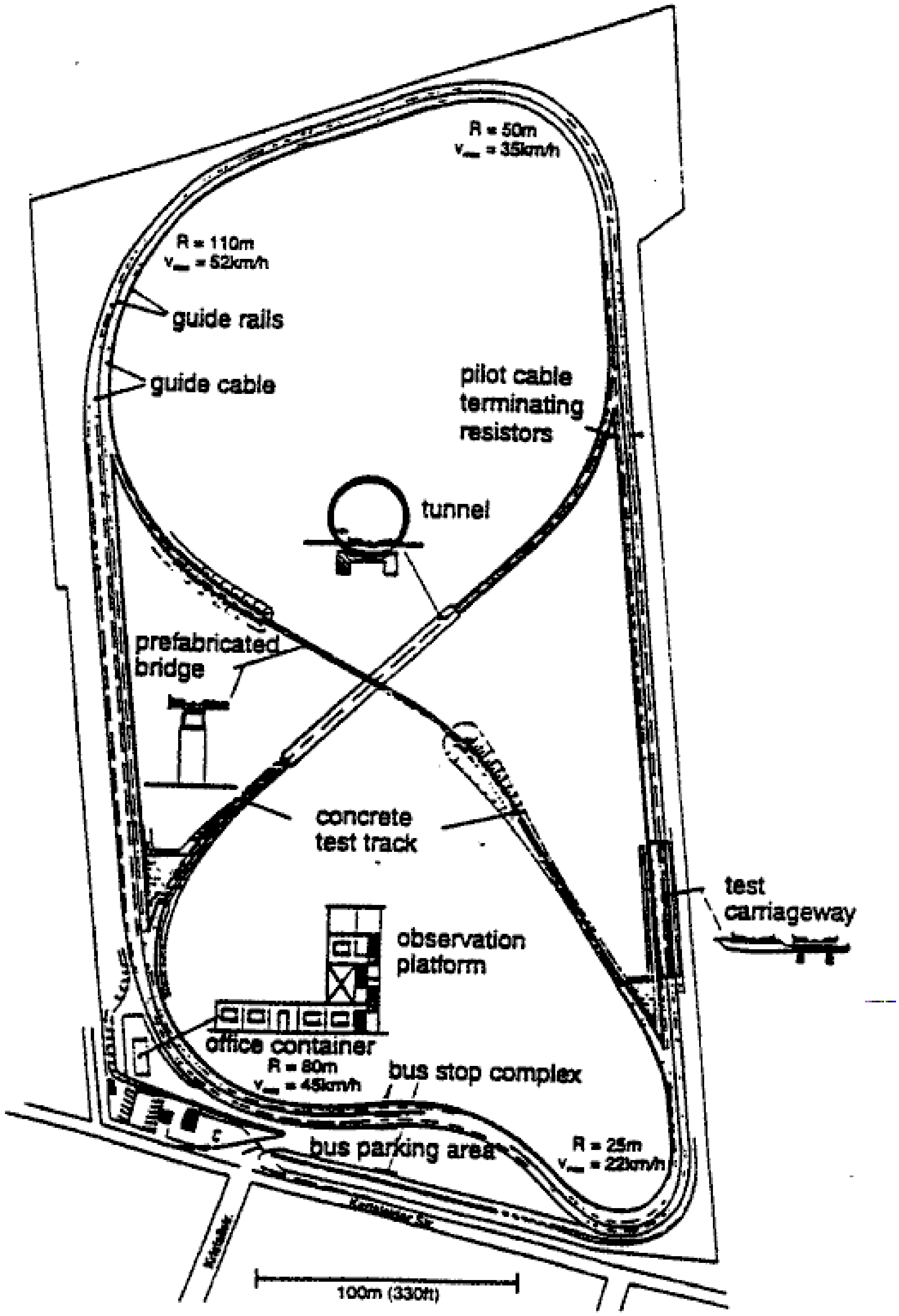


Figure 37. Test Truck Layout of M.A.N. In Munich, Germany

- Tests were carried out using additional cables as jamming cables set at various angles to the man guide cable. These resulted in a maximum deviation of the vehicle from the main guide cable of less than 15 mm (0.6 in). Attempts were also made to jam the vehicle using extraneous electric fields. Use of a powerful walkie-talkie resulted in a deviation of less than 10 mm (0.4 in). Simulated break-downs due to trolley operation (e.g., caused by trolley buses) showed no effect on the track guidance. On the basis of these tests the antenna signal can be said to be resistant against all conceivable extraneous influences.

6.3.1.1 Lateral Deviation Caused by Malfunction Outside the Guide Track

Both vehicle malfunction and roadway interference were simulated as malfunctions outside the guide track.

Tests were carried out in which sudden loss of air pressure in the tires due to slitting as an extreme malfunction factor for the track guidance was simulated. The front right tire was slit while the vehicle was driving at a speed of 30 km/h (19 *mVh).* The electronic power steering unit reacted very well in this situation.

- The maximum momentary deviation was recorded at only 35 mm (1.4 in). Driving and braking with reduced air pressure on one wheel led to no deviation.

- Vehicle behavior resulting from brakes pulling unevenly was investigated. In order to do this, the brakes of one front wheel were put out of action so that only one front wheel could be braked. Full application of the brakes at high speed with a braking deceleration of up to 4 m/sec^2 (13 ft/s2) led to a maximum deviation from the set track of 80 mm (3.1 in).

On slippery surfaces (soft soap) the vehicle behaves normally until it exceeds its adhesion limits. Further motion of the vehicle is uncontrolled depending on the adhesion factor of the individual wheels. The automatic track guidance always tries to steer in the direction of the guide cable (increase in the steering angle).

- Tests were also carried out on the test track under gusting wind conditions. ft was not possible to detect a noticeable increase in deviation in this case. The reactions of the automatic guidance system are dearly better than those of a driver-controlled vehicle. Driving past other vehicles with little clearance produced almost no measurable deviation. Deviations were always less than 50 mm (2 in).

6.3.1.2 Other Influences

- The influence of loading the vehicle lies within measuring tolerances. The greater inertia forces induced by fully loaded vehicles increase the travel comfort.
- Badly laid guide cables simulated here by the addition of constant background

noise signals induce only a slight increase in deviation. Steering control speed, however, increases considerably (vibration).

- Tests were carried out on vehicle behavior during frequency-dependent disturbances in the range between 0.1 to 10 Hz using a sinus wave generator.

- In the range around 1 Hz there is a slightly increased resonance point which corresponds to the yawing frequency of the vehicle. As this is also the top angular frequency of the steering control, maximum steering control speed is reached at this frequency.

- Theoretically there is a relationship between movement of the wheel in the vertical plane and the track guidance. This vertical displacement, however, has no effect on the stability of the track guidance. Tests over extremely bumpy roadway showed no measurable influence on the lateral deviation.

From all the tests results the vehicle clearance profile is shown in figure 38. This clearance profile takes into consideration all possible disturbances, e.g. control deviations, tire damage, broken spring. From this results an agreed deviation of the track guidance of I 150 mm (6 in). The Channel tunnel system occupies a special position. Due to the advanced technology and the comparably low speeds in the tunnel the laterally required free space can be reduced to I 50 mm (2 in).

In contrast to the standard width of bus lanes of 3.50 m (11.5 ft) there is a reduction in width requirement of about 20 percent due to the reduced width requirement of the electronic track guidance system. This track width requirement is the same as for mechanical track-guided buses, except in curves. The latter is due to the final time delay for signal processing and the time required for the hydraulics to react to the control signals. The tracks require widening at curve entry and exit points greater than the vehicle dynamic requirements. Depending on the vehicle speed, the vehicle deviates to a greater or lesser extent from the guide cable.

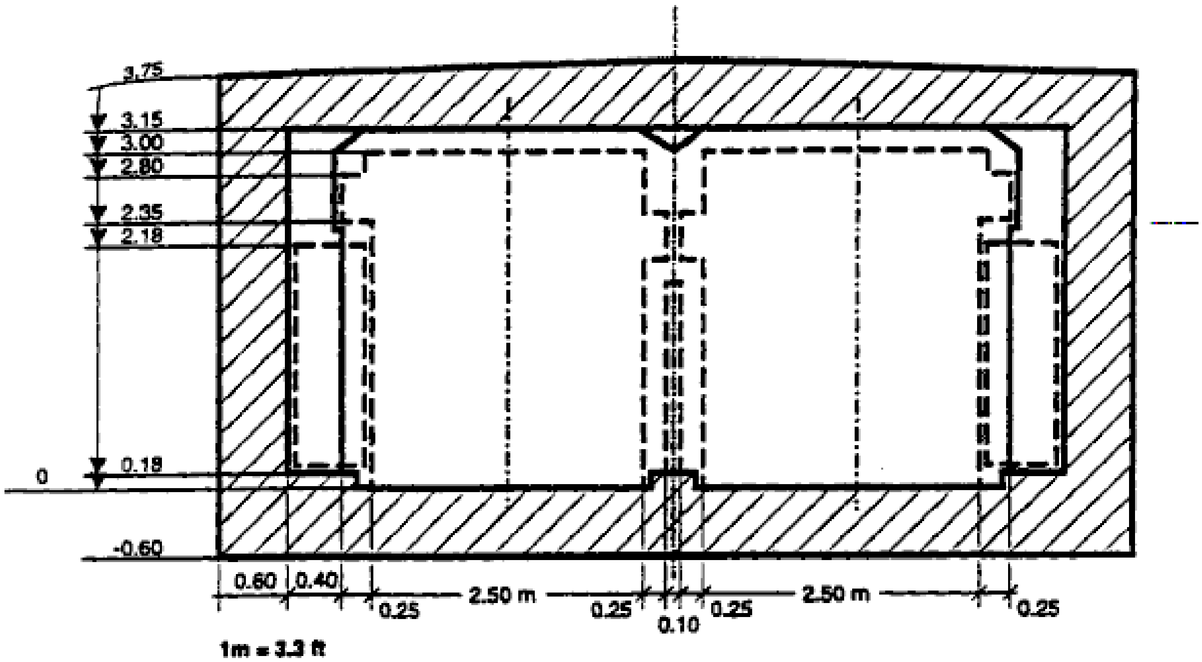


Figure 38. Vehicle Clearance Profile of me Electronically Truck-Guided Bus

As vehicle speed increases the deviation becomes greater. in order to determine the proportion of the deviation dependent on speed, deviation was measured in comparison with the slowest possible vehicle speed.

When driving at high speed in curves which requires a high degree of steering angle speed, there is a certain amount of deviation from the set track A tolerance width is required which increases in the curve. The beginning of the straight track at the exit point of the curve must also have a greater tolerance width until the point where the vehicle has settled itself into a straight driving mode. For this reason every curve must have its own optimal design speed for which the cable can be best laid. Moreover, the roadway must be designed so that vehicles can drive along it at a crawl. Increased track width at curve entry and exit points must therefore be taken into account.

Taking into consideration permissible lateral acceleration to which passengers in the Federal Republic of Germany can be subjected, curve speeds of 45 km/h, 30 km/h, and 18 km/h (28 mi/h, 18.5 mi/h, and 11 mi/h) can be driven on curves of 110, 50, and 25 m radii (36, 165, and 82 ft radii), respectively. ft is technically possible to achieve higher speeds.

6.3.2 Roadway

Electronic track guidance imposes the same demands on the roadway surface as conventionally driven buses; the road surface (top layer) must be designed for the relevant loads. Loads are especially high in the area around bus stops particularly on the Section where braking and acceleration take place. These high load factors must be taken into consideration when selecting the road surface materials.

6.4 SYSTEM CHARACTISTICS

In normal operations, the track-guided bus is at first manually steered like any other bus. Not until entering the guideway section does the conventional bus become a track-guided vehicle.

At the beginning of the guideway the driver executes the entry maneuvers, whereupon the guideway takes over the steering function, thus relieving the driver of this task. In case of the Channel tunnel system the distance to the guide cable is indicated to the driver by differently high frequencies, as soon as the track guidance system is switched on and the guide cable is within the frequency area of the antennae. The driver is still responsible for speed control and for the general supervision of the vehicle. The track-guided bus cannot steer around obstacles: it can only come to a standstill. To avoid obstacles$_{1}$ the driver must take over the steering, and to do this he has to switch off the track guidance system and then assume responsibility for steering the vehicle.

An expertise prepared by the technical supervisory authorities in the Federal Republic of Germany Technical Supervisory Board TUV) stipulates a maximum speed of up to 50 km/h (31 mi/h) for the participation of electronic track-guided buses in public road traffic. Speeds higher than 50 km/h (31 mi/h) may not be driven by buses in purely urban traffic according to German law (Road Traffic Statute). However, from the viewpoint of purely safety engineering considerations, the admissibility of driving at higher speeds is, in principle, possible. This has also been demonstrated in the course of trials run on test circuits, where speeds of up to 100 km/h (62 mi/h) were driven without problems.

Before being deployed in automatic track-guided operations, both the drivers and vehicles as well as roadway are to be prepared accordingly: a general introduction is to be given to drivers who have not as yet been confronted with track-guided buses at the beginning of the first trip; the vehicles are to be checked to see if they function properly each time before being put into operation; the roadway is to be kept under constant surveillance.

