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Assessment of the Applicability of Cooperative Vehicle-Highway Automation Systems to Bus Transit and Intermodal Freight: Case Study Feasibility Analyses in the Metropolitan Chicago Region

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The Chicago Area Transportation Study

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ABSTRACT

This report presents the results of its performance assessment of the feasibility of applying cooperative vehicle-highway automation systems (CVHAS) to bus transit and freight movements in the metropolitan Chicago area. Cooperative vehicle-highway automation systems are systems that provide driving control assistance or fully automated driving and are based on information about the vehicle's driving environment that can be received by communication from other vehicles or from the infrastructure, as well as from their own on-board sensors.

The Chicago Central Area is equipped with rail transit, commuter rail and bus transit service, however, the connections between the commuter rail stations and major destinations, especially across town, are not as good as they should be. Bus Rapid Transit (BRT) systems making use of CVHAS technologies have promise to help improve connectivity within the Chicago Central Area. Three BRT case studies were performed in which CVHAS technologies were evaluated, including transit signal priority, collision warning, precision docking and automatic steering control systems. For these evaluations there is a nearly universal ability for each CVHAS application (except for collision warning systems) to pay for the system with minimal time savings required and there are consistently large to very large B/C ratios across CVHAS applications accounting for uncertainty in parameter values and lack of complete data. For collision warning systems, there is not a strong economic case for or against the deployment of these systems. However, even a small number of serious crashes here could tilt the balance significantly in favor of deployment of systems that could avoid or mitigate those crashes.

For intermodal freight, a new truck-only facility is proposed and based on available rail rights-of-way, to serve a selected set of intermodal rail yards, industrial parks and points-of-entry to the region. A total of five operational concept alternatives were selected, including a baseline, against which to measure the impacts of CVHAS technology applications and by performing comparative analyses against the baseline calculating both benefits and costs. The evaluation showed that all of the alternatives are economically feasible and CVHAS technologies are able to help improve the performance of the intermodal freight system. One of the alternatives was recommended for further investigation, in which a conventional truck-only facility open to all trucks before 2015 and then upgraded to an automated highway open only to automated trucks.

These preliminary case studies have shown potentially significant benefits from use of CVHAS technologies to help solve specific problems for bus and truck transportation in the Chicago region. Although the case study examples are specific to Chicago, they indicate the potential that these technologies should have for use in other major metropolitan areas as well. Within the Chicago context, they should also stimulate follow-on studies to explore the design and deployment issues in more depth so that progress can be made toward the start of implementation.

Key Words: cooperative vehicle highway automation systems, bus rapid transit, intermodal freight, heavy trucks

EXECUTIVE SUMMARY

This report summarizes the research that has been done to determine how Cooperative Vehicle-Highway Automation Systems (CVHAS) could enhance the performance of Bus Rapid Transit and heavy truck systems in a major urban region. Using a case study approach to address specific transportation problems faced by the Chicago region, this report provides an indication of the types of benefits that can be gained by use of CVHAS technologies as alternatives to conventional transportation technologies.

The CVHAS technologies that have been evaluated here include:
- Transit signal priority (TSP) to speed up the movement of buses in dense urban traffic;
- Collision warning systems to help bus or truck drivers avoid crashes;
- Precision docking to facilitate easy boarding and alighting of transit bus passengers;
- Automatic steering control to enable buses and trucks to drive in very narrow lanes;
- automatic speed and spacing control to enable buses or trucks to follow other vehicles of the same type at short spacings, increasing the capacity of a roadway lane;
- fully automated operation, combining the steering control with speed and spacing control.

The case studies have been conducted to make sure that these technologies are not viewed as ends in themselves, but rather are used to help solve specific transportation problems. The case studies were directed at two different operating environments, each with its own special needs:

Bus Rapid Transit for the Chicago Central Area

The Chicago Central Area is already heavily equipped with rail transit, commuter rail and bus transit service, but the connections between the commuter rail stations and major destinations, especially across town, are not as good as they should be. Bus Rapid Transit (BRT) systems making use of CVHAS technology appear to have promise for helping to improve connectivity within the Chicago Central Area, particularly for service needs that were identified in the recent Chicago Central Area Plan (cross-town service across the Loop area, and service between the commuter rail stations to the west of the Loop and the Navy Pier and nearby growing neighborhoods to the northeast). The CVHAS technologies that were evaluated for BRT use were traffic signal priority, collision warning, precision docking and automatic steering control.

Improving Access for Freight Movement to and from Intermodal Rail Terminals, Warehouse and Industrial Concentrations and Highway Points of Entry to the Region

Chicago is the rail freight hub of the nation and the primary junction between the major railroads that serve the eastern and western halves of the North American continent. The connections among the intermodal rail terminals, the local warehouse and industrial concentrations and the highway points of entry to the Chicago region are impeded by difficult road access, involving highly congested highways and much travel on local streets that are not really suitable for high volumes of heavy truck traffic. This has adverse effects on the efficiency of freight movement, as well as creating additional traffic, noise and pollution impacts on all the residents and travelers who must coexist with the heavy truck traffic. These problems could be ameliorated by implementation of a truck-only roadway connecting many of the most important freight

movement nodes in the region, primarily by use of currently under-utilized former railroad rights of way, either adjacent to existing tracks or in air rights. The CVHAS technologies that were evaluated for use on the truck-only roadway were automatic steering control, automatic speed and spacing control, and fully automated driving.

The results of these case studies are summarized below.

1. Bus Rapid Transit Applications of CVHAS

1.1 Collision Warning Systems

These were evaluated for near-term use on the cross-town routes that currently operate on major one-way street pairs in the Loop Area. Recent crash data for bus operations in this area from the Chicago Transit Authority were reviewed to identify the crash problems that are currently encountered. These were then evaluated based on the potential that forward, side and rear collision warning systems have to help drivers avoid these crashes. The frequency and severity of bus crashes in the Loop Area are relatively low, particularly with the low prevailing traffic speeds, and their costs to CTA appear to be in the same general range as the costs of implementing the collision warning systems, considering the uncertainties in the available data. This means that there is not a strong economic case for or against the deployment of these systems. However, even a small number of serious crashes here could tilt the balance significantly in favor of deployment of systems that could avoid or mitigate those crashes.

1.2 Precision Docking

Precision docking was also evaluated for near-term use on the cross-town routes in the Loop Area. Precision docking has two different types of benefits, only one of which is susceptible to quantitative analysis. The first benefit is the enhanced quality of service to passengers, which provides a relatively intangible benefit that could eventually be translated into increases in ridership and favorable image. The more quantifiable benefit is in the reduction of bus stop dwell times by making it easier for passengers to board and alight the buses, especially those with mobility challenges. This can provide operating cost savings to the transit operator and time savings to the passengers. In the absence of definitive data about the time savings that can actually be gained from this new technology, the analysis was able to show that the economic break-even point for the transit operator could be achieved even if docking saved an average of only 2.52 seconds per bus stop, and if the value of time for an average of 20 passengers per bus was factored into the analysis, a time saving of only 0.73 seconds per stop would still produce net benefits. If docking could save as much as 5 seconds per bus stop, the benefit/cost ratio would be 4.4, even with an average bus occupancy of only 10 passengers. Longer time savings could of course produce even higher B/C ratios.

1.3 Transit Signal Priority

Transit signal priority (TSP) was also evaluated on the Loop cross-town routes, to determine its advantages in reducing the delays that buses experience at traffic signals. Thus the focus of this evaluation was on the benefits of TSP for the transit operator by reducing its overall operating costs and for bus passengers by reducing their total travel time. The analysis of TSP indicated that if would break even for the transit operator if it was able to save each cross-town Loop bus an average of only 7 seconds on a round trip across the Loop that currently takes an average of 15 to 20 minutes. When the travel time savings of the bus passengers are factored in, the break-even time saving is reduced to 3 seconds with an average of ten passengers per bus or 2 seconds with 20 passengers per bus. Preliminary analyses indicate the possibility that the actual time savings could be in the range of 42 seconds, which would produce B/C ratios of 14 to 21 with average passenger loads to 10 to 20 people.

1.4 Automatic Steering Control

In the long term, the Chicago Central Area Plan includes provisions for an underground busway to provide cross-town bus service beneath Monroe Street. Application of automatic steering control on the buses that operate there would make it possible to reduce the width of two lanes of busway from twelve feet to ten feet each. This saving of four feet of busway width could represent a significant saving in the cost of constructing the underground facility. Tunnel construction experts were reluctant to specify the costs of construction without detailed soils and engineering studies, but a break-even analysis showed that the automatic steering control would pay for itself even if the tunnel construction costs were as low as $25 per square foot (many times less than contemporary residential housing construction costs, and in all likelihood orders of magnitude lower than current urban tunnel construction costs). Even if the tunnel construction costs were to be one-third of the cost per square foot of the Seattle bus tunnel, the B/C ratio for automatic steering control would still be about 20.

The Chicago Central Area Plan also calls for a new busway on former railroad right of way along Carroll Avenue, just north of the Loop area. This busway would require construction of a new bridge over the north branch of the Chicago River, another location where the automatic steering of the buses could save four feet of lane width. That width reduction would reduce the cost of the bridge by more than $2 million, which by itself would provide a B/C ratio in excess of 22 for the automatic steering capability to be installed on all the buses using the busway. Another planned underground section of this busway, along Clinton, could produce an even larger cost saving because of the reduction in the busway width.

2. Heavy Truck Applications of CVHAS

The heavy truck applications of CVHAS were evaluated based on a hypothesized new truck-only roadway facility that would be built to connect several of the most important intermodal rail terminals, primarily on the south side of downtown Chicago, with additional connections to I-90 at the Indiana State Line and I-294 on the northwest side of Chicago. As part of this project, both near-term and long-term alignments were defined for this new truck roadway, in consultation with the freight movement staff at CATS, the regional MPO.

The case study analysis had to begin with evaluating the effectiveness of the new truck-only roadway without any CVHAS technologies, since this was not part of any previous study and had not even been designed before. The truck-only roadway was found to have significant benefits in reducing delays to truck traffic, as well as relieving the congestion imposed on other traffic by the trucks that currently need to use the regular highways in the region (B/C ratio 3.63 compared to do-nothing alternative). The more interesting part of the study was in exploring what the additional effects would be of applying CVHAS technologies to the trucks using the new facility.

The primary advantage of automatic steering control of the trucks is in reducing the width of lanes needed for the new truck facility, and hence their construction and right-of-way costs. However, in order to gain this cost-saving advantage, it would be necessary for the truck facility to be restricted to trucks with automatic steering (because drivers would not be able to steer their conventional trucks accurately enough to use the narrower lanes). That introduced a deployment staging challenge, because not enough trucks would be equipped with the automatic steering capability in the early years of operation of the truck facility, and it would be under-utilized until the population of equipped trucks increased significantly (and the costs of the technology declined significantly from its initial costs). This under-utilization of the new automated-truck-only facility made it less cost-effective than a full-width truck-only facility that would be open to all trucks, without any use of the CVHAS technology (B/C ratio of 3.27).

Automatic speed and spacing control of trucks makes it possible for them to operate in close-formation platoons of up to three trucks. In this way, a single roadway lane can accommodate about twice the volume of trucks as a conventional-technology truck lane. This means that in future years, as the volume of truck traffic grows, it will not be necessary to add lanes for the additional trucks, thereby saving considerable capital construction and right of way costs. In addition, the close-formation platoon operations reduce aerodynamic drag, saving significant fuel costs and reducing pollution emissions as well. Indeed, the evaluation scenarios that include automatic speed and spacing control show significant capital cost savings by avoiding the need of the construction of an additional lane in each direction as traffic grows. However, when these are based on use only by CVHAS-equipped trucks right from the start, the under-utilization of the truck facility in the early years reduces the B/C ratio below the B/C ratio for the conventional-technology truck lane system (B/C ratio of 2.45).

The most beneficial alternative for use of CVHAS technologies on the new truck facility involves deferring the implementation of the CVHAS technologies until after the facility has been in operation for a while and the costs of the vehicle technologies have declined. In this case, a single-lane (each way) truck facility would be opened to use by all trucks in the near term (as soon as it could be constructed), and then as the volume of truck traffic and of CVHAS-capable truck grows over time, it would be converted to automated operation in the longer term (perhaps year 2015). With this scenario, the utilization of the new facility is relatively high from the start, and the benefits of the capacity increase from the speed and spacing control technology are gained in the later years, when they are most needed. This mixed solution showed the highest B/C ratio by a substantial margin, 5.15. The automatic steering technology could be used in concert with the speed and spacing control technology to provide fully automated driving in those later years, but the additional benefits of that would be more associated with driving comfort and convenience because the lanes would have already been constructed to full width.

When this project began, the participants assumed that the dominant market need for heavy truck accessibility in the Chicago region was for rubber-tired cross-town transfers between intermodal rail terminals, as it had been twenty years previously. However, in the course of work on the project it became evident, through the insights of the CATS staff, that this is actually a shrinking (though not vanishing) segment of the Chicago trucking market. Increasing percentages of these transfers are now being handled by rail, while the more significant growth in demand is for linkages to and from the major highway points of entry to the region and the local industrial and warehousing concentrations. Therefore, this broader market has been addressed in the study, even though the networks of truck lanes that we have been conceptualizing are largely concentrated on serving the major intermodal rail terminals, reflecting the initial scope and focus of the study. It would be worthwhile to pursue an additional study addressing the full range of regional truck accessibility needs from the start, and considering the opportunities for developing truck lanes, both with and without CVHAS technologies, in other parts of the Chicago region, unconstrained by the locations of intermodal terminals and railroad rights of way.

Conclusions

These preliminary case studies have shown potentially significant benefits from use of CVHAS technologies to help solve specific problems for bus and truck transportation in the Chicago region. Although the case study examples are specific to Chicago, they indicate the potential that these technologies should have for use in other major metropolitan areas as well. Within the Chicago context, they should also stimulate follow-on studies to explore the design and deployment issues in more depth so that progress can be made toward the start of implementation.

TABLE OF CONTENTS

SECTION		PAGE

LIST OF TABLES **PAGE**

LIST OF TABLES **PAGE**

LIST OF TABLES **PAGE**

LIST OF FIGURES **PAGE**

LIST OF FIGURES **PAGE**

1.0 PROJECT OVERVIEW

The Cooperative Vehicle-Highway Automation Systems (CVHAS) pooled fund project was initially proposed by the California Department of Transportation (Caltrans) and joined by ten other state departments of transportation, and Honda R&D North America, with the purpose of promoting progress toward deployment of CVHAS technologies. The sponsoring states decided that their first projects should be evaluations of the opportunities for implementing CVHAS on transit buses or heavy trucks to solve transportation problems in specific locations in one or more of the states. These case study projects were "fast tracked" in order to take advantage of the opportunity to present the results to visitors to the demonstration of bus and truck automation systems that Caltrans and PATH organized in San Diego. (Eventually, the California state budget crisis required this demonstration to be scaled back to a low-profile event for a limited audience, with a focus only on the transit bus application.)

The representatives of the CVHAS states proposed a variety of potential applications for consideration in the case study projects. After evaluation by the CVHAS Technical Advisory Committee, the target applications that were chosen were both for the Chicago metropolitan region.

The proposed transit application was an update of the "Central Area Circulator Project" study of a decade ago, but now considering how a Bus Rapid Transit system augmented with CVHAS technologies could provide connections to major trip generators and the existing commuter rail and rail transit systems in and near Chicago's central business district. This application appeared promising because the prior study had favored light rail transit over buses for reasons of capacity and operating cost that could potentially be counterbalanced by application of CVHAS to buses. When the costs of the light rail system grew to be unaffordable in the early 1990s, that project was abandoned.

The proposed heavy truck application was an update of an intermodal freight terminal connector study that was done two decades ago, addressing how to provide better transfers among the many important intermodal terminals in the region by using trucks operating on roadways to be built on under-utilized rail rights of way. In the case of this study, many significant changes had occurred since the original study was completed, in issues such as the overall patterns of freight movements, the utilization of alternative terminals within the Chicago region, and the availability of right of way, so all of these issues needed to be re-examined, in addition to the potential for improving operations by use of CVHAS technologies.

The two case study projects were combined in a single contract from Caltrans to the University of California's PATH (Partners for Advanced Transit and Highways) Program, who in turn issued a subcontract to the University of Illinois-Chicago (UIC) for some of the work that needed to be based on collection of local operational data. Separate local stakeholder advisory committees were formed for the two projects to provide reality checks on the viability of the ideas to be proposed and to engage the key stakeholders in discussions that could lead to more detailed planning for system implementation if the results of the initial feasibility studies appear promising.

The case studies are primarily intended as evaluations of the real-world implementation issues associated with use of CVHAS technologies, to help identify the highest-priority problems that will need to be studied in further research on CVHAS. The key case study issues involve:

- Comparison of CVHAS solutions with conventional-technology solutions to identify differences in the most important measures of effectiveness;
- Identification of the incremental benefits that can be provided by each CVHAS technology in representative applications;
- Identification of the incremental costs associated with implementation of CVHAS technologies in these applications;
- Identification of practical constraints to the deployment of CVHAS technologies;
- Identification of potential synergies when several CVHAS technologies are combined;
- Assessment of timelines for CVHAS implementation, considering both technical and non-technical issues.

These issues are all of national significance, and should be relevant to all of the CVHAS states, regardless of the specific application site(s) chosen for the case studies. In addition, if the case study results appear promising for these specific sites, they should provide the foundation for the development of more detailed planning efforts to point toward development of specific deployment projects, which could then proceed under local sponsorship.

2.0 COOPERATIVE VEHICLE-HIGHWAY AUTOMATION SYSTEMS (CVHAS)

2.1 CVHAS Attributes

Before the planning evaluations can be done, it is first necessary to specify the types of technology that are under consideration. The CVHAS technologies have been under development for many years, and the first commercial products that use these technologies have only been on the market for a relatively short time. However, many more CVHAS products should become available within the next two decades, providing a rich basis for system design and evaluation. Most of the technologies are very similar for the applications to transit buses and commercial trucks, but there are likely to be significant differences in their respective costs and benefits because of the differences between the two application environments.

Figure 2.1 shows a schematic view of the range of possible CVHAS technologies, considering the two key dimensions of the degrees of automation and of cooperation.

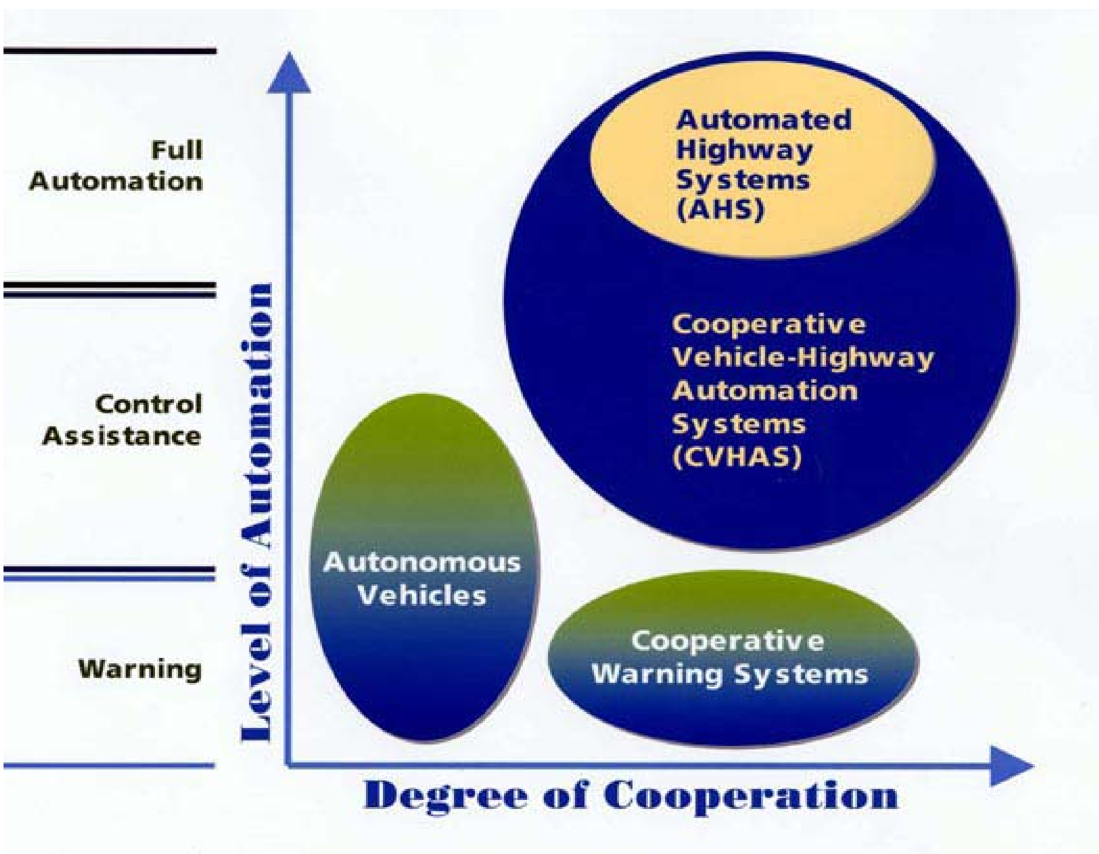

FIGURE 2.1 CVHAS Technology Characteristics

The terms used in Figure 2.1 are defined as follows:

- Warning – Audible, visible or haptic cue to alert driver to a potentially unsafe condition
- Control Assistance – Automatic control of a portion of the driving function to assist the driver by relieving workload (e.g., adaptive cruise control) or to enhance safety (e.g., collision avoidance braking)
- Full Automation – Completely automatic control of driving, relieving the driver of responsibility for driving functions
- Autonomous Vehicles – Vehicles that derive all their information about the environment from their own on-board sensors, without communication to or from the infrastructure or other vehicles. By analogy to human drivers, the autonomous vehicles can "see", but they cannot "talk" or "listen" to others.
- Cooperative Warning Systems – Warning systems that can receive information about the vehicle's driving environment by communication from other vehicles or from the infrastructure, as well as from their own on-board sensors.
- Cooperative Vehicle-Highway Automation Systems (CVHAS) – Systems that provide driving control assistance or fully automated driving, based on information about the vehicle's driving environment that can be received by communication from other vehicles or from the infrastructure, as well as from their own on-board sensors.
- Automated Highway Systems (AHS) – Systems that provide fully automated driving (which is only possible on separated, protected lanes), based on information about the vehicle's driving environment that can be received by communication from other vehicles or from the infrastructure, as well as from their own on-board sensors.

On the vertical axis of Figure 2.1, we can see a range of degree of automation from warning alone (with the driver retaining the responsibility for taking all vehicle control actions), through control assistance, and continuing to fully automated driving. The control assistance could be in the form of adaptive cruise control, which helps the driver maintain a proper separation to the vehicle ahead of his or her own, or assistance in steering to promote more accurate lane keeping. Full automation means that the driver is no longer responsible for controlling the movements of the vehicle, but it is controlled using electronic sensors and actuators, commanded by an onboard computer.

A variety of warning systems have recently become available on the market, but the pioneering system in the U.S. was actually the Eaton-Vorad forward collision warning radar system, which has been available for commercial trucks and intercity buses since 1993. In the control assistance category, the primary system is adaptive cruise control, which has recently become available for use on heavy trucks and a few high-end luxury passenger cars in the U.S. The fully automated vehicle systems have been used for many years as automated people movers at airports and commercial business parks, and they have been used as urban transit systems in a variety of other countries for several years.

On the horizontal axis of Figure 2.1, we can see the degree of cooperation ranging from none (meaning autonomous vehicles, with no cooperation) to a variety of levels that could include vehicle-vehicle cooperation, vehicle-roadway cooperation and fully integrated cooperation among vehicle and roadway elements. The existing commercially available products and most of the systems under design and evaluation in the USDOT's "Intelligent Vehicle Initiative" program are at the low end of the cooperation scale, but interest is growing rapidly in the improvements that could be gained with increasing cooperation enabled by wireless communications among vehicles and infrastructure devices.

2.1.1 CVHAS Opportunities in these Case Study Projects

The case study projects described in this report are important to the development of CVHAS technologies and identification of opportunities to deploy them for several reasons:

1. It appears most likely that earliest deployments of CVHAS technologies will be on heavy vehicles operating on their own special rights of way for a variety of reasons:
   1.1 Easier to develop and acquire rights of way for public purposes (transit service, getting trucks off mixed-traffic roads)
   1.2 Maturing technologies can be used more safely by professional drivers on professionally maintained vehicles than by the general public on vehicles that may not be maintained at all
   1.3 Costs of the technologies are a smaller percentage of total vehicle costs and vehicles are used much more intensively than private automobiles, so these costs are amortized much faster
   1.4 Benefits in travel-time reduction, trip reliability and safety can be translated more directly into cost savings than for private cars
   1.5 Customized, small-lot production of vehicles makes it possible to introduce the CVHAS technologies into the production process faster than for automotive mass production
   1.6 Packaging of new technological elements is easier on larger vehicles
   1.7 Heavy vehicles already have more onboard electronic infrastructure to use as a foundation for more advanced capabilities than passenger cars

2. Case studies of applications of CVHAS in specific sites are needed in order to shed light on important issues such as the definition of system operating concepts, system designs, institutional opportunities and constraints and system benefits and costs to the various stakeholders, as well as to society as a whole.

3. Case studies focused on the solution of actual transportation problems can provide a basis for focusing technical decisions and refining system design trade-offs.

4. The results of the case studies can be used to show the more general benefits of CVHAS as part of the outreach messages.

5. Case studies of applications of CVHAS in specific sites are needed in order to shed light on important issues such as the definition of system operating concepts, system designs, institutional opportunities and constraints and system benefits and costs to the various stakeholders, as well as to society as a whole.

6. Case studies focused on the solution of actual transportation problems can provide a basis for focusing technical decisions and refining system design trade-offs.

7. The results of the case studies can be used to show the more general benefits of CVHAS as part of the outreach messages.

8. Case studies for diverse locations around the country (and particularly locations outside California) can provide direct evidence of the broad, national applicability of CVHAS, to help stimulate broader interest in CVHAS, including at USDOT.

2.1.2 CVHAS Benefit Opportunities

CVHAS technologies can provide a variety of benefits to transportation system operations. These can be summarized as:

(a) Enhanced line-haul capacity/reduced congestion – Automatic longitudinal control (vehicle following) makes it possible for vehicles to drive more closely together than they could under normal driver control. This means that a single lane of vehicles under automatic longitudinal control can accommodate more vehicles per hour than under manual control. That increased capacity means that congestion delays can be reduced for the equipped vehicles, or alternatively it should be possible to provide the capacity needed to avoid congestion with fewer lanes than would otherwise be needed, saving on construction and right-of-way costs.