6.4.1 Operational Testing of the Vehicle

The functioning of the track guidance equipment is to be tested before each deployment of a vehicle as a track-guided bus. Because of the structure of the electronic track guidance system, this test can only be carried out with an external signal (e.g., via the guide cable). A directive issued by the supervisory authorities in Germany stipulated that the electronic track guidance system be tested on a test track which is at least 50 m (164 ft) long (e.g. on the maintenance and parking grounds). The test is a hardware test, extending to all components, from the antenna to the steering control cylinder.

A routine test of the electronic track guidance system on the test track takes the following course: the driver turns on the electronics, maneuvers the vehicle in the direction of the guide track and the electronic equipment tries to take over the steering of the vehicle. An internal logic-circuitry prevents the taking control of the steering if faults are present or occur in the track guidance system. If no errors of any kind occur, the electronic track guidance system assumes the steering function and the vehicle drives track-guided. In order to test both hydraulic circuits, the test must be carried out at a speed in excess of 6 km/h (3.7 mi/h). Should faults occur$_1$ the equipment will relay an alarm signal. The driver resumes steering at the end of the test track. A written record is made of the carrying out of the routine test.

In the event that the electronic system is defect, it will relay an alarm signal immediately upon receipt of the guide track signal. The driver then slows down the vehicle with the brakes and leaves the guideway while still in the track entry section.

6.4.2 Exit from Roadway Sections with Track Guidance Technology (Track Exit)

At the end of the guideway track (track exit)$_1$ the driver resumes the driving function. To do this, he puts his right hand on the steering wheel and activates the ON/OFF switch for track guidance system with his left hand. The design of a track exit section is exactly the same as that of the track entry sections in respect of its geometry and' markings. The traffic lane becomes wider and the position of the guide cable is marked on the roadway. In the track exit section the driver switches off the track guidance system and takes over the steering of the bus from this moment on.

Should the driver forget to switch off the electronic track guidance system, the automatic control system will transmit an alarm signal to him. This alarm is triggered by the absence of the second frequency in the guide cable. The guide line terminates in two stages: in the first stage the second frequency is absent, and then, a bit further on, the guide cable comes to an end. The driver is thus reminded in due time of his having to resume the steering function.

6.4.3 Selection of the Direction of Travel at Merging and Branching Points (Driving through Switches)

In switch sections, an additional third and fourth frequency in the guide cable is necessary. The switch$_1$ i.e. the direction of travel$_1$ can be selected and determined by a master station (active point) as well as by the driver (passive point). When the approach is controlled by the master station, the current flow in the guide cable is switched over from one to another cable in a terminal control element, so that no current flows in one cable and the bus follows the cable which is conducting a current. Where the driver has control, the direction of travel is chosen by means of frequency selection. The driver presets a frequency.

In the case of a branching point, one frequency is for straight ahead and the other for the branch line. Depending on the course of the pre-selected frequency, the bus drives straight ahead or turns Into the side road. The selection of the direction of travel with this kind of point is made by the driver in accordance with the line of the network which has to be covered. The procedure in crossing sections corresponds accordingly.

6.4.4 **Malfunctions En the Operation of Electronically Track-Guided Buses**

Operational malfunctions can be induced by occurrences external to the system as well as by incidents that are inherent to the system. The so-called system-external malfunctions can arise due to, e.g. influence of weather conditions, and the so-called system-inherent malfunctions may ensue, e.g. from faults in the steering hydraulic or in the guide cable.

6.4.4.1 Malfunctions Due to System-External Occurrences

System-external malfunctions are to be expected especially from the influence of weather conditions, especially icy road conditions and snow. For winter operations, a winter road-clearing service has to be effected just as for driver-steered buses because the electronic track-guided buses are also dependent on sure traction of the tires.

However, as regards track guidance in winter operations, minor differences can be noted between manual steering and electronic track guidance.

When the bus begins to skid it moves away from the guide cable. The electronic system tries to counter with greater steering action. The steering angle is increased and the bus will then approach the guide cable. However, when there is no more traction, the bus is no longer steerable, just as is the case for driver-steered buses.

If relatively large deviations from the guide track occur[1] be it because of a slippery roadway or due to excessive speed, a warning is given to the driver, who must then reduce his speed. As in the case of manually steered driving, the driver has to use his judgment in estimating the maximum speed at which he can drive under the given road conditions.

6.4.4.2 System-Inherent Malfunctions

System-inherent malfunctions are considered to be all occurrences which impair the redundancy of the entire track guidance system, but which, however, do not endanger the track guidance function. Such malfunctions are communicated to the driver by means of acoustic alarm signals, whereupon he must brake the vehicle and come to a standstill. Errors can occur within the system which do not arise again after a renewed switching on of the unit.

In order to be able to carry out a subsequent inspection of the standing vehicle, the driver must switch off the track guidance system and then switch it on again. By switching off the track guidance system, it becomes passive and the error signal is extinguished. The system is again activated by a renewed switching on. In case the previous error occurs once more, alarm is sounded once again; otherwise the track guidance system resumes control over the vehicle since it is positioned directly over the guide cable.

Where a fault in the steering hydraulic system has set off the alarm, a renewed alarm may be sounded after resumption of driving with the electronic track guidance system - however, not until some distance has been covered due to the fact that the steering hydraulic system can be tested only when the vehicle is moving. In this case the track guidance system must be switched off during driving: the driver must steer manually. According to German regulations, manually steered driving on guideway sections is to be signaled to the other vehicles by means of a warning system on the roadway. The other buses traveling on the section with electronic track guidance must then proceed with extra caution, as relatively large deviations from the true course track on the part of the driver-steered bus cannot be excluded. A lane borderline marking could be provided as an aid for the driver of a defective bus. Passing of the defective bus by other buses is possible, but only if the driver takes control of the steering. This is permissible only if the vehicle to be overtaken is at a standstill because of the narrow lane.

6.4.4.3 Removal of Defective Vehicles from the Roadway

Where malfunctions of vehicle components occur which are not connected with the track guidance system, and if the damage is to such an extent that the vehicle cannot be operated any further, the bus can then be towed away or be pushed by the following vehicle. In the event that there is no malfunctioning of the main engine, the track guidance system is fully operational when the engine of the defective vehicle is running: the defective bus can be towed away and be track-guided at a minimum speed of 4 km/h (2.5 mi/h). This minimum speed is required because the drive shaft powered hydraulic pump is not fully operational until this speed has been attained. In addition, provision must be made for communications between the drivers.

Where the engine is not running (e.g. in case of engine damage), one hydraulic channel is not supplied with oil pressure. This is why only manually steered driving is possible in such cases. The power steering is fully functional. At low speeds the driver should have no. difficulty in keeping the bus on a lane with a width of 2.80 m (9.2 ft).

6.4.5 Licensing of German Electronic Track guidance for use In Public Passenger Transit

Before electronically track-guided systems are licensed, all components of the system and the entire system itself must undergo a strict examination at the TUV. These examinations were carried out during the two years after development and made some changes necessary. All conceivable failure tests were carried out on the system and vehicles and led to positive, safe reactions of the system. Tests included exploding front wheel tires, brake and suspension failure on one side of the vehicle, sudden gusting of side winds of up to 70 km/h (43.5 mi/h) etc. During straight and level running, deviation from the guide cable was in every case less than 150 mm (6 in). Individual components were tested for safe functioning at extremely low temperatures and during extreme vibration.

Operating instructions for operation with passengers were drawn up from the results of the testing and serve as operating instructions for the drivers. The instruction laid down procedures to be followed in case of system malfunction.

6.5 OPERATIONAL EXPERIENCE WITH ELECTRONIC GUIDED BUSES

Electronic guided buses for passenger service were used in a pilot operation at the Transport '78 exhibition, as well as for regular line-haul service in Halmstad, Sweden (Volvo System) and Furth, Germany (Mercedes-Benz and M.A.N. systems). By far the most wide-ranging experience was obtained from the demonstration service in Furth.

6.5.1 Transport '78

During the Transport '78 exhibition in Munich, Germany in summer 1978, an M.A.N. prototype of an electronically guided bus operated within the exhibition grounds to transport people between the exhibition hails. Over a period of five days, this bus operated on a 1.2 km (0.75 mile) circle line and drove approx. 600 km (373 miles) using electronic guidance. A bus stop with an elevated platform was erected for demonstration purposes on the exhibition grounds. The bus was equipped with sliding doors on both sides, and since the platform of the bus stop was on the same level as the bus floor, the passengers were able to board and alight without the need for steps. The information acquired from this first practical operation with passengers made it possible to make a large number of improvements in the equipment and control of the vehicle itself, with a resulting improvement in reliability. No malfunctions in the system which might have been critical for safety occurred during operation at the lair.

6.5.2 Halmstad, Sweden

With the support of the Swedish Ministry of Transport, a model project was brought to life in the southern Swedish city of Halmstad with the aim of attaining the following objectives:

- Creation of a transit system which all categories of passengers could use without problem, including physically handicapped persons who are restricted to a wheelchair.
- Shortening of the trip times as compared with the conventional bus transit system by constructing special bus streets.
- Improvement of travel comfort with the new electronic longitudinal guidance system.
- Improvement of the working conditions for the driver through the implementation of automatic longitudinal and lateral guidance systems.

After a total development period of four years, an elevated platform system for buses was taken into operation for public transit in Halmstad on November 28, 1979. A total of eight Volvo vehicles fitted out with electronic track guidance equipment were deployed on a route having 25 bus stops (elevated platforms as well as bus stops at ground level).

The vehicles that were employed in this new system were standard line haul buses, model Volvo B 10 R, which had a level interior floor height of 510 mm (20.1 in) -- neither stairs for passenger boarding and alighting nor floor depressions in the forward part of the vehicle are incorporated in this vehicle model. Because of its design, the bus was able to use bus stops at which the platforms had the same height as the interior floor of the vehicle [510 mm (20.1 in)). A problem-free in-and-out exchange of passengers on the same level is thus possible, wheel-chairs and baby-carriages can be brought into the bus without additional assistance [today these advantages are available with low-floor buses with a floor height of 320 mm (12.6 in)].

To aid the driver when driving into a bus stop, an electronic guidance system was installed both to guide the vehicle laterally and to brake the vehicle automatically at the stopping point.

At the bus stops with elevated platforms, the vehicle is positioned at a distance of 0.4 m (15.7 in) away from the platform. The gap between the edge of the platform and the outside of the vehicle is bridged by means of a ramp which is extended from the vehicle with cylinders operating with compressed air. In the retracted position the ramp cannot be seen - it lies at rest under the floor of the vehicle.

In addition to the bus stops with elevated platforms, conventional bus stops at ground level were also driven up to. At bus stops of this type of construction, a treadboard was extended by means of cylinders in manner similar to that for the ramp described above in order to facilitate the boarding and alighting of passengers. Only one additional step was necessary because of the low floor height of 510 mm (20.1 in).

The Swedish parliament granted a subsidy of 1.5 million Swedish Crownas (SWC). The remaining funds were provided by the city and the Volvo enterprise. A special incentive for the Swedish government to participate financially in this project was the possibility of integrating physically handicapped persons - particularly those using wheel-chairs - into the public transit system.

After a three year period in passenger transport operations[1] it was decided to discontinue using the electric guidance system (both the longitudinal and the lateral guidance systems), due to the fact that the drivers could not perceive any assistance in their work driving from the system: it was possible to position the vehicles at the bus stops just as fast and just as accurately without the supplementary system.

Furthermore, because of the simple construction (no auxiliary aid to steering, constantly operating electric steering motor, etc.)$_1$ problems arose in the handling of the buses. In the operational period in Halmstad, the vehicles equipped with electronic guidance systems were not involved in any accidents which could have been caused by the track guidance system.

6.5.3 Furth, Germany

The guided bus operation in Furth was the only case to date in which an electronic guidance system of the type required for the Automated Highway Systems project was in service for a longer period of time. This operation will therefore be described in detail. In evaluating this operation, however, it must be considered that the level of technology used was that of the eighties.

Demonstration operation in Furth was implemented using 3 buses (1 M.A.N. standard bus and 2 articulated buses [1 M.A.N. and 1 Mercedes-Benz]) in the period from May 28, 1984 to December 7, 1985. Over this period, the M.A.N. buses covered between 56,000 and 58,000 kilometers (34,800 and 36,000 miles), and the Mercedes-Benz bus traveled 17,000 kilometers (10,600 miles) in the period between April 1985 and December 1985. Almost 10 percent of these mileages was covered using electronic guidance. The Technical Supervisory Board TUV) set the following conditions for operation of these guided buses:

- The area driven over by the guided buses had to be dearly marked.
- Operation of the guided buses had to be stopped if temperatures fell below freezing point.
- The functioning of the guided bus system had to be checked before each operation.

The second mentioned condition was a precautionary measure, as sufficient experience had not be gained on the behavior of the system on frozen road surfaces or with iced-over antennae. In order to fulfill the third mentioned condition a test route was set up in the depot (see figure 39), where the functioning of the track guidance equipment was tested each time before the vehicles left the depot. If irregularities became evident during this test, it was not permitted to operate the bus using track guidance, even if the malfunction had no effect on safety.