(b) Reduced lane width – Automatic lateral (steering) control makes it possible for vehicles to follow their lanes more accurately than drivers can normally steer, which makes it possible for the lanes to be only slightly wider than the vehicles. This introduces the potential for saving a portion of the cost of constructing these lanes, especially where they need to be accommodated on elevated structures or underground. The narrow lanes also reduce the cost of right-of-way acquisition and in special cases can produce major cost savings by enabling the lane to fit in a place that might otherwise be impossible, or enabling the lane to be provided at grade level rather than on much more costly elevated structures.

(c) Improved safety – A variety of the CVHAS technologies, but especially the warning systems, should improve safety by reducing the probability of occurrence of crashes. These can apply to a variety of crash types, ranging from lane departures to rear-end crashes and crossing-path crashes at intersections.

(d) Improved operational efficiency – Several of the CVHAS technologies can improve operating efficiency in different ways. Automatic steering control for precision docking of buses at bus stops can reduce the time needed for passenger boarding and alighting, especially when there are significant numbers of elderly, wheelchair-bound, or load-carrying passengers. Automated operation of buses in maintenance facilities can save maintenance labor costs. Automated operation of trucks on special truck ways could eventually save driver labor expenses.

(e) Reduced fuel consumption and pollutant emissions – Vehicles cruising at constant speed consume less fuel and produce less pollution than vehicles that are accelerating and decelerating frequently. The congestion-reducing ability of automatic longitudinal control systems should significantly reduce the occurrences of stop-and-go congestion for the equipped vehicles. Furthermore, the automatic control of acceleration and braking can be programmed to do these maneuvers smoothly and gradually, so that they are cleaner and more energy efficient than if they were done more abruptly. Finally, close-formation platoon driving of vehicles can significantly reduce aerodynamic drag at highway speeds, leading to savings in fuel consumption and emissions.

(f) Reduced driving stress and fatigue – Relieving the driver of some or all of the tasks of driving can reduce the stress and fatigue associated with driving, especially for professional drivers who need to drive all day. Control assistance systems can provide partial relief, while fully automated systems can change the driver's role more significantly, turning it into more of a supervisory or customer service assignment than manual labor. This category of benefits is harder to measure than the others, and cannot be relied upon until there is a considerable body of experience with drivers using these systems on a daily basis.

2.1.3 Incremental Cost Generators

The benefits of CVHAS systems are of course not gained for free, because there are costs associated with implementation of these new systems. There are up-front engineering and development costs, as with all new technologies, but these should be amortized across the deployed systems. The costs of these systems are primarily capital costs of acquisition, but it is important that they be compared equitably with the costs of the alternatives.

While partially automated and non-automated driving could be used on the same roadway, the more advanced CVHAS technologies ─ involving fully automated driving ─ require use of roadways that are fully segregated from non-automated vehicle operations. The costs of these roadways are very site-dependent, but in the highest density urban areas they are likely to be substantial. The key evaluation issue involves comparing the costs of the roadways intended for automated vehicles with the costs of the roadways that will otherwise be needed for non-automated vehicles. Since the additional costs for CVHAS technologies in the infrastructure tend to be small (communications transceivers and special reference markings), and the size of the infrastructure could be somewhat smaller than the analogous conventional infrastructure, the incremental costs could be either positive or negative.

The CVHAS costs that are generally most significant are associated with the additional equipment required on vehicles. This depends on the level of capability to be provided, the expected production volume of the equipment, and the year of implementation (which determines how much of the equipment may already be standard on vehicles for other reasons). Maintenance and operation costs for the CVHAS technologies are difficult to anticipate in advance of actual experience with products deployed in the field, but they should generally be small compared to the acquisition costs if the systems have been well designed.

2.2 Applicability of CVHAS Technologies Based on Right-of-Way Restrictions

For a limited-scope application case study it is necessary to narrow consideration to a limited set of the most promising system concepts rather than trying to consider the full range of possibilities. The concepts that are most applicable for the Chicago bus and truck applications turn out to be very similar to each other, and their costs are therefore also similar, simplifying the study somewhat. The applicability of CVHAS concepts is closely coupled to the degree of mixing that is permitted between the CVHAS-equipped vehicles and the general unequipped vehicle traffic. CVHAS concepts at the lower levels of automation functionality (warnings and the most basic control assistance) can be applied essentially anywhere, because the vehicle driver will be expected to maintain vigilance to deal with emergency conditions. As the level of automation increases, however, it is less likely that the driver will be able to maintain full vigilance to deal with all of the hazards created by the worst-behaving drivers, cyclists and pedestrians in the public roadway environment.

The state of the art in sensing and signal processing technology does not enable the CVHAS systems to take over full responsibility for vehicle safety in the complicated unrestricted roadway environment, nor is it likely to enable that for many decades to come. Indeed, at the fully automated level of driving functionality it will be essential to provide physical segregation of the equipped vehicles from the unequipped for the foreseeable future.

Table 2.1 provides a summary description of the technologies that could be applied to transit buses as a function of the degree of right-of-way restriction that is imposed. Mixed traffic flow refers to unrestricted use on public roads that are shared with other motor vehicles, as well as pedestrians and bicyclists. This is the most challenging operating environment because of the complexity and unpredictability of its conditions. In this environment, the driver must remain fully in charge of the driving process and must continuously monitor the vehicle surroundings for hazards.

The partially segregated environment is one in which the CVHAS equipped vehicles would normally coexist primarily with other similarly equipped vehicles, but their right of way could be shared occasionally and temporarily by other vehicles. In this case, it should be possible to take advantage of the opportunities provided by automatic steering control, but the more advanced control functions could not be implemented because of the hazards introduced by the “other” vehicles. In the fully segregated and protected environment, all vehicles with access to the roadway would be suitably equipped with sensors and communication devices and could safely coordinate their operations. Any faults that occur would be detected and reported so that all vehicles could respond appropriately and safely. This is the environment in which the maximum benefits can be gained from use of the CVHAS technologies, but it is also the environment that requires the largest political commitment to achieve because of the need to exclude all non-equipped vehicles from access.

Technologies that could actually be used on the buses in Chicago include collision warning, transit signal priority, precision docking, automatic steering control, automatic speed and spacing control, and fully automated vehicle operation.

Collision warning systems could augment the driver's normal driving and could provide alerts to hazards of which he may be unaware, and could also help out in conditions in which the driver is distracted or less than fully alert (fatigued or health impaired). Such systems may take the form of forward, rear, and side hazard warnings and can be delivered to the driver by either auditory, haptic, or visual cues. The driver retains responsibility for corrective actions based on the warnings provided. Technologies that may be used in these systems include radar, ultrasound or laser sensors and threat assessment software and the driver interface.

Transit signal priority is an operational strategy that facilitates the movement of transit vehicles through traffic-signal controlled intersections. By reducing the time that transit vehicles spend delayed at intersection queues, transit signal priority can reduce transit delay and travel time and improve transit service reliability, thereby increasing transit quality of service. It also has the potential for reducing overall delay at the intersection on a per-person basis because giving priority to a bus and thereby saving all of its passengers an amount of time at least the length of the red cycle is going to produce more overall benefits than the costs associated with a few seconds of delay to the car drivers waiting slightly longer for their green signal on the cross street. At the same time, transit signal priority attempts to provide these benefits with a minimum of impact on other facility users, including cross-traffic and pedestrians. The preferences given to buses may, for example, be in the form of an early green (red truncation) or green extension. Technologies include vehicle detection, identification, and location systems to identify a bus and communicate to a roadside signal controller cabinet together with GPS, differential GPS, dead-reckoning for positioning and wireless communication.

Precision docking is a low-speed automated positioning of buses relative to the curb or loading/unloading platform at bus stops under direct bus driver supervision. It offers precisely controlled lateral positioning with tolerances of 1 to 2 cm and it becomes possible to load and unload passengers as easily as rail transit vehicles, reducing the dwell times at bus stops and improving accessibility for mobility-impaired passengers (especially those bound to wheelchairs). It is difficult and stressful for bus drivers to try to achieve this kind of position accuracy, and if they try they often scuff their tires against the curb, creating maintenance and wear problems, as well as discomfort for their passengers. Since the precision docking maneuver is performed at low speed[1] in well-defined locations, and under direct supervision of the bus driver, it is a form of vehicle automation that could be implemented relatively early and with a minimum of liability concerns. Moreover, the driver would be able to devote more attention to looking out for possible safety problems involving pedestrians. Technologies that may be used in these systems for sensing include roadway "magnetic marker" sensors, vision or optical systems together with an electronically controlled steering actuator.

Automatic steering control is essentially the same as precision docking in that it automatically steers the bus to stay centered in a lane but it is not limited to low speeds that are necessary for docking a bus at a stop. Automatic speed and spacing control, rather than the driver, commands the bus speed and allows for buses to be operated very close together. Technologies for these systems include forward ranging sensors (radar or laser), electronic control of the engine and the

[1] In principle, there is no speed difference between automated or manual control

brakes, and vehicle-to-vehicle data communication. More detailed information on these technologies may be found in Appendix I.

TABLE 2.1 Applicability of CVHAS Concepts by ROW Restriction

Right-of-Way Restrictions	Collision Warning	Traffic Signal Priority	Precision Docking	Automatic Steering Control	Automatic Speed and Spacing Control	Fully Automated Vehicle Operation
Mixed traffic flow	X	X	X			
Partially segregated bus lane	X	X	X	X		
Fully segregated bus lane			X	X	X	X

3.0 BUS TRANSIT SYSTEMS IN THE LOOP AREA OF CHICAGO

3.1 Background Information

The city of Chicago has always been a major hub for mass transit, and it currently hosts the second largest public transportation system in the nation. Buses represent a major component of that system, with one million rides being taken daily on fleet of 2,080 buses (3-1). Within the city limits, the bus system is particularly crucial, transporting people to and from their jobs on a daily basis. Unfortunately, however, public opinion of riding the buses and trains in Chicago is alarmingly low – with only 34% of riders having a positive perception of it according to a recent poll (3-2). The obvious result has been more people choosing personal transportation instead, decreasing ridership and increasing traffic. Though that may sound bad, things are actually headed in the right direction due to improvements in service and facilities, as overall ridership has increased in 2001 for the fourth consecutive year (3-3). The key to having this trend continue is to persist in improving the service, and automation represents a very promising way of doing so.

Automation expands upon the concepts of Bus Rapid Transit (BRT) by applying advanced technologies as a way to enable fully or partially automated vehicle control. Exactly how and to what extent these CVHAS technologies are used depends on the properties of the particular area being serviced. However, the potential benefits of automation are very compelling. Such benefits include:

- Decreased travel times
- Increased schedule adherence
- Increased accessibility
- Increased safety
- A smoother ride
- Operation on narrower right-of-ways
- Increased vehicle and passenger capacity per lane
- Environmental benefits (reduced emissions)

Over the course of the last sixteen years there have been numerous investigations into improving transit service in the Loop. In this report we focus on three of these studies as they have been the prime motivation for the current investigation. The oldest study is the Central Area Circulator Project (CACP) in 1987 (3-4, 3-5, and 3-6) with the others being two recently completed studies, namely, the Chicago Central Area Plan (3-7) and the Carroll Avenue Busway Plan (3-8).

3.1.1 Central Area Circulator Project

In 1987 Chicago's Regional Transit Authority (RTA) began a study to assess the need for new downtown transit in Chicago resulting in the Central Area Circulator Project (CACP). CACP was a 9 mile, 32 station, light rail transit system designed to transport an average of 100,000 riders daily to major Central Area destinations such as the Illinois Center, Navy Pier, North Michigan Avenue, State Street, the Loop, Central Station and McCormick Place. The project budget was estimated to be $775 million with funding from the Federal Transit Administration, the state of Illinois, and the Circulator Special Service Area Taxing District. The CACP was proposed to interconnect all existing transit systems and link them to the activity centers in downtown Chicago. This interconnecting system would make it easier for travelers to use transit in Chicago thereby reducing congestion. RTA and the Chicago Development Council, a private sector consortium of developers and downtown property owners, funded the study.

The CACP evaluated a number of modes to provide transportation downtown including bus, automated guideway transit, and subways but eventually light-rail transit was selected as the best alternative. The study found that light rail transit offered the best combination of speed and capacity with only moderate capital and operating costs. The light rail system may have changed downtown by creating corridors giving pedestrians and the light rail system priority over personal vehicles.

Improving the bus system and exclusive busway lanes in the high-traffic corridors were evaluated in detail because the initial cost would be approximately one-third that of the light rail system. The critical disadvantages of the bus option were capacity and speed. Although large three-sectioned articulated buses were available at the time they were not yet legal to operate in the U.S. Therefore, standard buses would have to be used. However, these would not have offered as much capacity as the light rail system being proposed. A full-scale bus system would have peak hour capacity of 10,000 passengers per hour but would require very close spacing between buses and operation at the upper limits of efficiency. On some streets the new system would add 160 vehicles per hour creating noise, pollution and congestion in pedestrian areas and unacceptable delays on cross streets. In the future, expanding the capacity of the system would be almost impossible since the system would already be basically saturated with buses. MPC found it "impossible to structure a new bus system that could move people much faster than the current service, even with exclusive busways, because the sheer volume of vehicles overwhelms any attempt to coordinate traffic signals in favor of bus movements" (3).