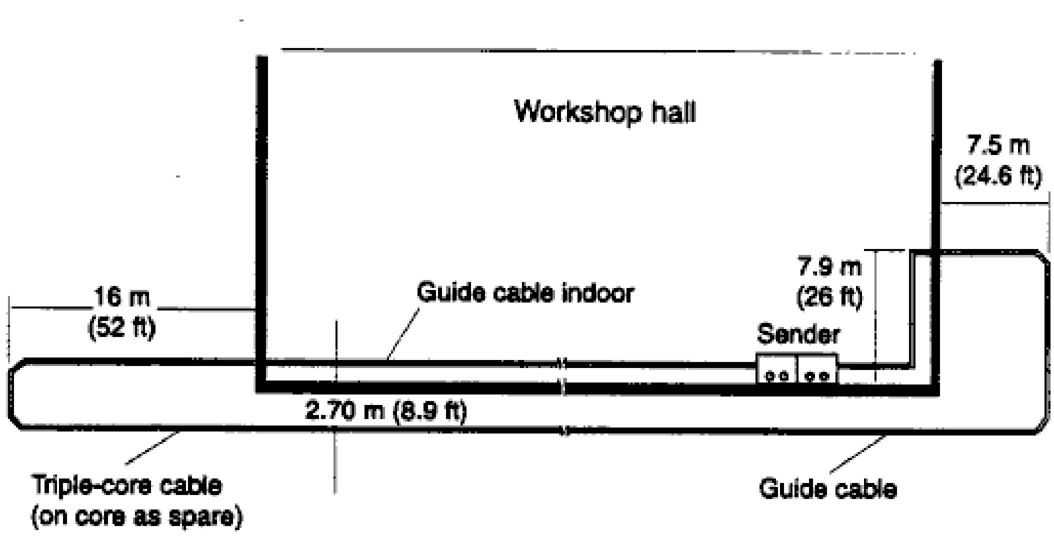


Figure 39. Test Truck Layout In Furth, Germany

For setting up the guided section with a total length of 700 m (2,300 ft), two stops and a turning loop (figure 40) it was necessary to be particularly careful in the area of the turning loop with its tight curve radii, as the vehicles each had different cornering characteristics. (This point is of particular relevance to the AHS, where vehicles with much more widely differing cornering characteristics might be used). After measurement, the guidance cables were laid by simply cutting open the road surface, which caused no particular problems. The required signals were generated by two leader cable transmitters along the route.

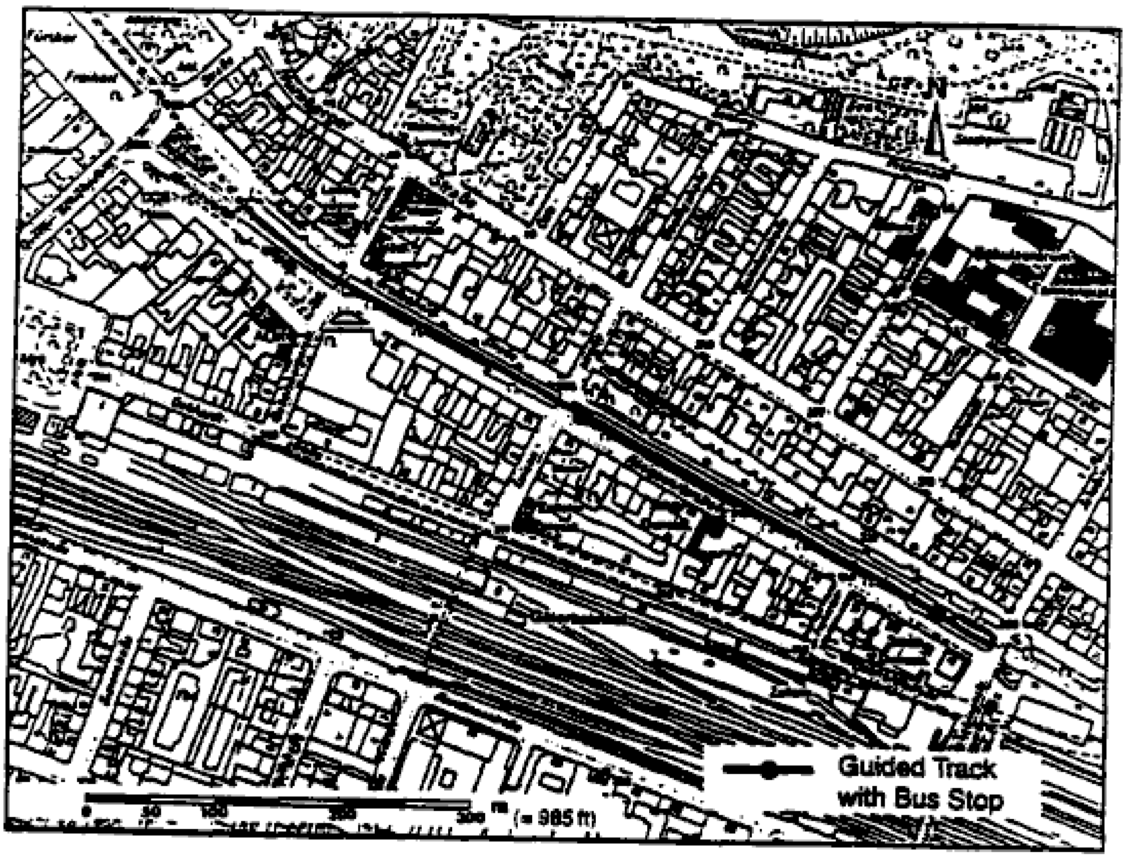


Figure 40. Location of the demonstration track In Furth, Germany

During demonstration operations complaints by drivers were continuously recorded in order to obtain information on the reliability of the guidance system. Altogether there Was a malfunction rate of 3 to 8 malfunctions reported over 1,000 kilometers (621 miles) of guided operation, whereby operating errors and/or reports of errors which could not later be determined are also included.

The main reason for the relatively high number of complaints was poor quality of the road, which was considerably worse on the demonstration route than on the test routes.

Overall, however, malfunctions were kept within reasonable limits with the result that the technical feasibility and suitability of the system can be regarded as proven. The

Furth operation of electronically guided buses was planned to show that the system works safely in daily passenger operation. Thus, the operation was successful. According to the planned timetable, it was finished by the end of 1985, because in the same street as an extension of the Nurenberg Metro was built.

6.5.4 Channel Tunnel

The track guidance system for the Channel tunnel is presently within the phase of final inspection by the technical supervisory authority. Accordingly$_1$ operational experience with the system is not yet available.

6.6 OPERATIONAL EXPERIENCE WITH MECHANICAL GUIDED BUSES

In order to complete the overview of electronic track-guidance systems$_1$ at this point it is intended to give a brief review of operational experience with the two mechanical track-guidance systems developed in Europe.

The technology developed in Germany with side guide curbs is currently in service in Essen (Germany), Mannheim (Germany) and Leeds (United Kingdom), while the technology developed in Belgium with a guide-rail located in the center of the lane is in operation in Rochefort (Belgium). Concrete studies for using guided buses with mechanical track-guidance are being undertaken in Bradford (United Kingdom) and Rotterdam (The Netherlands). It is intended here to report on experience with applications in Essen and Rochefort as track guidance systems have been operative there longest.

Experience in Essen is largely identical with that in the remaining cases where this technology has been applied, including that at the International Symposium on Traffic and Transportation Technologies in Hamburg, Germany in 1979. At this exhibition mechanical track-guidance was first presented to the general public and a test line operated between the exhibition halls and the outside area. A survey conducted amongst drivers and passengers produced an extremely positive response to the new system.

6.6.1 Mechanical Track-Guidance In Essen$_1$ Germany

The details of the mechanical track-guidance technology implemented in Essen, Germany was researched. The system background$_1$ local transport conditions, provided technology, actual operational experience, and need for further planning have been documented in this section. The typical guided bus in tunnel operation and the system route map are shown on figure 41.

6.6.1.1 Background

Since 1977 a change has been taking place from the traditional tramway to a modern light rail transit system (LRT) in Essen, Germany -- one of the centers located within the area organized by the largest European transport association, VRR Verkehrsverbund

Rhein-Ruhr (in the German Rhine-Ruhr urbationized area). The LRT system is characterized by its own track which is mainly separated from the other traffic; in Essen it also runs in tunnels below ground. Few of the old tramway sections are not worth the effort of being built up for LRT. For these sections conversion to bus service is planned.

This planning as well as the still available performance reserves in the tunnel sections have induced the local transit operator Esker Verkehrs-AG (EVAG) --in addition to the conversion from the tramway to an LRT system - to also make the move from the conventional diesel bus system to a bus transit system by the introduction of new bus components such as track-guidance and new designed bus stops.

The planning as well as the still available performance reserves in the tunnel sections have induced the local transport operator, Esker Verkehrs-AG (EVAG), -in addition to the conversion from the tramway to an LRT system - to also make the move from the conventional diesel bus system to a bus transit system introducing new bus components such as track-guidance and newly-designed bus stops.

To make the capacity reserve in the tunnel sections available for guided buses, the exhaust problems had to be solved.

Alternative one was to use Duo-buses (buses with two independent propulsion Systems) driven with electric propulsion in the tunnel sections. Alternative two was to use conventional diesel buses and to install exhaust extraction systems in the tunnel sections. The third alternative was to use buses fueled by methanol in order to reduce pollution to a very low level. A feasibility study showed that the first alternative was the best and, in the case of Essen[1] also the cheapest option. All the buses operating in tunnels are therefore Dual-Mode buses.

6.6.1.2 Peripheral Conditions

In the City of Essen, as in other cities, the bus runs on the city streets and during the peak traffic times together with the private transport causing, in some cases, considerable disruption to the service. On the other hand, an existing tunnel network, intended for light fall and tram systems, runs along approximately the same routes as the buses below the inner-city areas already overcrowded with private transport. The questions arose as to why it should not be possible to use the advantages of independent rights-of-way also for the buses and, at the same time utilize the free tunnel capacity for the bus services.

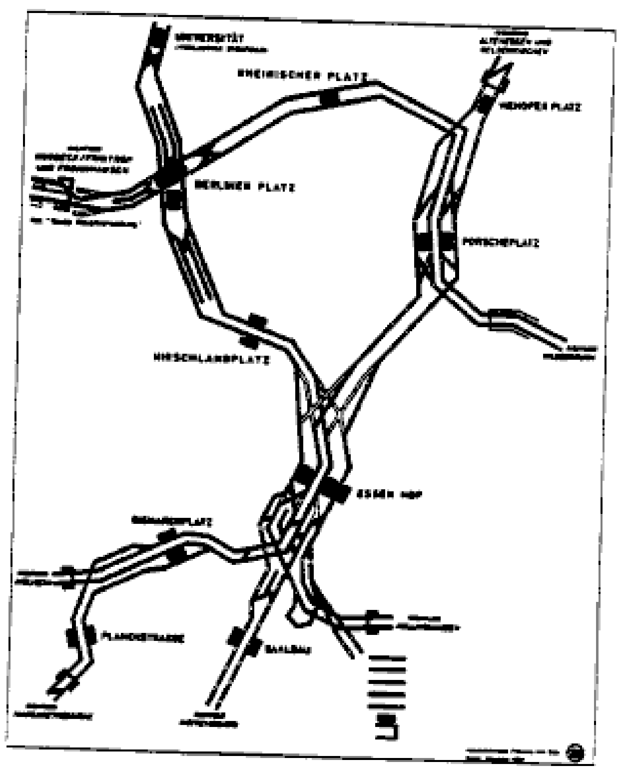


Figure 41. Guided Bus Essen, Germany

Before deploying buses in tunnels, however, there were a number of problems which had to be solved. This could only be achieved by step-by-step testing of the individual components needed, the most important of which are:

- The Guideways for the Buses (track-guided buses).
- The Safety Systems (signal equipment).
- Bus/Rail Combined Tracks.
- Guided Bus Switches.
- Duo-Bus (choice between diesel or electric drive systems).
- Power Transmission Lines.

The objectives of the Esker Verkehrs-AG with the support of the Federal Ministry of Research and Technology (BMFT) were the planning research, constructive design and production and a step-by-step realization of a demonstration of unguided buses". In the final phase, this led to partially combined operation of trams and buses on joint rights-of-way, without limiting the flexibility of the bus system in any way.

6.6.1.3 Technology

In Essen the second generation of the German standard bus SL II and the equivalent articulated buses and since 1993 also low floor buses are used as guided buses. But all existing standards buses can, at relatively low expense, be equipped with mechanical track-guidance, too. With the exception of new stub axles and a slight enlarging of the front wheel openings, the vehicles require no major alterations. On the guided bus routes in Essen, re-equipped standard buses and articulated buses as well as low floor buses from several German manufacturers are in service.

The mechanical track-guidance equipment allows the vehicle to be steered without any action being taken by the driver. This automatic steering is effected by rubber guide rollers positioned horizontally directly in front of the wheels which are guided along the sides of the guide rails installed on the guideway. The guide arms with the guide rollers are directly connected to the stub axles of the front wheels. If the bus moves away from the nominal track determined by the guide rails, the deviation will be immediately corrected via the guide roller, guide arm, and stub axle.

In normal street traffic outside the guideway, the guided bus is steered as a conventional bus.

The Duo-buses are equipped with two independent drive systems: an electric, emission-free drive for use in tunnels and certain selected route sections above ground and a diesel drive for a flexible regional deployment of vehicles. The Duo-bus concept was realized in a co-operative venture of various different companies also with sponsorship of the Federal Ministry of Research and Technology (BMFT). Today there are 18 Duo-buses designed for tunnel operation in service.

6.6.1.4 Experience

Mechanical track-guidance as possible component of a bus transit system at which transport operators are aiming today may stand for a considerable increase in the value of the transportation offer from passengers' point of view.

Buses run on the main corridors on their own right-of-way free of disturbances by private traffic; this means a gain in punctuality and speed, a dense fixed cycle as well as an addition to driving comfort (instead of nerve-racking stop-and-go rapid movement without jerks) which should not be underestimated. Since the track-guided bus is not bound to its right-of-way a direct connection between the outskirts and the city is possible without the need to change the bus, as it is frequently the case on such relations served by mixed systems (conventional bus/tram or LRT) comparable to the guided bus. When the track of the guided bus runs on a joint way with tram or LRT, there are optimal transfer conditions (comfortable, quick) at the joint cross platforms.

Of course, the transport operator makes a profit of the improved image of its transportation offer. Benefits and coots are in a very favorable proportion to each other, if one compares the possible later conversion of the available rolling stock and the exploitation of the already available infrastructure into/by mechanical track-guidance with the new installation of a completely new system having about the same efficiency.

Meanwhile mechanical track-guidance used in Essen has developed into a sufficiently proven technology with regard to reliability and safety$_1$ which - as it is based on conventional bus technology - does not result in a decisively higher maintenance than conventional bus operation. Also the susceptance to troubles of the guided bus is comparable to that of normal buses; initial diseases which necessarily accompany new technologies during their first years) have meanwhile largely been overcome. The Essen experience in details follows below.

A survey 1981 among passengers and drivers of the guided buses in Essen showed altogether positive results:

Most of the passengers (approximately 73 percent) enjoyed their journeys with the guided bus. Ninety percent felt that driving with automatic track-guidance was safe. Asked whether they would also drive with a guided bus through a tunnel, 87 percent of the passengers said ~

Drivers are also satisfied with guided bus technology. Many of them feel that their job has been made easier by the total separation from private transport and the reduction in street due to operation in the guided track Over 95 percent of the drivers experienced no difficulties in entering the guideway, in driving straight and in curved sections or in approaching the. bus stops.

Until mid 1986~guided buses ran about 8 Million vehicle kilometers (5 million vehicle miles) on the guided bus lines. Twenty percent of these have been done in guided operation. During this operation time no serious defectiveness have been stated neither with the guideways nor with guidance components.

Entering the guided sections, operation on these sections as well as driving with the guided buses on normal streets works out problem free after a short period of accustoming.

Since September 1988, the two guided bus lines in Essen have been running in passenger service through a tram tunnel, too.

To date no critical problems have occurred either with the guided bus components or with the security system. Nor has joint operation with the tram caused any problems. Nor have any critical problems occurred with regard to electrical safety. In summary, one can say that tunnel operation has not caused any specific problems related directly to the actual tunnel operation. From the passengers' point of view too, tunnel operation has been positively received.

Operational experience to date has shown that for the future development of components for tunnel operation their practical suitability for non-guided road operation must be given greater consideration$_1$ as the majority of problems which have arisen in tunnel operation originated from causes to be found in normal mad traffic. Here, the components needed for tunnel operation are so badly damaged by outside effects that fault-free functioning can no longer be guaranteed. A desirable aim would be to integrate these components into the vehicle structure in order to reduce the number of outside components at risk.

The Guided Bus Essen Demonstration Project has shown that joint use of tunnels by trams and guided buses is possible without any disruption of tram operations. And guided buses can be integrated into the trains' protection system with only moderate effort and expense. This means that guided buses can also use tram tunnels in other cities, inasmuch as suitable entry and exit ramps can be constructed and if, in the case of metre gauge trams, the clearance profile is sufficient for the wider guided bus. Furthermore, the use of the low-floor bus is quite unproblematic.

6.6.1.5 Further Planning

After the positive experience with mixed tunnel operation in Essen, a further tunnel section of 1.6 kilometers (1.0 mi) length is at present being equipped for guided bus operation. This section includes stops with central platforms. The buses are being equipped with doors on the left-hand side for this purpose. Experience gained with the first tunnel section is being made use of in the construction of the catenary system. This second tunnel section brings the development of joint tunnel operation in Essen to a provisional end.

The importance of the extended guided bus tunnel operation for public transport in Essen is evidenced by the fact that this extension is sponsored with funds granted on the basis of the German 'Gerneindeverkehrsfinanzierungsgesetz' (GVFG - Local Transport Financing Law).

6.6.2 Mechanical Track-guidance In Rochefort, Belgium

In Rochefort, Belgium another mechanical track-guidance based system was developed. This system used different guidance infrastructure from the German systems. This section discusses the background, local peripheral conditions$_{1}$ technology, experience, and further planning identified from the Rochefort demonstration project. The guided light transit bus in surface use and a system route map are shown on figure 42.

6.6.2.1 Background

The acute economic world-wide recession these last few years, however, has caused the limits of the financial capacities of municipal organizations to be cruelly felt. The result being that many an urban transportation project was suspended or threatened with cancellation, since these organizations can no longer afford to commit quickly the large sums required to build a tramway network or a fully exclusive lane network.

On the other hand the congestion of urban centers reduces speed drastically, and hence the quality of the bus service; the creation of special lanes or semiexclusive lanes (for buses) is proving to be no more than a small remedy.

In these times of budgetary restrictions$_{1}$ the decision to implant a public mass transportation system will have to be based increasingly on an in-depth study of the needs which this system has to meet, the financial consequences and its capabilities to adapt to the current and future socio-economic needs of a greater urban area.

This observation led the Belgian manufacturer, BN Division of Bombardier Eurorail, to carry out a technical and economic analysis of bus and light railway systems, which served as the basis for developing its new transportation system: the Guided Light Transit (GLT)$_{1}$ that continues the advantages of conventional bus and light rail systems.

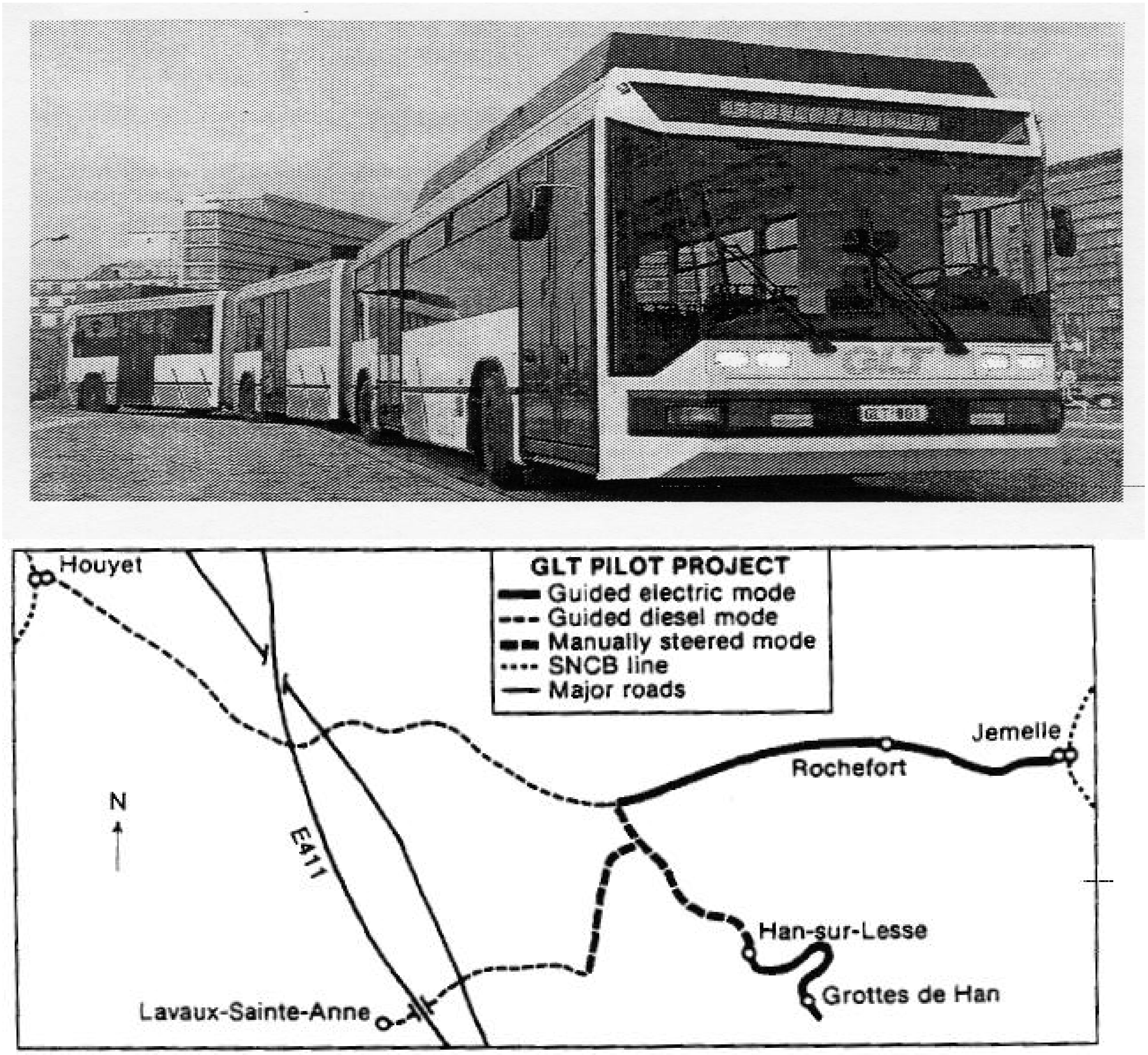


Figure 42. Guided Light Transit Rochefort, Belgium

6.6.2.2 Peripheral Conditions

The GLT system has been developed with the aim of achieving the following objectives:

- Combine the flexibility of the bus and the passenger transport capacity of the tram (LRV) while reducing their weak points.
- Offer rapid and comfortable transit with regular timetable and elimination of the breaks of load.

- Reduce investment costs for both the infrastructures (+/- 50 percent) and the vehicles (25 percent).
- Offer the option of implanting the infrastructure very gradually, especially the civil engineering requirements.
- Reduce the drawbacks for the traffic and the residents by using prefabricated tracks.
- Offer the option of beginning to operate the system (and thus have revenues)[1] and do so while the infrastructure works continue at a pace dictated by the availability of funds.

On the basis of these objectives a track-guidance system with the following characteristics was developed:

- Lifetime (30 years), safety, and operational reliability of vehicles in guided mode similar to those of a tram.
- Dual-mode vehicles that can be operated manually or in guided mode.
- Duo-bus vehicles from the propulsion point of view: in guided mode, electric power is supplied by conventional pantograph and overhead contact line; in manual mode, by a diesel engine electric generator.
- Large capacity vehicles 18 m (59.4 ft) single, or 25 m (82.5 ft) double articulated vehicles) which can be coupled while operating in guided mode.
- Taking of curves and maneuverability in manual operation mode similar to those of a bus. [Medium radius of 12 m (39.6 ft) due to the fact that all the wheels are steered.]
- A track which can be built rapidly and economically. The track is reduced to two concrete running treads with a built-in center rail.

This unconventional “dual-mode guided bus[8] has been operated since June 1988 on a 4 kilometers (2.5 mi) former railway line converted to guided bus operation between Jemelle and Rochefort and - with diesel drive on the roads -- extended further to Han-sur-Lesse in south-eastern Belgium. In the meantime there are two new double articulated duo-buses available (instead of the old prototype) connecting on a concrete right-of-way with a center rail the station in Jemelle through difficult terrain with the former station of Rochefort which nowadays houses a cultural center. This line mainly serves tourism (e.g. zoo and caves in Han-sur-Lesse) and was operated -by the manufacturer himself - until 1991 during the summer term.

6.6.2.3 Technology

In contrast to the German solution of mechanical track-guidance described above (guide rails along which buses are vertically led by guide rollers; example Essen) the Belgian manufacturer decided in favor of track-guidance with an iron center rail embedded in the guideway and a guide wheel in the vehicle:

Below the bus floor there is a wheel with two flanges which is moved into the guide trough when entering the special guideway.

The rail also serves for the recycling of current during electric operation. Hence, for current supply one single power transmission line is enough, one pantograph with throat-type bottom part serves for power collection. In addition to this, the bus has a diesel engine for operation on normal roads.

The double articulated duo-buses are 25.3 m (83.5 ft) long and 2.5 m (8.3 ft) wide and offer room for a total of 200 passengers, 55 of which seated. These buses with aluminum body weigh 28.7 short tons (26 metric tons) and are either driven by two electric motors with a total performance of 360 kW or by a diesel engine with 260 kW. The maximum speed is 70 km/h (44 mi/h), the smallest curve radius is 12 m (39.6 ft) for rail and road. The vehicles can be equipped with an automatic or semiautomatic coupling system which also enables traction in case of track-guided operation.

The guideway for guided operation consists of two 440 mm (17.3 in) wide guideway beams and has an axle width of an average 2.06 m (6.8 ft) in the center of which the guiding rail is embedded. The maximum distance between rail axle and interior of the tire is 810 mm (31.9 in) which leaves enough room for a tramway rail, in case also tramway/GLT joint operation is provided for. The guideway may consist of concrete which is cast on the spot or prefabricated concrete sleepers/metal beams. The center rail is a classic railway rail.