The proposed light rail system (Figure 3.1) would operate on a dedicated right-of-way with signal priority at intersections. The vehicles would run in trains with up to three cars with a capacity of 550 people, equivalent to approximately eight buses. Peak hour capacity in the peak direction would be 12,000 passengers per hour (20 trains/hour at 200 people/car). The light rail transit system would co-exist with pedestrians and personal vehicles as well as make connections with CTA rail transit and Metra commuter rail lines for easy travel within the Central Area and outlying neighborhoods and the suburbs.

Initially light rail transit was selected over bus alternatives for the CACP because it offered speed and capacity advantages over buses for moderate capital costs. However, over the course of the system's planning the cost of the proposed light rail system grew until it became prohibitively expensive to fully engineer and build. By 1990 the CACP was dropped from the regional transportation plan but it continued to be investigated into the mid-1990s. In 1994 some favored only a limited version of the plan connecting Navy Pier, Grant Park, the Museum Campus, Soldier Field, and McCormick Place (4).

Initially light rail transit was selected over bus alternatives for the CACP. The former offered speed and capacity advantages over buses for moderate capital costs, however, such costs grew over the course of the system's planning time horizon until it became prohibitively expensive to fully engineer and build. Modern CVHAS technologies offer the opportunity for buses to provide the same advantages as light rail transit, but at a significantly more affordable price:

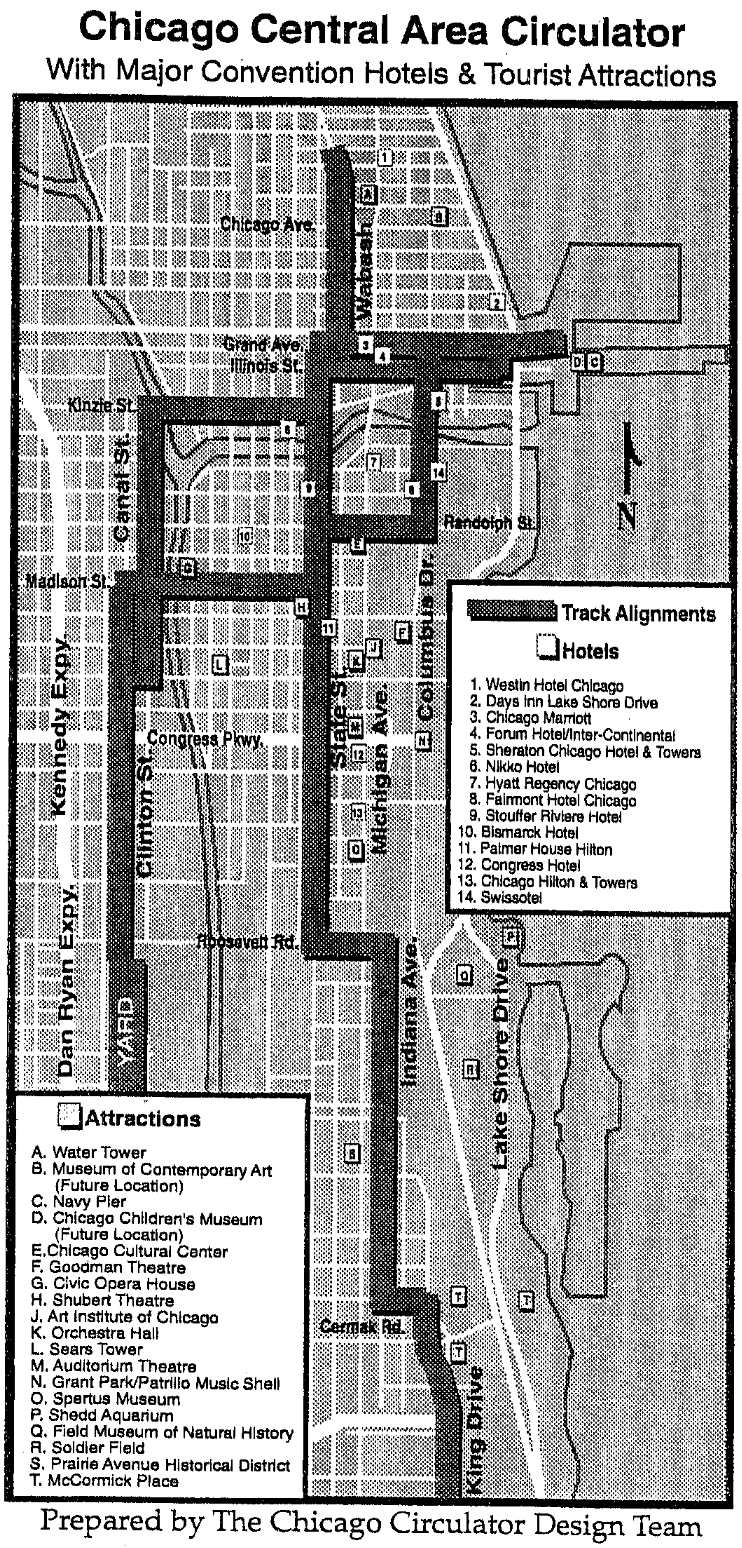

FIGURE 3.1 The Route of the Proposed Light Rail System for the Central Area Circulator Project.

(1) Speed — CVHAS technologies can make it possible for buses to operate at the same speed as light rail cars:

- Precision docking at bus stops can reduce dwell times, as well as provide better quality of service to passengers (especially mobility impaired), and reduce driver stress and maintenance problems from tire wear.
- Automatic steering control makes it possible to maintain full speed and good ride quality while traveling in very narrow rights-of-way, as well as permitting reduced lane width and therefore reduced capital cost.
- Traffic signal priority technology, using wireless communications between buses and the traffic signal system, can enable buses on the mainline circulator route to obtain priority over cross traffic, reducing or potentially eliminating signal delays for the passengers.

(2) Capacity — CVHAS technologies also make it possible for buses to provide equivalent capacity per lane to light rail cars:

- Use of electronically-coupled bus platoons in a fully protected right-of-way environment can enhance capacity and offer a high level of service to accommodate sufficiently large travel demand. The electronic coupling technology means that several buses (even buses from diverse origins) can be coupled together to form a “virtual train” and these “virtual trains” of buses can be operated closer together than traditional light rail trains.
- Modern double-articulated buses of the type used in a variety of BRT systems around the world also provide significantly higher passenger capacity per bus than the traditional single-unit buses that were available in the U.S. at the time of the original CACP study.

3.1.2 Carroll Avenue Busway Study

The information obtained regarding the Carroll Avenue busway came from the studies prepared for the Chicago Department of Transportation by the Parsons Company. During the design of the new route, an east-west corridor was deemed to be the best selection because of the ongoing challenges with efficiently transporting people from the west side of the Loop (major terminus for Metra Commuter Rail lines arriving from the western suburbs. Moreover, the possibility of using a dedicated transit facility was also part of the favored option. This option may be achieved using Carroll Avenue under the Merchandise Mart. Increasing congestion in the area north of the Chicago River has generated interest in using the “Pacific Railroad” which lies between the north shore of the river and Kinzie Street and is no longer in use, as a dedicated transit facility. This corridor can connect from the Chicago River at Canal Street to the west side of Rush Street and using this option under an appropriate operational strategy would improve travel time by 60% and enhance bus connection between the Central District Metra and CTA rail stations. Figure 3.2 depicts an overhead view of the Carroll Avenue route relative to major activity centers in this part of the city.

FIGURE 3.2 Carroll Avenue Busway (Reference 3-8)

Carroll Avenue is a 7.2 – 8.4 m. wide road that is currently used for parking and loading/unloading purposes. The traffic in the corridor is a mix of automobiles and singles-unit trucks. There are a total of six ramps entering the corridor, and during peak morning hours most of the traffic enters at LaSalle Street between Clark and Dearborn. There are two main access points on the west side of the avenue, namely, a ramp at Orleans, by crossing the river at the existing Kinzie Street Bridge and a new bridge over the river in the same location of the old railroad. The project team visited the case study locations and photographs taken of the Carroll Avenue area are included in Appendix II.

3.1.3 Chicago Central Area Plan

The following is an excerpt from the Chicago Central Area Plan of 2003 (3-7):

> *CTA buses currently use eastbound lanes on Washington and Adams and westbound lanes on Madison and Jackson. These lanes are affected by vehicles making right turns at cross streets and by vehicles exiting driveways, extending travel times for bus riders and discouraging transit use. As a first step, these on-street bus lanes will be upgraded through improved signal timing, streetscape enhancements and other amenities. An exclusive transitway may be created at the street level, in the short term, on Adams and Monroe Streets.*
>
> *If warranted by future traffic growth, a below-grade transitway could be built on Monroe Street to improve east-west bus times through the Loop. This below-grade transitway would make use of a right-of-way reserved by the City for a potential east-west subway in the 1970's. It would extend from Michigan Avenue*

to Clinton Street, crossing the Chicago River via tunnel. Portals would permit buses to enter and exit at Michigan Avenue and at Clinton. A connection could also be provided to the existing South Lakefront transitway to McCormick Place.

Buses operating in the East-West transitway could be primarily existing line-haul routes that currently use Loop streets. Convenient connections could be provided to the State and Dearborn subways below. Escalators and elevators would transport riders between platform and street level, with bus waiting times displayed on electronic signs. The platforms could be extended to create a continuous pedway between Michigan Avenue and Union Station, with connections to the existing pedway. As a first step, this right-of-way may also be developed as a pedway.

Figures 3.3 and 3.4 are also taken directly from the Chicago Central Area Plan and show an artist's rendering of a future East-West busway in the Loop.

FIGURE 3.3 A Future East-West Busway on Adams Street (Reference 3-7)

FIGURE 3.4 A Future East-West Busway under Monroe Street (Reference 3-7)

In summary, Chicago is considering two plans to connect the east and west sides of the Loop: a short-term plan (before 2011) placing bus lanes on Adams and Monroe Streets (referred to as the East-West Bus Lanes), and a long-term plan (2012-2016) that would connect the West Loop Transportation Center to McCormick Place via a busway under Monroe Street (referred to as the Monroe Busway) and the currently existing Lakefront Busway.

Currently, there already exists a bus lane on Adams Street. However, the lane is not truly exclusive because of the presence of illegally parked cars, right turning vehicles and vehicles exiting/entering driveways. These problems could potentially be solved by adding a physical barrier of some type (Figure 3.3), eliminating all conflicting driveways and using traffic signal priority to deal with right turning vehicles. The barrier would also permit automatic steering control, and thus reduce the required lane width. The same may also said for Monroe Street, which currently is not used by the CTA bus fleet.

The initial plans for the Monroe Busway have already been completed by TranSystems Corporation under contract to the Chicago Department of Transportation (CDOT). The plan envisions a three-lane busway with eight docking stations, transporting people between Michigan Avenue and Clinton Street. The basic layout and docking stations are pictured in Figures 3.5 and 3.6.

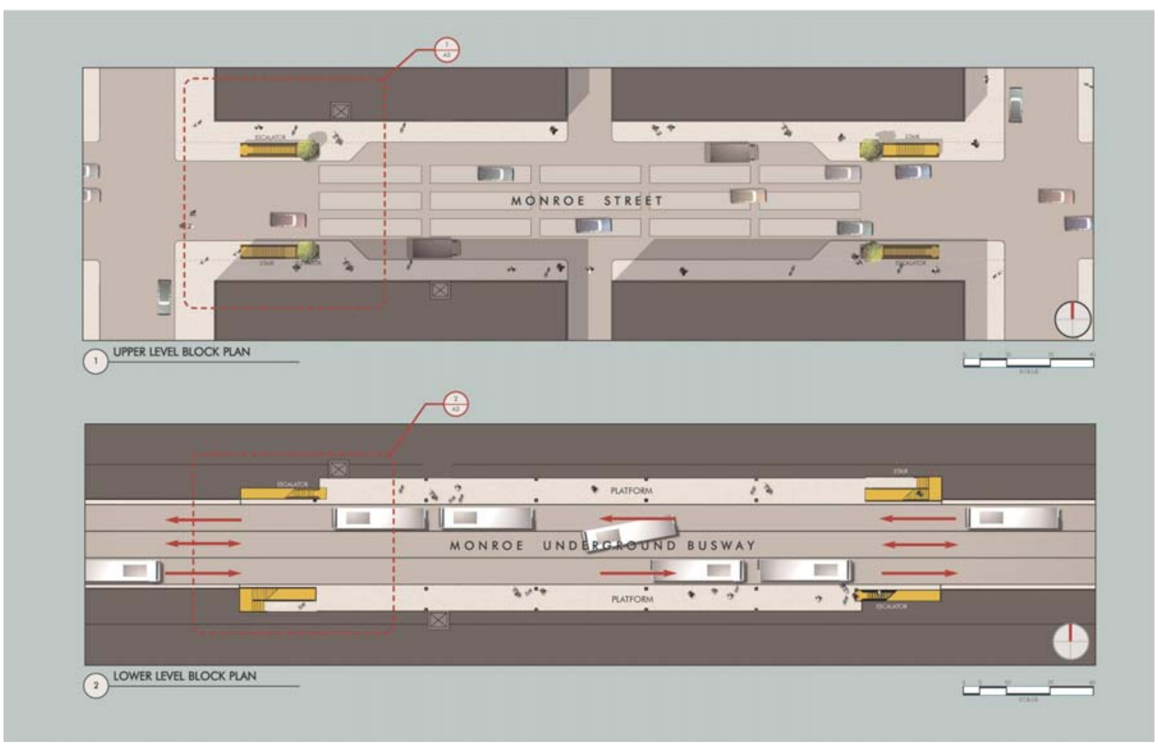

FIGURE 3.5 Top View of Proposed Monroe Busway (Source: TranSystems, Inc. and Chicago Department of Transportation)

As can be seen from Figure 3.5, the center lane runs in both directions. It would allow docked buses at a particular bus stop to be passed by other buses that have already docked and picked up passengers, or buses that do not provide service to that stop. It would also make it possible for emergency vehicles to use the busway when absolutely necessary.