The change from the rail system to the road system or vice versa does not necessitate any track installations and can be made at any location. Preferably the change from one system to the other should occur on a straight section.

6.6.2.4 Experience

In 1991 BN stopped regular passenger service on the line between Jemelle and Rochefort in order to make reconstructions which had become necessary on the vehicles (e.g. the concrete guideway cast on the spot in connection with rolling noise of the small guidance wheel did not give rise to driving comfort). However, since that time guided bus operation is continued to be shown on request to expert visitors.

Despite these technical problems the developer invariably sticks to the system, as he is convinced that the GLT system can be an adequate solution for transportation problems everywhere in medium-sized and large cities, where the use of conventional diesel buses does no longer fulfill the requirements of passengers.

The cost of the GLT system, BN declares, is based on two major points:

- The selling price of the vehicle is 30 percent lower than that of a similar LRV (light rail vehicle).
- The infrastructure cost in guided mode is 20 percent lower than an LRT (light rail transit) track.

The biggest saving of the system is to have segregated and guided tracks only at places where it is profitable and necessary to avoid traffic.

The GLT system is an intermediate system between bus and I-RT. Under 1,500 passengers per hour per day, a bus line is more profitable than a GLT line. Above 8,500 passengers per hour per day an IRT system is well justified.

6.6.2.5 Further Planning

At present BN is also working on a low-floor version of GLT. The floor height shall be 370 mm (14.6 in) or 440 mm (17.3 in) respectively above the articulation. They plan to offer a single articulated (GLT 2300) and a double articulated version (GLT 2400). The price for the latter shall be around US $ 1.34 million per bus at an order volume of 25 vehicles (price 1993; exchange rate US $ I - DM 1.58). Apart from Rochefort in Belgium there is no other application so far. However, interest in the GLT system has been shown by several French cities (Lyon, Caen, Tours, Le Mans, and Muihouse) as well as Bristol in Great Britain. The City of Caen, France and BN signed a contract to introduce the GLT system.

6.7 SUMMARY OF EUROPEAN EXPERIENCE

In Europe mechanical track guidance has market advantages in comparison with electronic track guidance. These advantages are due to lower system costs and to the possibility of supplementing available vehicles with mechanical track guidance equipment. On the other hand, with regard to new systems also electronic track guidance has chances of application, as the example of the Channel tunnel shows. Seen from the technological point-of-view mechanical track guidance has proved technically feasible and will more likely experience improvements in details in the short and medium term. In contrast to this, electronic track guidance still has a large potential for development. In order to be able to exploit this potential, a reference plant reliably working over a longer period of time would be required, as it is the case in the Essen application with mechanical track guidance.

6.7.1 Implication for the Development of an American AHS Program

The mechanical and electronic track-guidance systems developed in Europe have proved technically feasible and suitable for operational use.

However, electric track-guidance systems are of the greater interest for an AHS. The mechanical systems display features which make them less suitable for this purpose.

Leaving the track-guidance sections is only possible at special exit and entry points, which have to be driven through at low speed. This means that it is impossible either to overtake and or leave the track-guidance section in the event of a vehicle fault.

If guide curbs are used (German system), all vehicles must have the same width in order to be able to run in the guideway trough. The AHS must be entered at certain specified entry points, which can only be driven through at moderate speed, thereby having a negative effect on the system as a whole.

European experience with electronic guideway systems can be summed up as follows with regard to their relevance to an AHS:

- The principle applied of guide cables with transmission facilities on the route and receivers in the vehicles means that the principal functions for fully automatic operation are available. For some functions (e.g. maintaining a fixed distance from the next vehicle ahead) an additional transmitter on board the vehicle is required.

- The safety philosophy selected of designing all the systems to be mutually redundant and allowing only one safe and stable system in the event of a system breakdown (as a rule a vehicle breakdown) has proven itself and should also be aimed at for an AHS. In the case of an AHS, however, in view on the larger dimensions involved - with regard to space requirements and the number of vehicles, a strategy will have to be developed for resuming service rapidly after a system breakdown.

In Europe, the optimal strategy for introducing a new type of system such as an AHS has proved to be introduction in phases: this procedure means that it is possible to remedy weak points in individual sub-systems before these are integrated into the overall system. The parallel development of individual sub-systems reduces the time required for development.

6.7.2 What Were the Goals of These Systems and Did They Achieve Their Goals?

With the exception of the track-guidance system for the Channel tunnel, all the remaining systems were developed with the aim of reducing costs and increasing the attractiveness of public transportation. This is true of both electronic and mechanical track-guidance. In the medium term, track-guidance technologies were intended to represent an alternative to tramways, which had proved increasingly unprofitable in many smaller towns. A further aim was to use buses on the existing railway infrastructure especially in tunnels. Increased attractiveness was to be ensured by greater punctuality and more exact approaches to stops.

In the Channel tunnel[1] the track-guidance system is used to operate the service tunnel. Service and rescue vehicles are intended to reach any point in the tunnel safely and rapidly using track-guidance, even in the event of smoke hazards.

In the course of developments[1] mechanical track guidance proved to be the more flexible and less expensive variant for use in public transportation. Accordingly, development work concentrated increasingly on this technology and work on electronic track-guidance was discontinued after the corresponding research programs had been concluded. Especially the possibility of simply and cheaply converting existing vehicles to mechanical track-guidance turned out to be a considerable advantage of this system. Thus the main reasons for discontinuing the development of electronic track-guidance were primarily of an economic rather than technical nature.

Mechanical track guidance, on the other hand, was continuously further developed with a view to fulfilling the goals set. In the 1980's, however, in many European cities a trend towards tramways and light rail started, which ran counter to the widespread use of guided buses. Recently, however, it has been possible to observe a trend back to guided buses in some European countries (as a means of providing an improved service compared to conventional buses). The role of the guided bus in European public transportation has thus not yet been clearly defined. To date no reliable data can be given on the success of the practical implementation of the Channel tunnel system, as the tunnel was only opened this year, with restricted operation. So far no serious practice for a disaster situation and/or for an emergency has been documented.

CHAPTER 7: BRINGING IT ALL TOGETHER: FUTURE IMPLICATIONS FOR COMMERCIAL MOTOR CARRIER AND TRANSIT AHS STRATEGIES

This concluding section of the report summarizes the findings involved in the identification of commercial motor vehicle issues as they relate to the constraints of institutions, market segments, fleet size/fleet ownership, and regulation constraints. The unique composition of the commercial motor vehicle market is best described by its own unique Representative System Configuration (RSC) equivalent groupings depicted as 19 distinct AHS Commercial Motor Vehicle Clusters shown in appendix A of this report. By using this more descriptive application to describe this unique transport segment, the best implementable deployment of AHS can more easily be identified.

The results of previous European advanced transit research/deployment/testing has produced many valuable "lessons learned" for the possible U.S. application of AHS. The results of the electronic/mechanical automated bus guidance technology advancements that took place in Sweden, Germany, Italy, Great Britain, and Belgium carried the state-of-the-art to an advanced technical level. This technology experience, coupled with the Dual Mode Transit applications of the United States in the 1 970s, provided a unique confirmation for insertion into the concept of AHS Transit. The concept of this exclusive or shared guideway/right-of-way application may help to satisfy the passenger carrying capacity requirements needed at significantly lower infrastructure costs while adding greater route/service area flexibility to the transit operation. This new Dual Mode AHS Transit concept would extend the passenger capacity of transit bus based Systems into and beyond the service capacity range of the more costly and location restrictive typical light/heavy rail service.

The flexibility of using fully automated line-haul transit buses on limited access right-of-way capacity facilities (i.e., tunnels, bridges, elevated tracks, or narrow available rights-of-way) and also having the full flexibility of local collector bus service at the terminus points is explored in the prototyplcal Dual Mode AHS Transit system between the hypothetical airport and urban centers described in the report.

The multimodal potential for such a facility could be realized by sharing commercial motor vehicle service in the system on a scheduled off-peak or contra-flow basis for automated trucks. Separate specialized truck-only off ramps and distribution clusters could be created to serve the urban/suburban goods movement market segment.

7.1 AHS RESEARCH FOR TRANSPORTATION POLICY IMPLICATIONS FOR COMMERCIAL MOTOR CARRIERS

The results of this initial analysis have a number of implications for future policy efforts intended to develop and promote AHS for the commercial trucking industry. A review of the potential matches between the operating characteristics of the representative motor carrier industry segments and the AHS technologies and services clearly suggests that the applicability of different AHS operations will vary with respect to different segments of the trucking industry. Policy makers must recognize that, with respect to AHS, trucking definitely is not a "one-size-fits-all" industry.

The most obvious ramification of this finding is that the benefits derived from public investment in any particular AHS will be unevenly distributed across the trucking industry. Certain industry segments may benefit greatly, while others obtain little or no advantages. Furthermore, implementation of a broad range of AHS may not necessarily yield benefits to a broad range of industry segments. Indeed, wholesale support of any and all AHS for the motor carrier industry would most likely be counterproductive, diffusing funding and resources rather than focusing them on the AHS that have the potential to benefit the largest segments of the trucking industry.

Consequently, policy makers must be highly selective in the AHS technologies and services they choose to develop. Moreover, those AHS that are developed must be implemented so as to make the costs and benefits equitable. The costs that any particular segment of the trucking industry bears should be proportionate to the benefits that segment will derive. This may mean depending heavily on user fees rather than industry-wide taxes to fund AHS projects. Alternatively, it may mean that the development of AHS for the commercial motor carrier industry is limited to those systems that require minimal infrastructure-based technologies, and instead rely on in-vehicle devices. That way, individual trucking firms could decide whether or not they wished to participate in a given AHS, and would bear the costs for only those technologies from which they would derive direct benefits.

7.2 CONTINUING RESEARCH PROGRAM FOR COMMERCIAL MOTOR CARRIERS

The results of this study suggest several areas in which additional research would be beneficial. First, the current "state-of-the-art" in AHS must be documented. Although the various AHS scenarios are based on current technologies (e.g., distance sensors[1] brake and throttle controls), significant challenges remain in terms of integrating these technologies to form systems that are user-friendly, reliable, and fail-safe. A study that evaluates the current level of development of each AHS cluster, as well as likely near-term advances, would help to determine how soon and at what scale each AHS variation could be implemented. This is particularly important with respect to the ability of each variation to accommodate commercial motor carrier traffic. Further efforts to refine the dusters themselves also are recommended.

Additional research would be useful in determining the actual costs to motor carriers of various AHS at different levels (e.g., geographic scope) of implementation. In particular, research is needed to determine how the various AHS compare in terms of both their infrastructure costs (which likely would be widely distributed) as well as their per vehicle costs (which individual trucking firms would bear). Not only would such research help to determine the acceptability of different systems to the trucking industry, it might also suggest ways of reconfiguring certain AHS to make their costs more equitable.

Research also is needed to investigate the specific technical and non-technical, or "institutional," Obstacles to the widespread adoption of AHS by the commercial motor carrier industry. Specifically, there is a need to differentiate between AHS that are impractical for trucks because of physical constraints, which possibly could be overcome through technological advances; and AHS that are likely to be rejected because of concerns over driver complacency and incompatibility with the nature of commercial vehicle operations. The development of strategies to overcome obstacles to AHS implementation is possible only after the impediments are identified and analyzed.

Finally, more research is required to evaluate the operational characteristics of the motor carrier industry. This study has presented a methodology for studying trucking operations, and has analyzed some representative examples, but the trucking industry is large and complex; several dozen key market segments exist. All of these segments need to be understood in order to make a complete appraisal of the applicability of AHS to the industry.

7.3 TRANSIT INDUSTRY OBSERVATIONS AND CONCLUSIONS

Like the commercial motor carrier industry, the transit industry in the U.S. is impacted by numerous unique opportunities and constraints with regard to possible AHS implementation. Although many of these constraints are technical in nature, others are institutional or societal. The following section reviews some of the most critical observations.

7.3.1 Observations

Observation # 1. The transit industry has been working for decades on the task of providing high quality service at reasonable cost. Innovative light-rail strategies have been developed to attain shared use of right-of-way on key segments where capital costs for total grade separation would have been excessive. Still, the cost of building and maintaining many miles of facilities has stifled the development of higher quality transit services across the country. If major high-speed segments of the AHS network that guarantee high performance operations could be provided, and the cost of those segments borne by resources beyond the transit sector, significant cost savings could result compared with presently available technology.

Observation # 2. The transit industry will not turn to the automated AHS for reasons of line capacity. The potential scale of capacity stemming from existing bus technology (as expressed both in the theoretical literature and in practice) far exceeds what most American cities will be able to utilize. The transit industry may, on the other hand, turn to AHS technology for a series of issues involving the management and control of large numbers of vehicles operating in extremely demanding conditions, such as the accessing of complex, multi-platform stations. AHS Transit should be seen as a family of key improvements that deal as much with reliability as with capacity; in turn, those reliability improvements may generate valuable dividends in terms of tighter, narrower geometric requirements.