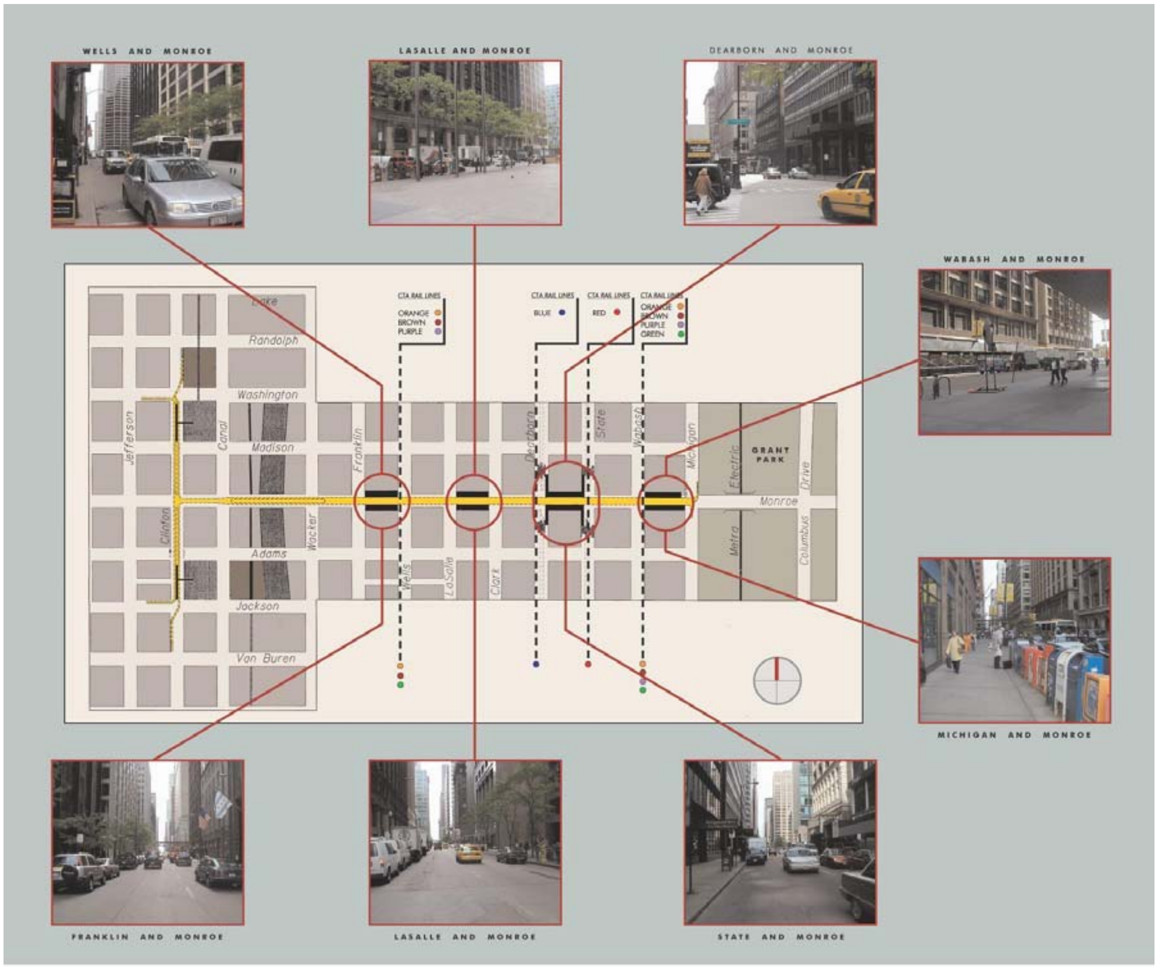

FIGURE 3.6 Monroe Busway Docking Stations (Source: TranSystems, Inc. and Chicago Department of Transportation)

Each platform, as well as each lane, would be 12 feet wide. Grating above each lane will function to provide natural lighting and give the busway a more "open" feeling. Kiosks at the street level will lead into the escalators and elevators to transport people to and from the busway. These features are illustrated in Figure 3.7.

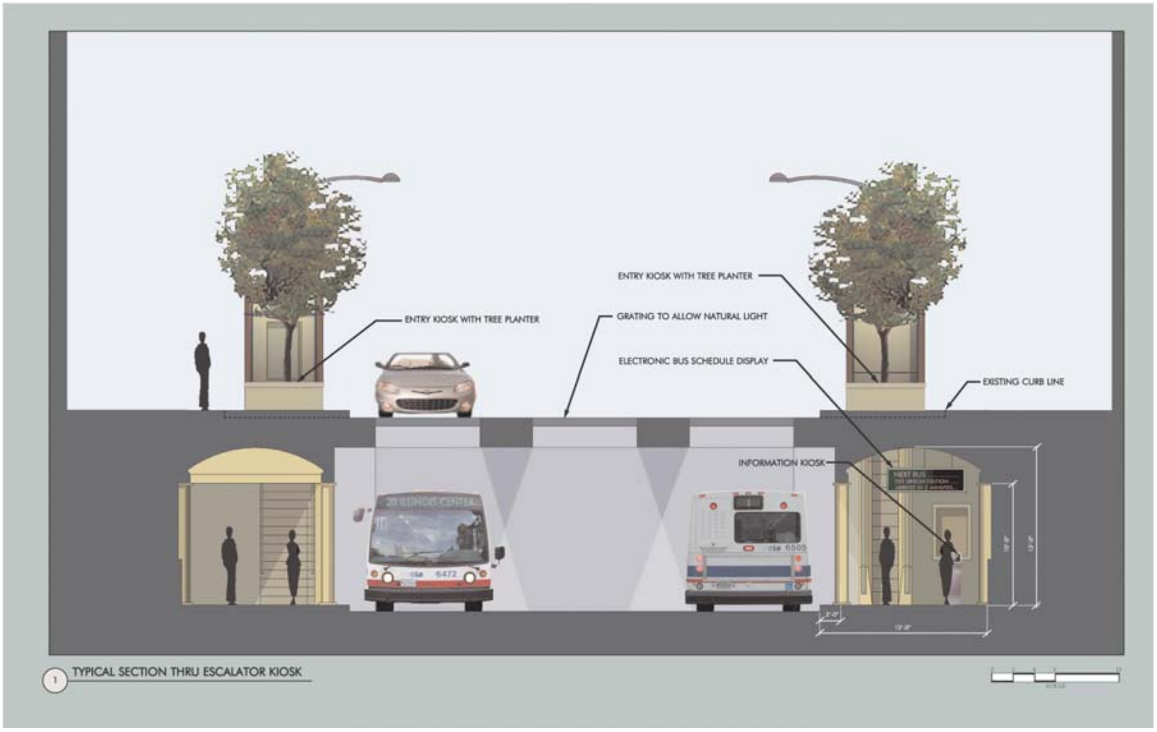

FIGURE 3.7 Front View of Proposed Monroe Busway (Source: TranSystems, Inc. and Chicago Department of Transportation)

Going from west to east, the busway starts out at the West Loop Transportation Center, where it connects to the proposed underground Clinton Busway and also has a set of portals. It then goes underneath the Chicago River and then returns to just below street level, extending over the existing Dearborn and State Street Low Level Subways. Some buses would dock at each of the stations, while others will likely pass through the entire busway without stopping. While portals will exist at Michigan Avenue, there is also strong consideration to providing a direct connection to the Lakefront Busway. The total length from Clinton St. to the Lakefront Busway is 0.97 miles.

3.2 Selection of Case Study Alignments

We met with the project stakeholder advisory committee – consisting of members from CTA, CDOT and RTA in September 2002. During this meeting the project team presented information about CVHAS technologies and concepts to the stakeholder advisory committee. The stakeholder advisory committee proposed transit routes that could potentially benefit from CVHAS technologies both in the near term (in the next five to ten years) and in the long term. We examined the near and long term transportation environment for transit vehicles on these routes.

Figure 3.8 shows transit routes in the Chicago downtown area that could benefit from CVHAS technologies in the near term grouped by their right-of-way characteristics. In Figure 3.8 the red color denotes mixed traffic operations (CVHAS buses freely mixed with normal traffic), while blue denotes partially segregated transportation environment for transit vehicles.

Figure 3.9 shows transit routes in the Chicago downtown area that could benefit from CVHAS technologies on the long run grouped by their right-of-way characteristics. In Figure 3.9 again red denotes mixed traffic, blue denotes partially segregated and yellow denotes fully segregated transportation environment for transit vehicles. The original map from which Figures 3.8 and 3.9 were modified to show the location of the case study corridor; the CVHAS right-of-way characteristics are from the Chicago Central Area Plan (CCAP) in Reference 3-7, in which the original figure in that document is Figure 3.2.8.

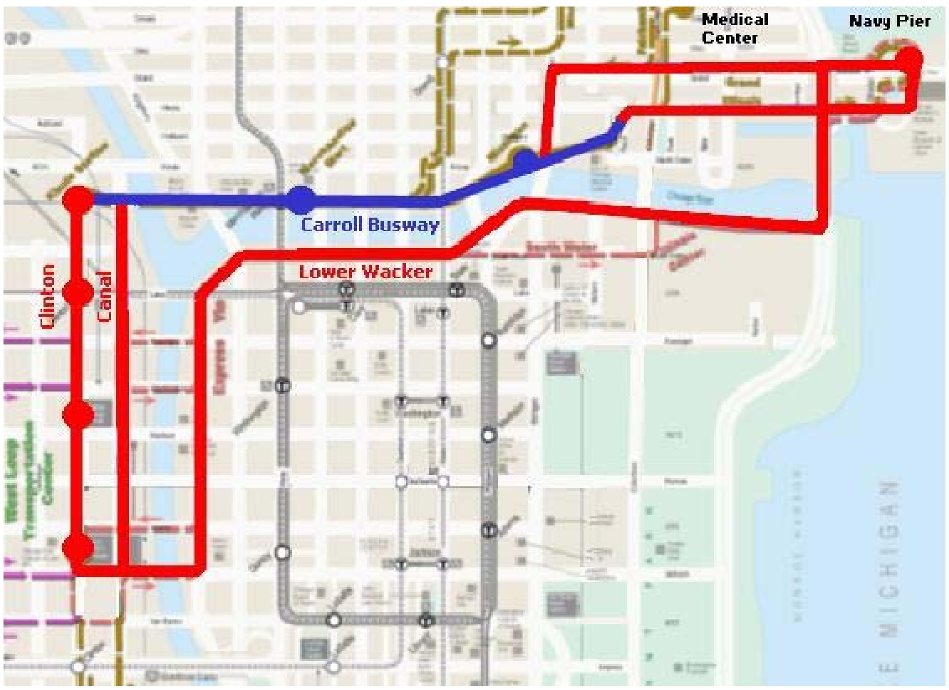

FIGURE 3.8 Routes in Downtown Chicago Potentially Benefiting from CVHAS Technologies in the Near-Term (Reference 3-7)

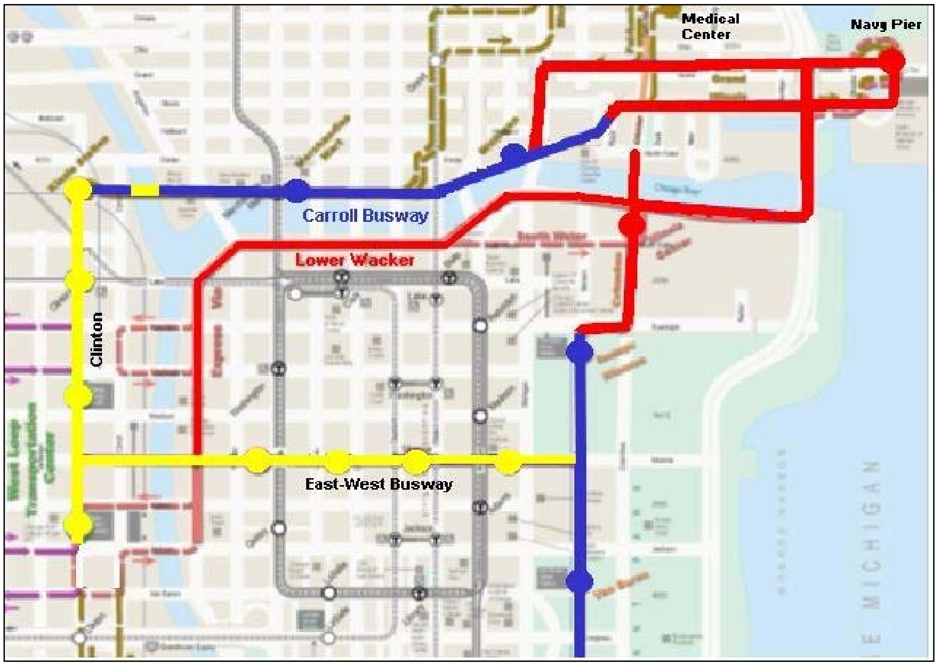

FIGURE 3.9 Routes in Downtown Chicago Potentially Benefiting from CVHAS Technologies in the Long-Term (Reference 3-7)

During our meeting the stakeholder advisory committee recommended the following three case studies for primary attention shown in Figure 3.10:

- East-West At-Grade bus-only lanes on arterial streets – Near-term alternative
- East-West Underground "Monroe" Busway – Long-term alternative
- Clinton-Carroll Avenues Busway – Long-term alternative

3.3 Method Applied in Case Studies

For each of the three case studies, that is, the near-term East-West Loop arterial scenario, the long-term underground Monroe busway, and the long-term Clinton-Carroll Avenue busway, we perform incremental benefit cost analysis of CVHAS technologies on the case study transit corridors. In such incremental analysis we isolated and measured the benefits and costs due to applying CVHAS technologies.