Observation #3. Pathways to AHS: Our team has examined a variety. of strategies for the development of AHS Transit, ranging from ignoring it to redesigning the entire AHS work program to allow AHS Transit to be developed to the exclusion of private vehicles. Based on this policy review, we are now focusing on the following concept for review by USDA: allow AHS Transit to be developed on a parallel path, while, at the same time, ensuring that its technology development program be a subset of the larger AHS research effort. Our examination of possible use of AHS Transit in our "Prototypical Intermodal Corridor" suggests that AHS Transit may play its most important role off the automated highway segment, and in such unique configurations as the on-line one-way loop, or in the automated dispatching through series of multi-slot off-line stations.

7.3.2 AHS Transit Potential Overview

The use of "train-like" platooning of many vans and buses in the entering and exiting of transit stations at 40 kilometers per hour (25 mi/h) may pose significantly different technological challenges from the issues of vehicles entering and exiting from platoons at 97 kilometers per hour (60 *mi/h).* Similarly, the challenge of increasing throughput capacity through the Express Bus Lane of the Lincoln tunnel may largely lie in the problem of reliably sending more buses through a complex multi-platform system within the bus terminal at the end of the lane.

These issues -- the use of AHS technology in trip segments other than the automated highway segment -- may seem somewhat peripheral to the primary research effort of the AHS program. it is important that a research management structure be established that deals with those transit-oriented issues that need to be resolved in order for AHS Transit to gain full benefit of the automated highway systems being developed. At the same time, it is critical that the technological components designed to deal with these transit-oriented issues be developed to integrate back into the larger AHS system technology. Thus, we are proposing a parallel development effort for AHS Transit, which remains a subset of the larger AHS research and development program.

Dual-Mode Transit may not be the best choice by itself, but it can be an effective catalyst or component for an efficient multimodal transportation system. In the examination of a Prototypical Intermodal Corridor, a staged process of implementing an ultimate system that could provide high quality, truly "seamless" transportation services under highly demanding conditions was explored. The long-term advantages of such a system were clear; what remains for further analysis is how much advantage is gained by AHS Transit over the interim phases of high investment in HOV/busway systems, which offer exceptional levels of benefit.

AHS Transit must be analyzed in terms of its role in a system where ultimately both benefits and costs are distributed over a wide cross-section of transportation users. A national research program must now be designed that at once acknowledges the uniqueness of the AHS Transit potential, while remaining true to the long term need to keep it apart of larger system.

7.4 SUMMARY OF EUROPEAN AUTOMATED TRANSIT EXPERIENCE

In Europe mechanical track guidance has market advantages in comparison with electronic track guidance. These advantages are due to lower system costs and to the possibility of supplementing available vehicles with mechanical track guidance equipment. On the other hand, with regard to new systems$_1$ electronic track guidance has chances of application, as the example of the Channel tunnel shows. Seen from the technological point-of-view, mechanical track guidance has proved technically feasible and will more likely experience improvements in details in the short- and medium-term. In contrast to this, electronic track guidance still has a large potential for development. In order to be able to exploit this potential, a reference plant reliably working over a longer period of time would be required, as it is the case in the Essen application with mechanical track guidance.

7.4.1 implications to the U.S. AHS Program

The mechanical and electronic track-guidance systems developed in Europe have proved technically feasible and suitable for operational use. However, electronic track-guidance systems are of the greater interest for an AHS. The mechanical systems display features which make them less suitable for this purpose. Leaving the track-guidance sections is only possible at special exit and entry points, which have to be driven through at low speed. This means that it is impossible either to overtake and or leave the track-guidance section in the event of a vehicle fault. If guide curbs are used (German system), all vehicles must have the same width in order to be able to run in the guideway trough. The AHS at certain specified entry points, which can only be driven through at moderate speed, thereby having a negative effect on the system as a whole.

European experience with electronic guideway systems can be summed up as follows with regard to their relevance to an AHS:

- The principle applied of guide cables with transmission facilities on the ~ and receivers in the vehicles means that the principal functions for fully automatic operation are available. For some functions (e.g. maintaining a fixed distance from the next vehicle ahead) an additional transmitter on board the vehicle is required.

- The safety philosophy selected of designing all the systems to be mutually redundant and allowing only one safe and stable system in the event of a system breakdown (as a rule a vehicle breakdown) has proven itself and should also be aimed at for an AHS. In the case of an AHS, however, in view of the larger dimensions involved with regard to space requirements and the number of vehicle$_{s,}$ a strategy will have to be developed for resuming service rapidly after a system breakdown.

In Europe$_1$ The optimal strategy for introducing a new type of system such as an AHS has proved to be introduction in phases: this procedure means that it is possible to remedy weak points in individual sub-systems before these are integrated into the overall system. The parallel development of individual sub-systems reduces the time required for development.

7.4.2 Were the European System Goals Achieved?

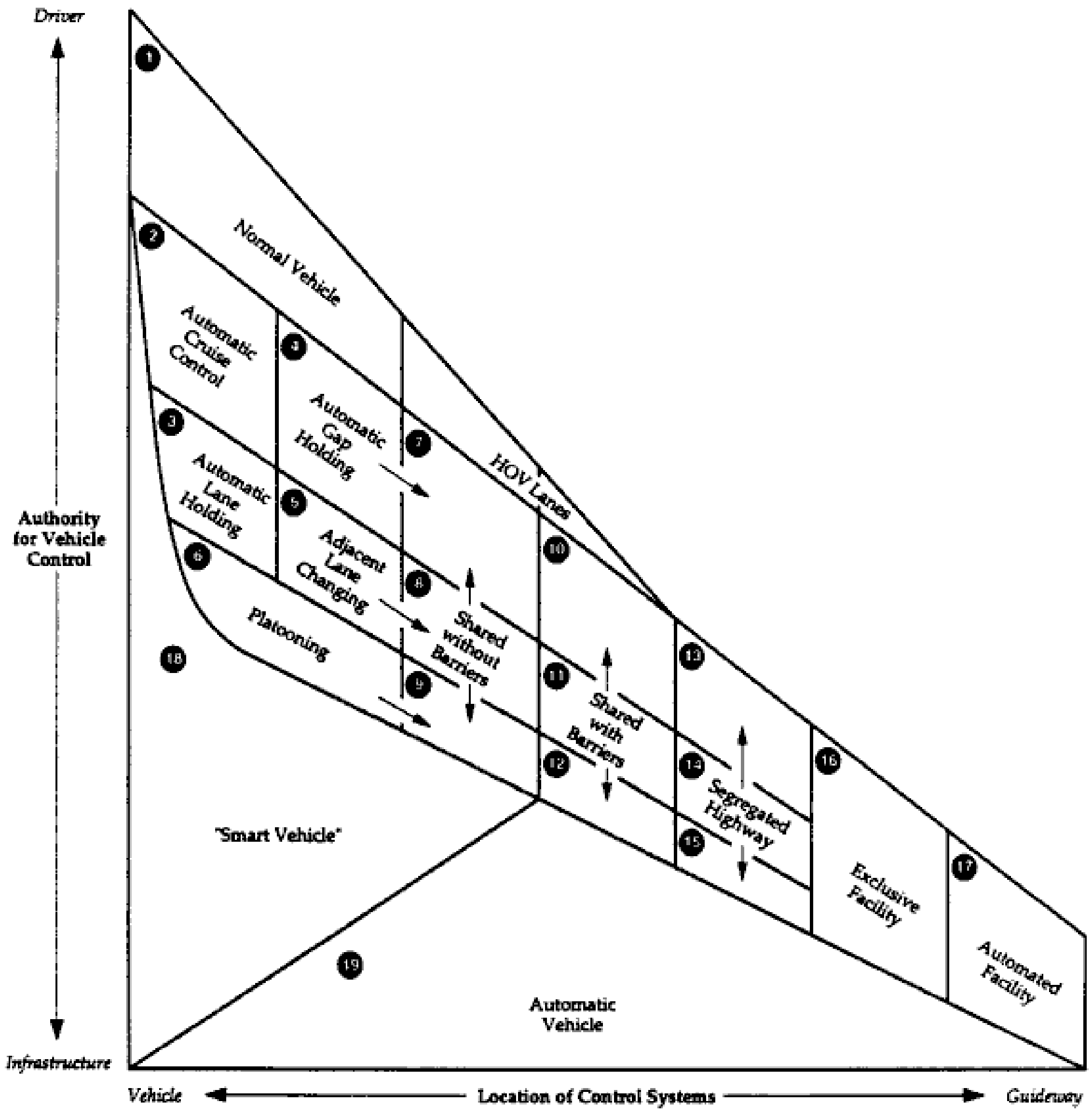
With the exception of the track-guidance system for the English Channel tunnel, all the remaining systems were developed with the aim of reducing costs and increasing the attractiveness of public transportation. This is true of both electronic and mechanical track-guidance. In the medium term, track-guidance technologies were intended to represent an alternative to tramways, which had proved increasingly unprofitable in many smaller towns. A further aim was to use buses on the existing railway infrastructure, especially in tunnels. Increased attractiveness was to be ensured by greater punctuality and more exact approaches to stops.

In the Channel tunnel[1] the track-guidance system is used to operate the service tunnel. Service and rescue vehicles are intended to reach any point in the tunnel safely and rapidly using track-guidance, even in the event of smoke hazards.

In the course of developments, mechanical track guidance proved to be the more flexible and less expensive variant for use in public transportation. Accordingly, development work concentrated increasingly on this technology and work on electronic track-guidance was discontinued after the corresponding research programs had been concluded. Especially the possibility of simply and cheaply converting existing vehicles to electronic track-guidance turned out to be a considerable advantage of this system. Thus the main reasons for discontinuing the development of electronic track-guidance were primarily of an economic rather than technical nature.

Mechanical track guidance, on the other hand, was continuously further developed with a view to fulfilling the goals set In the 1980s, however, in many European cities a trend towards tramways and light rail started, which ran counter to the widespread use of guided buses. Recently, however, it has been possible to observe a trend back to guided buses in some European countries (as a means of providing an improved service compared to conventional buses). The role of the guided bus in European public transportation has thus not yet been dearly defined. To date no reliable data can be given on the success of the practical implementation of the Channel tunnel system, as the tunnel was only opened this year, with restricted operation. So far no serious practice for a disaster situation and/or for an emergency has been documented.

APPENDIX A: DETAILED ASH CLUSTER MAP CATEGORY DESCRIPTIONS



Appendix A. AHS Cluster Map

AHS Cluster Map

Cluster 1~ Conventional Vehicle

A. Functional Description of Technologies

- This is the current driving situation.
- Current technologies; potential for use of navigational aids (ITS, GPS, etc.).

B. Distinguishing Variables

- Authority for vehicle control (driver vs. infrastructure):
  Driver has control authority (limited only by speed restrictions).
- Location of control systems (vehicle vs. guideway): The vehicle controls all of its actions (limited only by existing roadway).
- Cost: Fuel and vehicle maintenance costs are the highest per mile traveled of any cluster. Road maintenance and safety costs are high.
- Right-of-way: Uses existing right-of-way.

C. Positive Factors

- Complete flexibility.

D. Negative Factors

- Trucks must deal with driving patterns of passenger vehicles
- Inefficient and unpredictable delays can hamper time-sensitive business. To compensate, trucks may choose to operate on alternate routes or at off-hours to increase efficiency.
- Incremental increases in safety are difficult to achieve.

AHS Cluster Map

Cluster 2. Automatic Cruise Control (ACC)

A. Functional Description/Technologies

- Semi-automatic throttle control in current driving situation. Activation is determined by driver.
- Incorporates a speed sensor and throttle actuator.

B. Distinguishing Variables

- Authority for vehicle control (driver vs. infrastructure): Driver maintains most control; infrastructure has slight control authority over vehicle (speed).
- Location of control systems (vehicle vs. guideway): Vehicle essentially maintains control over its actions (see Cluster 1).
- Cost: Cost of basic ACC is very low. The per vehicle fuel and maintenance costs of Cluster 1 still apply (as they will to varying degrees in every cluster).
- Right-of-way: Uses existing right-of-way.

C. Positive Factors

- Attempts to create a steadier, and therefore safer, traffic flow.
- Potentially provides greater independence than Cluster 1~ if there are no infrastructure restrictions (i.e., when on '.open road").
- Helps to reduce some speed fluctuations, which may reduce fuel use somewhat.
- ACC may help limit speed and speeding violations.

D. Negative Factors

- Even though cost is low$_1$ ACC is not available for large commercial vehicles and is unlikely to be in the future.
- Loaded trucks generally lack the torque: weight ratio to use ACO without specific advance information about changes in road grade.
- Truck drivers would be able to rely on ACC only for long distance, flat terrain applications because ACC lacks the ability to predict terrain. Therefore, drivers would still have to disengage ACC and downshift on hills. This problem is common to nearly every cluster.

AHS Cluster Map
Cluster 3. Automated Lane Holding (ALH)

A. Functional Description[Technologies

- Semi-automatic steering control in current driving situation. Activation is determined by driver.
- Vehicle senses displacement from lane centerline and adjusts steering control. Can be GPS/radio link, magnetic nail homing, embedded electric wire homing, magnetic/reflective paint line tracking, etc. or even complex radar and vision sensors (precursor technologies for independent "smart vehicles.")

B. Distinguishing Variables

- Authority for vehicle control (driver vs. infrastructure): Driver is responsible for over half of the control.
- Location of control systems (vehicle vs. guideway): Aside from better lane indicators placed in the roadway, most actions are controlled by the vehicle.
- Cost: Sensor/actuator costs would be over $1 ,000 per vehicle. Depending on the technology used (paint, nails, wires, etc.), infrastructure costs could be equal to highway resurfacing costs.
- Right-of-way: Uses existing right-of-way.