First, we describe the case study corridor in its current state through current data and map. We give information about the running way characteristics, such as number of lanes, lane width, intersections, traffic signals; what type of traffic environment the future bus operation will take place in term of segregation from general traffic; stop locations and characteristics; transit routes currently using the corridor; current transit operation characteristics, such as travel time, operating hours; and passenger demand, where available. This will establish the location, the physical and transit operational characteristics of the corridor studied.

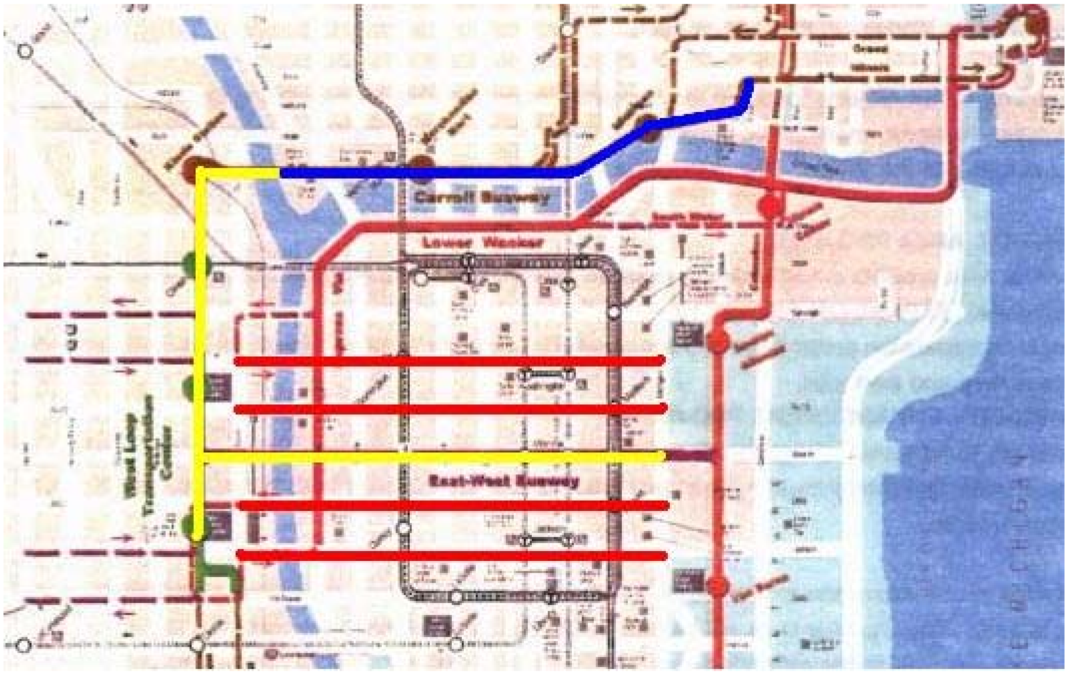

FIGURE 3.10 Three Bus Transit Case Study Corridors (Reference 3-7)

Second, we discuss, for each of the three scenarios, the particular areas where CVHAS technologies may be used and benefits gained. For example, in the near-term east-west scenario, we discuss collision warning systems, precision docking, and traffic signal priority as the CVHAS technologies most appropriate for application here.

Third, we discuss the data inputs that are required, appropriate performance measures to use to measure the effects of CVHAS technologies, and anticipated benefits of CVHAS technologies. Next, we discuss our evaluation and present our findings for each of the specific areas for each of the three scenarios, which includes a determination of benefit-cost ratios, a "break-even" analysis and a sensitivity analysis of initial findings.

3.4 East-West At-Grade — Near-Term Case Study

3.4.1 Case Study Corridor

The following sections will describe the case study locations.

Currently, the two one-way pairs of East-West arterial streets that are major transit corridors are:

1. Washington Ave. – East bound with Madison Ave. – West bound;
2. Adams Ave. – East bound with Jackson Ave. – West bound

They are marked as four parallel red lines on the map of downtown Chicago in Figure 3.10. The corridors are marked between Canal Street and Michigan Ave. There are 10 major North-South bound streets crossing the East-West arterials between and including Canal and Michigan.

Currently, Madison Ave. has four lanes: the right most is a bus-only and right turn only lane. Right turn is allowed at every other cross street. The lane's width is mostly 13' with the exception between Wells Street and Wacker Drive, where it is only 10'. The two middle lanes are straight through lanes while the left-most lane is left only at every intersection.

Washington Ave. has similar configuration. Here the bus lane is mostly 10'wide, with the exception between Wacker Drive and Franklin Street where it is 15'. Before any intersection where a left turn is allowed a fifth lane is squeezed in.

Both Adams and Jackson Ave. have three lanes with the right-most lane a bus-only and right turn only lane. On Adams the bus-only lane is mostly 10' wide, while on Jackson it is mostly 12'.[2]

Cars use bus lanes for right turns. No parking is allowed in the bus-lanes at any time. This is enforced by police and towing. Trucks are prohibited to stop in the bus lane in peak time but they can use the bus lane to turn into loading docks.

Bus stops are on-line, mostly located on the near side of the intersections.

Through the Loop area the traffic signals are directed by a computer system. However, there is no central control. All control needs to be manually reprogrammed at each intersection. Signals operate on a simultaneous 75 second cycle that starts on zero second offset North-South bound. Pedestrian and arrow turn signals vary by intersection. For pedestrians, "Don't walk" is displayed during arrow turning signal phase. Based on information from CDOT, there is no data on pedestrians blocking right turning traffic. CTA does not have data on how much time buses spend stopped at red lights. Currently, there is no signal priority anywhere in Chicago.

Buses serving the Loop area are stationed at two bus depots. The fleet is made up of conventional and low floor buses, and both are used on the currently examined routes.
1. Bus Depot #1: Total # of buses: 234, low floor: 117
2. Bus Depot #2: Total # of buses: 221, low floor: 122

Buses are not equipped with any kind of AVL technologies.

Peak periods in the Loop Area are:

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[2] Washington Avenue from Austin to Michigan, Pavement markings, Last revised at 2-08-01
Madison Avenue from Austin to Michigan, Last revised at 2-08-01
Jackson Avenue from Jefferson – Michigan, Concurrent bus lanes, Last revised at 2-16-01
Jackson from Austin to Lake Shore, Last revised at 5-1-92
Adams Avenue from Jefferson – Michigan, Concurrent bus lanes, Last revised at 2-9-01
All drawings Prepared by the City of Chicago, Department of Public Works, Bureau of Traffic Engineering and Operations (Reference 3-9)

AM: 7:00-9:30AM all direction
PM: 3:30-7:00PM all direction

Transit operation is schedule based. Buses can enter regular traffic (leaving the bus lane) to over take slower moving buses, or illegally parked vehicles. Passengers board only at the front door, but alight anywhere. Fare collection is either by coins or cards (either feed-into-reader or proximity card).

Table 3.1 shows the routes currently using the Washington-Madison arterials:

TABLE 3.1 CTA Bus Routes on Washington-Madison Streets

Washington E – Madison W			
Bus number	**Headway**	**Travel time**	**Comment**
14 E	12 min in AM **4-7 min in PM**	W/Jefferson – Balbo/Michigan 12 min	Express PM
14 W	3 -6 min in AM **12 min in PM**	Madison/Michigan – W/Jefferson 16-18 min	Jeffery express AM
20 E	7:00-8:20 5min AM 8:20-9:30 6-8 min AM **3:30-6:00 5-9 min PM** **6:00-7:00 9 min PM**	NA	Owl service
20 W	7:00-8:00 8min AM 8:00-9:30 5min AM **4-6 min in PM**	NA	
56 E	8-10 min AM **8-10 min PM**	NA	
56 W	10 min AM **8-10 min PM**	NA	
157 E	7:00-9:00 9 min AM 9:00-9:30 12 min AM **3:30-5:00 10min PM** **5:00-7:00 15min PM**	Canal/Adams (Union st) to Randolph/Mich 12 min	
157 W	10 min AM **3:30-6:00 10min PM** **6:00-7:00 15min PM**	Mich/Randolph to Clinton/Jackson 13min	

Data in table is from Reference 3-10.

Based on the published schedule, scheduled travel time on Washington between Jefferson and Michigan is 14 minutes; on Madison between Michigan and Jefferson it is 16 minutes.

Because there are multiple routes on this section on Madison – Washington Avenue there is a bus every 2 minutes for passengers traveling within the Loop Area. This data is verified from CTA's bus schedule as presented in Tables 3.2 and 3.3. There is a bus on average every 1.7 –

2.4 minutes on these two arterials between Canal and Michigan. However, those who wish to travel further out away from the Loop Area must wait for their bus. Then the headway is based on schedule and it is anywhere between 3 to 15 minutes, depending on the route.

TABLE 3.2 Frequency of Buses on Washington Avenue During Peak Periods

Washington Avenue	**AM**		**PM**	
	Headway	**Number of buses per hour**	**Headway**	**Number of buses per hour**
14 E	12 min	5	4 – 7 min	15 – 8.5
20 E	5 – 8 min	12 – 7	5 – 9 min	12 – 6.6
56 E	8 – 10 min	7.5 – 6	8 – 10 min	7.5 – 6
157 E	9 min	6.6	10 – 15 min	6 – 4
Total	**1.9 – 2.4 min**	**31 – 24.5**	**1.5 – 2.4 min**	**40.5 – 25**

TABLE 3.3 Frequency of Buses on Madison Avenue During Peak Periods

Madison Avenue	**AM**		**PM**	
	Headway	**Number of buses per hour**	**Headway**	**Number of buses per hour**
14 W	3 – 6 min	20 – 10	12 min	5
20 W	5 – 8 min	12 – 7	4 – 6 min	12 – 6.6
56 W	10 min	6	8 – 10 min	7.5 – 6
157 W	10 min	6	10 – 15 min	6 – 4
Total	**1.4 – 2.1 min**	**44 - 29**	**2 – 2.8 min**	**30.5 – 21.5**

The scheduled time to complete these cross-town runs is not directly accessible because no time points on any of the routes listed in Table 3.4 corresponds to the section we are investigating. Time points are located such that they indicate scheduled travel time for a longer section of the route that includes the section between Canal and Michigan. However, it is not unreasonable to expect similar scheduled times to those on the parallel cross-town routes on the Madison/Washington pair.

TABLE 3.4 CTA Bus Routes on Jackson-Adams Streets

Jackson E – Adams W			
Bus number	**Headway**	**Travel time (schedule based)**	**Comment**
126 E	7:00-8:30 5-9 min AM 8:30-9:30 10 min AM **3:30-6:00 10 min PM** **6:00-7:00 12min PM**	NA	Main route
126 W	7:00-8:30 5-9 min AM 8:30-9:30 10 min AM **3:30-5:00 8 min PM** **5:00-6:00 10 min PM** **6:00-7:00 15 min PM**	NA	
151 E	7:00-8:00 8 min AM 8:00-9:30 12-14 min AM **2-8 min PM**	NA	
151 W	Irregular schedule: 1-10 min average: 7:00-8:30 4min AM 8:30-9:30 5-12 min AM **5-12 min PM**	NA	151 L starts operating at 6:41PM
1 E	12 min AM **12 min till 6:40 PM**	NA	Indiana/Hyde Park Rush hours only
1 W	12 min AM **12 min till 6:30 PM**	NA	Rush hours only
60 E	7 min AM **3:30-6:00 6-12 min PM** **6:00-7:00 15min PM**	NA	
60 W	7:00-8:00 8 min AM 8:00-9:30 7-10 min AM **3:30-6:00 7-10 min PM** **6:00-7:00 12 min PM**	NA	
7 E	15 min AM **3:30-6:00 15 min PM** **6:00-7:00 20 min PM**	Jackson/Canal - Congress pl 12 min	Harrison
7 W	15 min AM **3:30-5:00 12 min PM** **5:00-6:00 15 min PM** **6:00-7:00 20 min PM**	NA	

Data in table is from Reference 3-10.

Bus headway is on average between 1.35 – 2.3 minutes on Jackson, and 1.45 – 2.5 min on Adams Avenue between Canal and Michigan. However, those who wish to travel further out away from the Loop Area must wait for their bus. Then the headway is based on schedule and it is anywhere between 2 to 20 minutes, depending on the route. Tables 3.5 and 3.6 show the frequency of buses on Jackson Avenue during the peak periods.

TABLE 3.5 Frequency of Buses on Jackson Avenue During Peak Periods

Jackson Avenue	AM		PM	
	Headway	**Number of buses per hour**	**Headway**	**Number of buses per hour**
126 E	5 – 10 min	12 – 6	10 – 12 min	6 – 5
151 E	8 – 14 min	7.5 – 4	2 – 8 min	30 – 7.5
1 E	12 min	5	12 min	5
60 E	7	8.5	6 – 15 min	10 – 4
7 E	15 min	4	15 – 20 min	4 – 3
Total	**1.6 – 2.2 min**	**37 – 27.5**	**1.1 – 2.4 min**	**55 – 24.5**

TABLE 3.6 Frequency of Buses on Adams Avenue During Peak Periods

Adams Avenue	AM		PM	
	Headway	**Number of buses per hour**	**Headway**	**Number of buses per hour**
126 W	5 – 10 min	12 – 6	8 – 15 min	7.5 – 4
151 W	4 – 12 min	15 – 5	5 – 12 min	12 – 5
1 W	12 min	5	12 min	5
60 W	7 – 10 min	8.5 – 6	7 – 12 min	8.5 – 5
7 W	15 min	4	12 – 20 min	5 – 3
Total	**1.3 – 2.3 min**	**44.5 – 26**	**1.6 – 2.7 min**	**38 – 22**

For all routes on all four arterials, the examined section between Canal and Michigan is only a small section of the total routes. We do not have data on the percentage of passenger demand that uses buses only in the Loop area. Only these passengers can take any route on this section. All other passengers have to wait for their own bus. CTA does not collect passenger data per stop and estimates of average daily passenger demand per route are based on fare box collections. Data are shown in Appendix II.

Currently, we have inconsistent run-time information for these arterials between Canal and Michigan:

- From the published schedule:

East-bound: Washington/Jefferson to Balbo/Michigan: 12 minutes
West-bound: Madison/Michigan to Washington/Jefferson: 16-18 minutes

- From the field data collection:

West bound between Wabash and Canal (excluding dwell time at Canal) 7.21 min. or 433 sec or if dwell time at Canal is included, 8 min or 480 sec.

East bound between Canal and Wabash (excluding dwell time at Wabash) 7.58 min or 455 sec (data does not exist to include dwell time at Wabash).

A possible explanation for the inconsistency is if the published schedules include some additional slack time to allow for unanticipated delays that may not have been encountered during the times that the field data was collected. More detailed data on the bus routes along these four parallel arterials may be found in Appendix III.

3.4.2 Evaluation of Near-Term East-West Alternatives in the Loop

3.4.2.1 Collision Warning Systems

Collision warning systems could augment the driver's normal driving and could provide alerts to hazards of which he may be unaware, and could also help out in conditions in which the driver is distracted or less than fully alert, e.g., due to fatigue. Such systems may take the form of forward, rear, and side hazard warnings and can be delivered to the driver by either auditory, haptic, or visual cues. The driver retains responsibility for corrective actions based on the warnings provided. Technologies that may be used in these systems include radar, ultrasound or laser sensors and threat assessment software and the driver interface.

Our objective in this analysis was two-fold, again focusing on the four east-west streets in the Loop (Madison, Jackson, Adams, Washington). First, we assessed the impact that equipping CTA buses with collision warning systems would have on the number of crashes involving these buses; that is, how many crashes might have been avoided had the bus been equipped with CVHAS technologies. Second, we estimated the return on investment from deployment of collision warning systems.

The first step in our investigation was to examine CTA incident data records for 2002, followed by a more concentrated examination of those incidents occurring on the four east-west streets (Madison, Washington, Adams, and Jackson). The last stage in our evaluation was to assess the return on investment from having CTA equip those buses running on the four east-west Loop arterials.

We began our assessment with an examination of CTA incident data for 2002, which is the most recent year for which there are complete records. In total there were 407 records in the database, of which 12 records were duplicates, and 5 records indicated the apparent incident was not a real incident at all. Thus there were a total of 390 records remaining, of which 134 (34.4%) were located on one of the four east-west streets. In the database were included fields such as incident location, date, time-of-day, whether there was an injury, the type of incident as described by one of more of the Supervisory Call Codes[3], and remarks/details written at the time of the incident. We examined closely these remarks to discover what action the bus was taking at the time of the incident and the point of contact on the bus of the crash.

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[3] The Supervisory Call Codes are the shorthand expressions that CTA personnel use to communicate information from the site of the incident to CTA offices. For example, common codes appearing in the database include "10-73" and "10-71", which mean "Collision of CTA vehicle and other vehicle" and "Collision of CTA vehicle and fixed object, respectively.

Upon examining the database, we grouped the incidents into several categories by type within which the records were aggregated as shown in Table 3.7. We have highlighted in bold italics those incidents that we believe might have been avoided with the implementation of collision warning systems on the buses. This belief is based on the current state of knowledge in research, development, testing, and evaluation of collision warning systems and these systems are likely to become available within the next ten years.

For two types of incidents, #s 1 and 2, proximity warning systems could help in these situations, but are only effective at very short range (up to a couple of meters), which means that they can only be used when the vehicle is moving very slowly (squeezing into a parking space). These incidents likely occurred with vehicles moving faster, not on straight trajectories, and with considerably less well-defined target obstacles (such as the mirrors of other buses or trucks). Moreover, detecting these impending crashes is very difficult. For incident type #10, these door-opening impacts occur with so little lead time that it is unlikely that any system would be able to detect the door opening and issue a readily-understandable warning in nearly enough time to cause the person to stop opening the door before hitting the bus.

TABLE 3.7 Distribution of Incident Types in the Loop in 2002

INCIDENT TYPE	NO INJURIES	WITH INJURIES
1. Bus drivers misjudged lateral clearance	59	1
2. Bus hitting a passenger	1	2
3. Failed brakes	1	0
4. Flying debris	1	0
5. Frontal crash	***4***	***1***
6. Insufficient information	155	7
7. Nature/Act of God	1	0
8. Other drivers misjudged lateral clearance	81	3
9. Passenger falling/hitting self boarding, while on or after alighting bus	1	6
10. People opening car doors hitting side of bus	15	0
11. Rear crash	***16***	***6***
12. Rear and frontal crash	***1***	***1***
13. Sideswipe crash	***2***	***1***
14. Turning corners, interfering with other vehicles	5	0
15. Vehicles cutting in front of buses or trying to squeeze around their sides	16	3
Total number of incidents	359	31

We also observe from the table the enormously large number of records for which there was insufficient information in the database to ascertain either what the bus was doing at the time of the incident or the point of impact on the bus. These "insufficient information" records account for approximately 42% of the 390 records in the database.

Furthermore, the only information regarding the severity of the injuries contained in the database were phrases such as “transported to hospital”, “serious injury”, “refused medical attention”, and “refused hospital transport”. Approximately one-third of the 31 incidents with injuries resulted in either a trip to the hospital (we have no follow-up information on the severity of such injuries) or mention of the word “serious” in the records. Of the 9 incidents classified as either a front, rear, or side crash, two were described in the database with the phrase “transported to hospital”, otherwise either no description was given or the phrase “refused medical attention” was used.

The next stage of the analysis was to focus on those incidents that took place on one of the four east-west streets (Madison, Washington, Adams, or Jackson) and to account for the 162 incidents that were initially classified as “insufficient information”. For the “insufficient information” incidents, we redistributed them among the remaining types, i.e., types 1-5 and 7-15, consistent with the percentage distribution for these incidents. After this redistribution, we scaled down the number of incidents from the entire Loop to the four streets previously mentioned—the focus of this analysis. The results of this two-stage redistribution and scaling are shown in Table 3.8.

TABLE 3.8 Distribution of Incident Types on Four Arterials in the Loop in 2002 After Redistribution and Scaling

INCIDENT TYPE	NO INJURIES	WITH INJURIES
1. Bus drivers misjudged lateral clearance	36	0
2. Bus hitting a passenger	1	1
3. Failed brakes	1	0
4. Flying debris	1	0
5. Frontal crash	**2**	**0**
6. Nature/Act of God	1	0
7. Other drivers misjudged lateral clearance	49	1
8. Passenger falling/hitting self boarding, while on or after alighting bus	1	3
9. People opening car doors hitting side of bus	9	0
10. Rear crash	**10**	**3**
11. Rear and frontal crash	**1**	**0**
12. Sideswipe crash	**1**	**0**
13. Turning corners, interfering with other vehicles	3	0
14. Vehicles cutting in front of buses or trying to squeeze around their sides	10	1
Total number of incidents	123	11

We also observe that there is one incident that was classified as both a rear and frontal crash and so is counted in both those categories. In summary, we have derived the following distribution of frontal, rear, and side crashes with and without injuries on the four east-west streets in the Loop (Table 3.9).

TABLE 3.9 Distribution of Crashes on Four Arterials in the Loop

	No Injuries	With Injuries
Frontal	3	0
Rear	11	3
Side	1	0

The next stage of the analysis is to evaluate the return on investment from having CTA equip their buses, that is, those buses running on the four east-west Loop arterials. There are several parameters to consider for this evaluation. To assess the benefits associated with equipping CTA buses with these collision warning systems, we require an estimate for the cost of such crashes, but these data are not available from CTA. In the absence of such data, we have relied on other data that are available, even though they apply to different transit properties.

According to Reference 3-11, the average cost over five California transit agencies of frontal, rear, and side crashes is $9,221, $1,128, and $3,353, respectively. We assume that these costs are for non-injury crashes. To estimate the costs of equipping CTA buses with these three systems, we require the cost of equipping each type of system and the number of buses that would need to be equipped. Based on current knowledge of such systems and what is likely to be implemented in 2010, we estimate that the cost of equipping one bus with frontal, rear, or side collision warning systems will cost, respectively, $2,000, $2,500, and $500. Even if such collision warning systems were to be implemented on buses together as a single forward-rear-side collision warning system, it is unlikely that there would be significant economies of scale or synergistic effects whereby the integrated system would be much less expensive than the sum of the individual costs for the three systems implemented separately.

We assume a 15-year lifetime for each bus and equipment and a 7% discount rate. We have to estimate the total benefits associated with the implementation of each of the three types of collision warning systems over the course of the 15 years. These benefits depend on the crash profile (Table 3.9), which we assume here will follow that for the year 2002, that is, as given by the number of crashes for each type of crash in Table 3.

Based on peak period headways for the bus routes traveling on the four arterials, we have estimated there to be 165[4] buses that would have to be equipped with front, rear, and side collision warning systems. From Table 3.9, only rear crashes involved injuries and initially we assume that these were not serious injuries and so we initially used the same average cost for a rear crash with or without injuries, i.e., $1,128 per rear crash. Initially we derive the following results, shown in Table 3.10.

[4] We estimated the number of buses needed to service a route in the PM peak by following these steps for each route:

1. Determined loop runtime of the route from CTA bus schedule
2. Determined frequency of buses on the route
3. Assumed layover of one headway or minimum 10 minutes except in the case when buses operate more frequently than one bus every 10 minutes in which case we allowed for a layover of two headway periods.
4. Assumed that there is 1 backup bus for every 10 buses based on estimating the number of buses needed from the schedule and comparing this value with the data that the team collected out in the field.
5. Calculate number of buses needed = {loop run time + layaway}/frequency + backup buses

TABLE 3.10 Net Benefits and B/C Ratio for Collision Warning Systems

Interest rate	0.07	0.07	0.07
Lifetime (years)	15	15	15
Total benefits	$27,663	$15,790	$3,353
Number of buses	165	165	165
Cost per bus	$2,000	$2,500	$500
Total cost	-$330,000.00	$412,500.00	-$82,500.00
Present value of benefits	$251,956.14	$143,810.58	$30,536.11
Net benefit	($78,043.86)	($268,689.42)	($51,963.89)
B/C ratio	0.76	0.35	0.37

From Table 3.10, we see that the return appears not to be worth the investment for the three crash types. However, the B/C ratios for the different kinds of crashes are within a factor of one of each other, so the investment decisions are "borderline" for each type of collision warning system, within the margin of error based on the uncertainties in the analysis. Recall that our sample size is small and with the presence of more injuries or more serious injuries, the costs are going to be considerably greater and the resultant total benefits would increase, thus making the net benefit increase as well.

3.4.2.2 Precision Docking

Since precision docking is a relatively new transit service function and not widely used, there are definitive quantitative sources of data that can be cited about its benefits. There are two primary kinds of benefits it can offer:

(a) Improving the amenity value and status of bus transit, by making it more like rail transit. This is particularly difficult to quantify, but in the long term it should be manifested as a ridership increase. In the absence of precision docking, an alternative way of providing the "gapless" boarding of a bus, without passengers having to step across a gap or up a step, would be by deploying the wheelchair ramp for passengers to board from the curb. PATH has measured the time needed to do this on its New Flyer buses, and has found the complete cycle to extend and retract the simplest flip-style ramp to be 30 seconds. This would be a significant penalty to bus travel time, but provides an indication of how this amenity value could be provided in the absence of precision docking.