C. Positive Factors

- Enables safer operation in high-speed environment. Trucks, being substantially wider than other vehicles, may benefit initially from automated steering at higher highway speeds.
- If regular lane changing is not required, as in rural or uncontested situations, ALH may increase safety significantly.
- Driver can spend more time monitoring front and rear separation.
- Safety increases might reduce insurance costs.

D. Negative Factors

- The driver is removed from continual control over the vehicle's primary control device (the steering wheel), thereby abdicating responsibility for a critical part of highway driving. This substantial dependence on the infrastructure, with its potential for subsequent unattentiveness, may lead to complacency and safety lapses in a long-haul situation, at the resumption of a regular lane changing situation upon exiting an AHS, or in an emergency situation.

AHS Cluster Map

Cluster 4. Automated Gap Control (AGC)

A. Functional Description/Technology

- Automatic longitudinal spacing control; automatic throttle and braking.
- An electromagnetic (radar, microwave, etc.) distance sensor commands brake and throttle actuators to maintain spacing. Some versions combine data links to indicate the best following distance for the type of vehicle ahead.

B. Distinguishing Variables

- Authority for vehicle control (driver vs. infrastructure): Driver is responsible *for* over half of control authority.
- Location of control systems (vehicle vs. guideway): Vehicle becomes automatically dependent on the actions of the vehicle ahead, so the guideway takes some control of operations from the vehicle.
- Cost: Cost is limited to sensors and brake/throttle actuators; similar to per vehicle coots of Cluster 3.
- Right-of-way: Uses existing right-of-way.

C. Positive Factors

- By maintaining safe headways, enables more regular use of automated speed control than in Cluster 2.
- Has potential to reduce following distances dramatically, thereby increasing highway capacity.
- Safety benefits to trucks are similar to those of Cluster 3: driver can concentrate on steering and lane position, reducing some accident potential and increasing safety; insurance costs may be reduced.
- Technologies may be more readily accepted by motor carriers because there are no roadway improvement costs associated with AGC.

D. Negative Factors

- Requires significantly less monitoring than ACC (Cluster 2), yet removes driver from a large part of driving situation; complacency may be an issue here.
- Driver becomes more dependent on actions of surrounding vehicles, and in some cases through the automation of both throttle and brake can be directly regulated by infrastructure speed restrictions. The automation of speed control also offers the potential (and perhaps incentive) to control vehicle speed directly with the help of Advanced Traveler Information Systems and traffic management programs through the infrastructure.
- Increased traffic density make lane changing and entry/exit harder for longer, less maneuverable trucks. Entry facilities will have to be longer to

allow for merging with a tight traffic stream.

- There may be substantial safety gains in less congested, long-distance hauling$_1$ but the limited nature of these benefits may not justify any cost outlays by motor carriers.

AHS Cluster Map

Cluster 5. AdJacent Lane Changing (ALC)

A. Functional Description/Technology

- Combines ALH (Cluster 3) and AGC (Cluster 4) to provide automated access to adjacent lanes. Activation is controlled by driver.
- Sensors are similar to AGC sensors, but provide additional closure information on vehicles ahead and behind in adjacent lanes. Either the driver is informed when merging is safe, or ALC performs the merge.

B. Distinguishing Variables

- Authority for vehicle control (driver vs. infrastructure): The infrastructure now commands about half of the control. Decisions to merge are in the drivers hands, although the actual merge is done by the infrastructure.
- Location of control systems (vehicle vs. guideway): The guideway still controls some actions as in Cluster 4.
- Cost: Cost now includes multiple advanced versions of sensors for AGC. ALH is most likely included implying roadway improvement requirements.
- Right-of-way: Uses existing right-of-way.

C. Positive Factors

- Enables safer lane changes and entries/exits.
- Maintains tight headways throughout.
- Potential to further increase capacity over Cluster 4 while further improving safety.
- Trucks would have an automated ability to merge with automobile traffic.

D. Negative Factors

- Driver impacts: To improve safety by automating lane changes and merges, it is advantageous to provide greater infrastructure control of speeds, removing even more driver independence. Complacency is now a greater concern than in Cluster 3.
- Unless most vehicles become ALC-equipped or at least AHS-capable, ALC drivers will still need to maintain a high degree of awareness.
- When trucks merge into adjacent lanes, they alter the required headways for preceding and following vehicles to accommodate for trucks' slower acceleration.

AHS Cluster Map
Cluster 6. PlatoonIng

A. Functional Description/Technologies

- Utilizes at least AGC and inter-vehicle communication to group moving vehicles with similar travel patterns together tightly into a single unit.
- Combines AGC ability of Cluster 4 with a data communications device and drivers interface. ALC would most likely be included because the dose headways of platooning give drivers little notice of lane changes. The driver would determine the destination while the data link determines vehicle eligibility and requirements.

B. Distinguishing Variables

- Authority for vehicle control (driver vs. infrastructure): Control strategy is split fairly evenly between the driver and the infrastructure (driver selects participation and destination, but infrastructure controls travel).
- Location of control systems (vehicle vs. guideway): The vehicle directs three-fourths of the actions (vehicle maintains AGC and ALC if present, but speed/route plans come from other vehicles or roadside traffic management via data links).
- Cost: Cost includes sensors, actuators, and communications links. Therefore, per vehicle costs combine a refinement of basic AGC (and possibly ALC) with data communication, display, and processing ability.
- Right-of-way: Uses existing right-of-way.

C. Positive Factors

- Has ability to almost triple highway capacities if platoon participation is high.
- Trucks would be able to travel in tight clusters with other trucks that share similar performance characteristics without excessive maneuvering through other traffic.
- Carriers would benefit from increased safety.

D. Negative Factors

- Driver becomes responsible only for steering (if ALH is not present) and entry/exit decisions. Independence is reduced to merely monitoring safety and routing. The driver in a platoon can only go where the platoon goes, but this restriction on independence is necessary to achieve better travel benefits.
- The performance characteristics of trucks would exclude them from most mixed platoons (i.e., those including both trucks and automobiles), and an "all-truck" platoon would be a significant physical obstacle for other vehicle. Platoons with varied vehicle classes are feasible, but they would

lack the capacity of all-car platoons and would require more sophisticated technology to accommodate safety concerns.

AHS Cluster Map

Cluster 7. Automated Gap Control/Shared Right-of-Way/No Barriers

A. Functional Description(Technologies

- AGC vehicles operating in an adjacent AHS lane (possibly separated by a merge lane). Similar to an HOV lane.
- Technology is the same as for AGC in Cluster 4.

B. Distinguishing Variables

- Authority for vehicle control (driver vs. infrastructure): Control is split fairly evenly between the driver and the infrastructure.
- Location of control Systems (vehicle vs. guideway): Approximately one third of the vehicle's actions are controlled by the guideway.
- Cost: Technology costs are limited to gap sensors (see Cluster 4); however, a dedicated highway lane must be separated or built to accommodate the AHS. This can be costly for four-lane highways, because normal traffic needs at least two lanes to p55. Cost is low if there are existing HOV lanes.
- Right-of-way: Modifications required.

C. Positive Factors

- Provides smoother, faster, and safer operations to AGC-equipped vehicles.
- Separate lane of AHS vehicles has higher capacity and more throughput for time savings. With all traffic operating under AGC, fuel consumption decreases due to reduced braking and acceleration; brake wear also is reduced.
- Trucks would benefit from safer Operations[1] slightly reduced fuel costs, and slightly reduced maintenance costs.
- Trucks could have a more stable operating environment, especially at rush hours.

D. Negative Factors

- Trucks would face the same acceleration limitations as in Cluster 4. On hilly terrain, trucks would most likely be excluded from participation.
- Driver complacency may be a problem when trucks exit AHS lanes and merge with other traffic.
- To participate, truck operators would not experience significant equipment costs per vehicle, but guideway construction costs would have to be absorbed. There is also the possibility that trucks would be excluded from a single-lane AHS to provide the benefit of increased capacity to the largest number of vehicles (i.e., automobiles).

AHS Cluster Map

Cluster 8. AdJacent Lane Changing/Shared Right-of-Way/No Barriers

A. Functional Description/Technologies

- Same infrastructure requirements as Cluster 7 plus an automated merge lane and/or a second AHS lane. Vehicles have ALC ability.
- Combines sensors of AGC and ALC described in Clusters 4 and 5.

B. Distinguishing Variables

- Authority for vehicle control (driver vs. infrastructure): Driver and infrastructure share control responsibility.
- Location of control systems (vehicle vs. guideway): One-third of the vehicle's actions are controlled by the guideway.
- Cost: in addition to the basic technological costs established with ALC in Cluster 5, at least two lanes must be AHS-capable.
- Right-of-way: Modifications required.

C. Positive Factors

- Further increases lane capacity by having automated merges in at least one AHS lane.
- Provides a more efficient facility with at least one main automated through lane.
- Operational safety should improve for motor carriers, helping to reduce insurance costs.
- Trucks will be more readily accepted by all users if it is easier for other vehicles to pass them.

D. Negative Factors

- Driver impacts: After easily merging onto the AHS-only entry lane, the driver is automatically moved into the AHS system. The driver's independence is limited to entry/exit decision making. Complacency, due to a lack of independence, would be of still greater concern. The implementation of routing control by the infrastructure is likely in this cluster.
- Trucks are limited by their slower accelerations and larger size.
- in any attempt to increase the number of AHS lanes without excessive or prohibitive highway expansion, the tendency would be to reduce lane widths (to as few as eight feet). This often would preclude trucks from using such lanes.

AHS Cluster Map
Cluster 9. Platooning/Shared Right-of-Way/No Barriers

A. Functional Description/Technologies

- Similar infrastructure needs to Cluster 8 with vehicles able to platoon.
- Same technology as for platooning (Cluster 6).

B. Distinguishing Variables

- Authority for vehicle control (driver vs. infrastructure): The infrastructure now has two thirds of control authority.
- Location of control systems (vehicle vs. guideway): The vehicle still controls two-thirds of its actions.
- Cost: Costs would be as in Cluster 7 plus the costs of platooning in Cluster 6. The cost of equipping trucks with appropriate actuators, sensors, and data devices would be significant. Infrastructure costs would still be relatively low. The per vehicle costs for carriers would be worthwhile only if facilities provided sufficient accommodation for trucks (additional lanes).
- Right-of-way: Modifications required.

C. Positive Factors

- Lane capacity is again increased. In addition, merge lanes would carry more capacity as vehicles queued to join platoons.
- The number of AHS lanes would probably increase, preferably to at least two full-time and one merge lane. Throughput would increase markedly.
- Assuming enough lanes were provided to accommodate platooning, the inclusion of truck operations in a dedicated lane would be more acceptable.

D. Negative Factors

- Unless there are multiple AHS through lanes, platoons with heavy trucks again may be opposed by other vehicles as in Cluster 6. A group of queuing trucks would be a large obstacle for other vehicles, regardless of the number of AHS lanes. The automobile-driving public would not want truck platoons in an AHS unless there were lanes dedicated to trucks.
- Forming platoons for trucks would only be beneficial in long-haul applications. However, on long-distance stretches$_{1}$ it is unlikely that enough AHS lanes would be designated or constructed to accommodate trucks platoons (this does not preclude, however, truck platoons in normal lanes; i.e., combining Cluster 6 with Cluster 9). Cover short distances, the time involved to form platoons on even a well-automated facility could be incompatible with truck routing needs.

AHS Cluster Map

Cluster 10. Automated Gap Control/Shared Right-of-Way/With Barriers

A. Functional Description(Technologies

- AGC in an adjacent lane separated by barriers. Intermittent entry/exit ramps/lanes are provided.
- Technology is the same as in Cluster 4.

B. Distinguishing Variables

- Authority for vehicle control (driver vs. infrastructure): The driver and the infrastructure share responsibility for the control strategy about equally.
- Location of control Systems (vehicle vs. guideway): Control systems are split fairly evenly between the vehicle and its guideway.
- Cost: Sensor costs are the same as those for AGC (see Cluster 4), but the required physical infrastructure investment is increased over Cluster 7. In addition to the cost of providing barriers, merge lanes or entry/exit ramps must be provided for limited access to the AHS lane.
- Right-of-way: Modifications required.

C. Positive Factors

- Separation from non-AHS traffic greatly enhances safety and prevents intrusions. Therefore, higher speeds are possible, providing even greater capacity.
- Safety and efficiency benefits to motor carriers are more significant.
- Trucks would be part of a safe and stable flow where sudden accelerations would not be present because merging from adjacent lanes would be controlled.

D. Negative Factors

- Trucks would have a sizeable impact on guideway design by requiring merge lanes/ramps to provide adequate room for the relatively poorer performing trucks to access the AHS lane(s) safely. Also, short-haul and long-haul operations may suffer from the inadequacies of platoons as in Cluster 9.
- Trucks' performance limitations would constrain the entire System if there were only one barriered AHS lane.
- Because infrastructure costs are significant, trucks would have to be adequately accommodated in order for operators to support this cluster. Even so, the long-/short-haul considerations will come into play (as in Cluster 9).

AHS Cluster Map

Cluster 11. Adjacent Lane Changing/Shared RIght-of-Way With Barriers

A. Functional Description/Technologies

- Same barriered AHS lanes as in Cluster 10 with modified merge ramps/lanes and possibly extra dedicated AHS lanes. Vehicles utilize ALC.
- Same ALC technology as in Cluster 8.

B. Distinguishing Variables

- Authority for vehicle control (driver vs. infrastructure): The infrastructure is responsible for more than half of the control.
- Location of control systems (vehicle vs. guideway): Actions are restrained evenly by both the vehicle and its guideway.
- Cost: Cost is the same as for Cluster 10 with the addition of the costs for ALC as in Cluster 8. Therefore, per vehicle costs are about twice those of Cluster 10, and infrastructure costs rise slightly as in Cluster 8 with the addition of ALC.
- Right-of-way: Modification required.

C. Positive Factors

- Essentially provides a separate dedicated AHS facility with high throughput and no incursion threat (it is assumed that at least one lane will be dedicated to through traffic).
- With automated merges into the through lane(s), traffic can be more tightly spaced with little or no slowing down. Therefore, lane capacity is very high.
- Further reduction in congestion.

D. Negative Factors

- Whereas efficient implementation of technology might be able to decrease merge ramp/lane lengths for automobiles with longitudinal and lateral control, the greater size and poorer performance of trucks, combined with the more tightly packed traffic on the through lane(s), might require longer merge ramps/lanes than those for just longitudinal control (Cluster 10).
- Truck widths might be incompatible with the facility when there is only room for small AHS lanes (see Clusters 8 and 10).
- Without significant infrastructure expansion, there will not be room to accommodate trucks effectively into this duster. Carriers will not want to bear any costs of implementing a system in which they are unable to participate.
- Multiple AHS lanes will allow for significant congestion improvements, but the space currently available for such expansion demands smaller car-like

lane widths that are unsafe for trucks. Just one AHS lane capable of accommodating trucks will not provide sufficient lane capacity or throughput due to merges.

AHS Cluster Map

Cluster 12. PlatoonIng/Shared Right-of-Way/With Barriers

A. Functional Description/Technologies

- Utilizes barriers like those of Clusters 10 and 11. However, the need to form platoons would require either a queue lane or longer merge facilities.
- Same technology as with platooning (Cluster 6) with the probable inclusion of ALC.

B. Distinguishing Variables

- Authority for vehicle control (driver vs. infrastructure): The infrastructure now is responsible for two-thirds of control.
- Location of control Systems (vehicle vs. guideway): Actions are restrained evenly by both the vehicle and its guideway.
- Cost: In addition to the higher sensor costs required for platooning (Cluster 6), platoon formation would require a dedicated AHS or merge lane (not just ramps), making this cluster possibly more expensive than Clusters 10 and 11.
- Right-of-way: Modifications required.

C. Positive Factors

- Platooning significantly increases capacity. Additionally, the merge/queue lane would carry still more vehicles.

D. Negative Factors

- Truck performance and size again would hinder platoon formation. The combined effect of automated platoons and physical lane barriers could encourage greater driver complacency.

AHS Cluster Map

Cluster 13. Automated Gap Control/Segregated Right-of-Way

A. Functional Description/Technologies

- A very limited access, AHS-only highway, segregated from the adjacent or nearby conventional highway. Access is only at high capacity, unobtrusive entries/exits. Vehicles are equipped with AGC.
- Utilizes AGC technology (see Cluster 4).

B. Distinguishing Variables

- Authority for vehicle control (driver vs. infrastructure): The infrastructure takes responsibility for more than half of the control.
- Location of control Systems (vehicle vs. guideway): Two-thirds of the vehicle's actions are controlled by the guideway.
- Cost: Sensor costs are similar to Cluster 4, but this cluster also requires the construction of entire new highways or the complete taking of existing facilities. Social costs become significantly higher.
- Right-of-way: New right-of-way required.

C. Positive Factors

- The facility would serve only AHS vehicles, enabling consistent high capacity and consistent, safe headways.
- In an infrastructure similar to today's highways, trucks would be able to operate more safely with even lower fuel and maintenance costs than mere AGC (see Cluster 4) because all vehicles would have AGC.
- The high throughput of this cluster might generate sufficient incentive for motor carriers to support the high national development costs.

D. Negative Factors

- Poor truck performance would affect headways for other vehicles. Complacency developed after long-distance travel could affect driver performance when returning to conventional roadways.
- In a heavily utilized mixed car and truck system, trucks will have a difficult time changing lanes and entering/exitlng.
- Under rush hour conditions$_1$ trucks will not only be an impediment to other vehicles, but will be unable to maneuver out of a lane easily (without ALC). With only AGC, other drivers would have no incentive to permit gaps for trucks to maneuver.
- Unless accommodations can be made for large trucks, carriers will not support a system in which they would not be able to participate.

AHS Cluster Map

Cluster 14. Automated Lane Changing/Segregated Right-of-Way

A. Functional Description/Technologies

- same segregated layout as for Cluster 13 with vehicles operating under ALC.
- Same ALC technology as in Cluster 5.

B. Distinguishing Variables

- Authority for vehicle control (driver vs. infrastructure): The infrastructure is responsible for two-thirds of control authority.
- Location of control systems (vehicle vs. guideway): Two-thirds of vehicle actions are controlled by the guideway.
- Cost: Overall construction costs are similar to those of Cluster 13 with the addition of sensors for ALC. New facilities possibly may be smaller (and therefore, compatible with existing right-of-ways) due to decreased lane width under ALH.
- Right-of-way: New right-of-way[1] in most cases.

C. Positive Factors

- Safety and capacity are further increased. Entry/exit areas can be smaller yet hold greater capacity.
- ALC enables trucks to fit into the system more effectively.
- Carriers benefit from easier and subsequently more efficient operations with less potential driver error.

D. Negative Factors

- Driver impacts: As described in Cluster 3, ALC may lead to complacency.
- Trucks might be excluded from many lanes or entire facilities in this cluster as lane widths are reduced to provide greater capacity. Under this scenario, trucks would be relegated to special wide lanes, forcing them to be restrained by other (possibly slower) trucks.
- Without a separate truck facility, even trucks accessing truck-only lanes would still have to pass through other vehicle lanes.
- Development of this cluster will not be supported by carriers if it does not accommodate standard truck widths and performance characteristics.

AHS Cluster Map

Cluster 15. PlatoonIng/Segregated RIght-of-Way

A. Functional Description/Technologies

- same layout as Clusters 13 and 14 with the addition of platooning and possibly ALC.
- Same AGC technology of Cluster 14 with the communications links for platooning (see Cluster 6).

B. Distinguishing Variables

- Authority for vehicle control (driver vs. infrastructure): The driver now is responsible for less than 25 percent of vehicle control.
- Location of control systems (vehicle vs. guideway): Two-thirds of vehicle actions are controlled by the guideway.
- Cost: Same costs as for Cluster 14 with the addition of inter-vehicle communications for platooning.
- Right-of-way: New right-of-way required.

C Positive Factors

- Increases capacity further.
- Enables maximum capacity for a given roadway without the infrastructure having absolute control over the participating vehicles.
- Carriers benefit from easier and subsequently more efficient operations with less potential driver error.

D. Negative Factors

- Driver impacts: The driver is limited only to platoon participation decisions; platoon formation and entry/exit are easily automated with ALC. With so many vehicles tightly packed on this AHS, vehicles must respond to infrastructure controls to maintain safety.
- On such a multi-lane dedicated facility, all-truck platoons would not be as significant an impediment as they were under previous scenarios, but the trucks themselves would have to deal with each others' performance disparities. But with ALC_1 trucks may again be limited by their width (see Cluster 14).
- Development of this cluster will not be supported by carriers if it does not accommodate standard truck widths and performance.

AHS Cluster Map
Cluster 16. Exclusive Facility /Private Vehicles

A. Functional Description/Technologies

- A completely separate and exclusive facility where all participating vehicles are directly controlled by the infrastructure.
- Technologies vary significantly, but generally utilize advanced forms of AGC, ALC, and platooning.

B. Distinguishing Variables

- Authority for vehicle control (driver vs. infrastructure): The infrastructure has at least three-quarters of control authority.
- Location of control systems (vehicle vs. guideway): The guideway now restricts at least three-quarters of the vehicle's actions.
- Cost: In addition to the significant cost of building or renovating an exclusive faculty (see Clusters 13-15), the infrastructure's technological costs would be substantial, as every vehicle would have to be accurately detected and manipulated. Motor carrier per vehicle cost may be low.
- Right-of-way: New or dedicated right-of-way required.

C. Positive Factors

- All vehicles are controlled to prevent any slow downs. Capacity can approach an absolute maximum.
- Operators may be enticed by an efficient, foolproof transportation system. Distinct separation from normal driving may eliminate the problem of a false sense of complacency when returning to conventional roadways.

D. Negative Factors

- Driver impacts: Driver is responsible only for indicating when to enter/exit.
- with enough technological development, the performance restrictions of trucks could be better mitigated by a fully automated facility. However, accommodating truck widths would be contrary to attempts to increase capacity for a mixed truck/automobile facility (see Cluster 14).

AHS Cluster Map

Cluster 17. Automated facility/provided Vehicles

A. Functional Description/Technologies

- The infrastructure provides the vehicles or the “pallets” on which to park vehicles. All travel is then entirely automated.
- The provided vehicles or pallets use the same technologies as an exclusive facility (see Cluster 16) but with greater reliability and control. There is no need to verify equipment reliability at check-in.

B. Distinguishing Variables

- Authority for vehicle control (driver vs. infrastructure): The infrastructure holds the vast majority of control responsibility.
- Location of control systems (vehicle vs. guideway): Actions are controlled almost entirely by the guideway.
- Cost: Overall social costs are radically higher than other scenarios (though there may be no private vehicle costs at all). The responsibility for moving vehicles now lies with the infrastructure. At the least, the roadway powers and controls privately-owned vehicles; most concepts propose publicly provided vehicles or automated pallets for carrying privately-owned vehicles.
- Right-of-way: New right-of-way required.

C. Positive Factors

- May relieve carriers from the expense of owning an AHS-capable vehicle, although there may be fees associated with using this facility. There is also no need for automated check-in. The driver (rider) is responsible only for selecting a destination.
- Safety and efficiency are at a maximum in this cluster.
- Truck operators would be assured of a consistent delivery system on the facility.

D. Negative Factors

- In a provided vehicle scenario, freight would have to be transferred to the system's vehicles. With a pallet system, trucks would require special large pallets that could be difficult to build or integrate into a system with smaller pallets.
- The need to transfer trucks or their cargo to the system may cause delays that reduce the system's efficiencies. Utilization of pallets would only be worthwhile in a long-haul application. The perceived expense and boarding time make them undesirable for short-haul applications.

AHS Cluster Map
Cluster 18. "Smart Vehlcle/Drlver and System Control

A. Functional Description/Technologies

- Most sensor and automation technology stays within the vehicle. A high-end smart vehicle can travel with little help or information provided by the surrounding infrastructure.
- Under full implementation, sensor technology is a combination of everything previously mentioned including a system to either automate decision making or efficiently integrate the driver into the complex decision-making process.

B. Distinguishing Variables

- Authority for vehicle control (driver vs. infrastructure): Control can be the entire responsibility of the driver or the infrastructure; however, under most configurations, the system generally has almost three-quarters of the control.
- Location of control systems (vehicle vs. guideway): The vehicle controls most of its actions (although under certain variations the guideway can control almost half).
- Cost: Physical infrastructure costs might only be to provide lane guidance and communication links. A very significant cost would be the complex onboard sensor and control devices, the most advanced of which may not be possible with current technologies.
- Right-of-way: Existing right-of-way, as is or modified.

C. Positive Factors

- There is no need to construct special facilities. Also, the vehicle is autonomous and designed for continuous, safe performance.
- Depending on the number of participating vehicles, safety may be very high.
- Operators would be assured of efficient routing and predictable operating costs. Development of smart trucks would avoid the possibility of being excluded from other infrastructure intensive AHS clusters.

D. Negative Factors

- Driver impacts: Depending on how the technology is implemented, a driver could have little say other than destination, or could be overwhelmed with (or distracted by) decision making based on multiple sensor data. High independence can be achieved with intelligent human factors applications to ensure the efficient provision of information, as opposed to automating the driving.

AHS Cluster Map
Cluster 19. "automatic Vehlcle/Total System Control

A. Functional Description/Technologies

- Automated individual vehicles operate from origin all the way to destination.
- Technology is comprehensive. At the core is computerized muting that determines the most efficient path based on all variables the vehicle could encounter. Generally, this involves an advanced traffic management system.

B. Distinguishing Variables

- Authority for vehicle control (driver vs. infrastructure): The system possesses essentially all control.
- Location of control systems (vehicle vs. guideway): Control can be based in nearly any combination of vehicle and infrastructure.
- Cost: Depending on the cost of stages of development proceeding full automation, the costs could be the highest both per vehicle and for the overall infrastructure.
- Right-of-way: Modifications required.

C. Positive Factors

- Complete, safe, efficient, and ordered transportation.
- Trucks may no longer require drivers.

D. Negative Factors

- Driver impacts: The driver could become merely a passenger, selecting only the destination and, for commercial vehicles, overseeing the safety and security of the cargo.
- May be impractical and expensive for motor carriers.

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