(b) Reducing the time needed for passenger boarding and alighting. This should be easier to quantify, but there are no references available to provide specific values for time saved. The actual time saving will depend on many factors, and is likely to have large variability across transit properties, as well as from stop to stop within the same property. The factors that will influence the boarding and alighting times include:

- Low floor or high floor bus
- Fare payment policy (off-board, onboard cash or card)
- Door-use policy for boarding and alighting

- Bus positioning at stop (closeness to curb, presence of obstacles, snow, or running water in gutter, height and condition of curb)
- Weather conditions
- Passenger mix, including proportion of:
    - Young and agile
    - Parents escorting children
    - Elderly and frail
    - Carrying packages
    - Wheelchair-bound or on crutches

It is not practical to develop a comprehensive data set to address all of these issues. Precision docking has an obvious direct influence on the bus positioning at the stop, and its potential for time saving will depend heavily on the passenger mix, which is a variable that is impossible to control. In order to focus attention on the effect of precision docking rather than the other influences on boarding and alighting time, we will assume that it will be applied only to the newer low-floor buses. While off-board fare payment and flexible door-use policies can speed up boarding and alighting and can be recommended in general to reduce dwell times at stops, their potential interactions with precision docking are beyond the scope of the current evaluation.

The cost-effectiveness of precision docking in the Loop Area can be addressed from two different perspectives. On the one hand, after estimating the costs of implementing the docking capability, we can estimate how much time saving would be sufficient to "break even" over the lift of the bus. On the other hand, we can estimate several possible credible levels of time saving and determine what their benefit/cost ratios would be. In the absence of hard data on time savings, we will bound the problem by approaching it from both directions.

The systems that enable buses to be steered automatically, both at bus stops for precision docking and while driving at cruising speed, require the investment in essentially the same elements on the buses and the roadway infrastructure: reference markings to define the desired path of the bus and the following in-vehicle components: lateral position sensors, steering actuator, control computer and driver interface. The reference markings and position sensors can be based on a variety of different technologies, but the other elements are largely unaffected by the choice of technology. At PATH, we have experimented with magnetic, machine vision and GPS systems for the reference/sensing technologies and have found the magnetic system to provide the highest accuracy and robustness, which is particularly critical for the performance needed to provide precision docking.

The costs of the in-vehicle components are very sensitive to the number of units produced, particularly because of the need to amortize up-front development costs. We have estimated these costs for two different assumed rates of annual production of vehicle guidance systems (which could include trucks as well as buses). These represent higher costs in the near term, when production volumes are lower, and lower costs in the long term, when the production volumes are higher, as shown in Table 3.11

TABLE 3.11
Unit Costs of Precision Docking Technologies

Element	Production of Hundreds (near term)	Production of Ten Thousand (long term)
Steering actuator	$2500	$ 500
Magnetic sensors	$5000	$1000
Computer and interfaces	$5000	$1000
Driver interface	$1000	[included]
Installation/ integration	$ 500	$ 200
Total	$14,000	$2700

Thus we estimate the cost per bus of implementing precision docking to be about $14 K in the relatively near term. The infrastructure improvements needed to complement the vehicle improvements are two: installation of reference markings at the bus stops and construction of boarding platforms that will be level with the bus floor. If the reference markers are magnets, their installation will likely cost about $500 per stop (50 magnets at $10 each), and the boarding platform could add another $2000 per stop. For the routes serving the two one-way pairs of streets under consideration, there will be about 24 bus stops to equip, for a total cost of about $60 K. If this cost is assigned to 165 buses providing the cross-town services in the Loop, it will add an average of about $360 to the cost per bus. In order to be conservative, we round up the cost per bus to $15 K.

The eleven cross-town Loop bus routes have different numbers and patterns of stops and different route lengths. Without going into intimate detail on each route, we estimate that on average each bus makes 12 stops on its east-west round trip through the Loop Area, and does an average of 8 round trips per day, for a total of 96 daily stops. With about 260 weekdays of annual operation, plus a lower level of weekend service, we can estimate an average of approximately 300 annual operating days of 96 stops for each bus, for an annual total of 28,800 stops.

CTA reports an average operating cost of $81.64 per hour for its buses, which should be the minimum consideration in the value of time saved by precision docking at the bus stops. However, the value of time of the passengers on those buses should not be ignored. In the absence of hard data on the occupancy of the buses in the Loop Area, we can estimate several different occupancy levels for consideration: 10, 20 or 40 passengers. At a value of time of $10 per hour per passenger, these would add $100, $200 and $400 per hour respectively to the direct CTA operating cost savings.

"Break-even" Analysis
Using a discount rate of 7%, and a bus life of 15 years, the $15 K per bus cost of implementing precision docking is amortized into an annual cost of $1647. This could be a "break-even" investment based on the following time savings (annually and per bus stop) in Table 3.12

TABLE 3.12 Time Savings: Annually and Per Bus Stop

	Annual Hours Saved	Seconds Saved per Stop
CTA Direct costs @ $81.64	20.17	2.52
CTA+10 passengers @ $181.64	9.07	1.13
CTA+20 passengers @ $281.64	5.85	0.73
CTA+40 passengers @ $481.64	3.42	0.43

So, even very small amounts of time saved at each bus stop from precision docking could be found cost effective, particularly when the value of passenger time savings is added to the direct operating cost savings by CTA.

Sensitivity Analysis Based on Assumed Docking Time Savings
The Transit Capacity and Quality of Service Manual (3-12) provides information on passenger boarding and alighting times for North American LRT services that can shed light on the potential for time savings from precision docking. These results show that access directly from the platform to the vehicle interior saves 1.5 sec/pass if all the passenger flow is in one direction (boarding or alighting) and 3.2 sec/pass when the flow is in both directions, compared to stepping up three steps from street level. Even a conservative use of this data to estimate time savings for precision docking could show significant benefits. If we assume a low-floor bus with a single step from ground to bus floor and assume that the time saving in this case would therefore only be 1/3 as large as it is for the three steps up into an LRT vehicle, the time saving per passenger would still be 0.5 seconds for one-direction passenger flow and 1.0 seconds for two-way flow. At the passenger flow rates per bus stop for the CTA routes in the Loop area, this would indicate a time saving per stop of *at least* 2 to 3 seconds with uni-directional passenger flow and twice that amount with bi-directional passenger flow per door.

We hypothesize several possible levels of time saving to see the sensitivity of the benefits and B/C ratios to these time savings. We have selected values of 5 and 10 seconds per stop as the primary sensitivity estimates, to allow for a mixture of cases in which most travelers save a fraction of a second, while others could save several seconds based on their mobility limitations. In addition, we have included a more extreme case of 30 seconds per stop to represent the "comparable amenity level" associated with deployment of the wheelchair ramp at each stop (recognizing that such a large additional delay at each stop would not be acceptable to most passengers).

Using the same value of time and docking system cost estimates as in the previous analysis, the savings and B/C ratios for these cases are in Table 3.13

TABLE 3.13 Savings and Benefit-Cost Ratio Findings: Near-Term Precision Docking

Time Saved per Stop (s)	CTA Saving	Avg. Pass. Load	Passenger Saving	Annual Saving Total per Bus	B/C
5	40 hr = $3265	10	$4000	$ 7,265	4.4
5	40 hr = $3265	20	$8000	$11,265	6.8
5	40 hr = $3265	40	$16000	$19,265	11.7
10	80 hr = $6530	10	$8000	$14,530	8.8
10	80 hr = $6530	20	$16000	$22,530	13.7
10	80 hr = $6530	40	$32000	$38,530	23.4
30	240 hr = $19590	10	$24000	$43,590	26.5
30	240 hr = $19590	20	$48000	$67,590	41
30	240 hr = $19590	40	$96000	$115,590	70.2

Regardless of the potential benefits that could be gained from saving time and improving the quality of bus service using precision docking, CTA has some serious concerns about the practicality of implementing the docking capability on the Loop area streets that must be shared with a multitude of other users and services. CTA is concerned that it will be difficult to implement precision docking, or to gain its benefits even it if is implemented, for reasons including:

- Sidewalks are narrow and cluttered, making it difficult to find space for the raised loading platforms that would be needed to provide seamless transfers from curbside to the bus floor;
- Raised loading platforms in this crowded environment could be a hazard for pedestrians;
- It is difficult to specify bus stopping locations precisely in this environment because of the closely bunched operations of the multiple bus routes, which sometimes require as many as four buses to access a stop on the same block at the same time;
- Buses often have difficulty accessing the stopping locations because of interference from parked vehicles or vehicles queued to make right turns at intersections, where they are often blocked by pedestrians crossing the streets;
- The curb areas are not well maintained and are subject to obstruction by debris, including snow, sometimes making it difficult for buses to pull up immediately adjacent to the curb.

3.4.2.3 Transit Signal Priority

Transit Signal Priority (TSP) in its simplest form makes it possible for a bus approaching an intersection during the final seconds of the green signal cycle to request an extension of the green cycle so that the bus can pass through before the signal turns red, thereby saving the bus and its passengers the red cycle time. This tends to provide some ancillary time saving benefits to the other vehicles traveling in the same direction as the bus, while increasing the time delays to the crossing traffic (3-13).

The Loop area is more amenable to potential use of TSP than many other areas because its streets are on a rectilinear grid and its traffic signalization pattern is currently very simple, with all signals simultaneously switching between green for north-south traffic and green for east-west traffic. More sophisticated signal patterns, particularly those with progressive “green waves”, would significantly complicate the design and evaluation of TSP alternatives. With the current signalization scheme, delaying the onset of red for an east-west bus at one intersection would provide some modest gains for the other east-west traffic on that street and some modest delays for the north-south traffic on the cross-street. If the cross-street traffic volume is significantly larger than the east-west volume, there could be net negative effects on area traffic. However, the available data for the Loop area indicates relatively equal traffic flows on the north-south streets and the east-west streets that have the bus lanes. The exceptions are Dearborn and State Streets, which carry significantly larger traffic volumes than the east-west streets with the cross-town bus lines, so perhaps TSP should not be applied (or should be applied more conservatively) at the intersections with those streets.

A detailed evaluation of traffic impacts should be done before implementation of any TSP scheme, but here we are doing a more general and preliminary evaluation of the potential benefits from TSP. At this level of analysis, it appears to be reasonable to assume that the effects on traffic other than the buses will generally cancel each other out for the north-south and east-west traffic, so attention can be focused on the potential time savings for the buses and their passengers.

A short yet informative summary of only the through traffic at intersections on the four arterials show that the north-south running streets carry traffic that is often greater than that carried by the east-west arterials (Tables 3.14 and 3.15).

TABLE 3.14 Through Traffic at Intersections in the Loop

	Canal	Upper Wacker	Upper Wacker	Franklin	Wells	La Salle	Clark	Dearborn	State	Wabash	Michigan
	↑	↓	↑	↑	↓		↓	↑		↓	↑↓
Washingt. → cross street	910 570	1050 800	930 870	1145 850	1250 560	1200 ↑450/↓625	1475 1505	850 985	705 ↑350/↓490	965 620	↑1210/↓1625
Madison ← cross street	1195 840	885 580	915 760	860 870	900 680	680 ↑445/↓530	700 1185	670 1135	640 ↑530/↓590	645 725	↑1160/↓1670
Jackson → cross street	555 **770**	890 400	690 280	575 860	990 1485	545 ↳775	1260 1165	595 980	585 ↑605/↓540	985 800	360 ↑1075/↓1125
Adams← cross street	765 700	650 500	660 430	300 420	580 525	480 ↑420/↓360	665 1245	675 1380	915 ↑1100/↓740	645 670	↑1170/↓1265

In each cell the upper number is the through traffic from east-west direction and the lower number is the through traffic on the north/south direction. Most streets are one-way, except for Wacker, La Salle, State, and Michigan. These traffic volumes do not include turning traffic, only through traffic. Yellow highlights the higher traffic volume direction.

TABLE 3.15 All Traffic (Through and Turning) at Intersections in the Loop

	Canal	Upper Wacker	Upper Wacker	Franklin	Wells	La Salle	Clark	Dearborn	State	Wabash	Michigan
	↑	↓	↑	↑	↓		↓	↑		↓	↑↓
Washingt. → cross street	1010 805	1150 890	1140 970	1275 1165	1450 760	1450 ↑650/↓825	1650 1785	1120 1155	1010 ↑420/↓535	1170 785	820 ↑1210/↓1625
Madison ← cross street	1280 1225	1045 825	1005 890	1045 1025	1015 880	950 ↑540/↓725	935 1355	880 1400	640 ↑630/↓720	865 925	 ↑1670/↓1945
Jackson → cross street	739 915	1035 550	890 315	760 995	1180 1580	735 ↳775	1430 1325	835 1050	730 ↑790/↓595	1320 945	805 ↑1340/↓1190
Adams← cross street	1345 700	730 760	800 455	470 570	655 715	665 ↑460/↓495	855 1460	900 1625	990 ↑1275/↓885	850 870	 ↑1670/↓1590

In this table all traffic (through and turning) from indicated direction is included (pink marks where higher volume direction changes).

Even though the traffic volumes in the North-South and East-West directions are of comparable magnitudes, it is important to keep in mind that each bus is carrying many more passengers than each passenger car. So, giving priority to a bus to avoid a red light (and saving all of its passengers an amount of time at least the length of the red cycle) is going to produce more benefits than the costs associated with a few seconds of delay to the car drivers waiting slightly longer for their green signal on the cross street. Because the traffic signal cycles in the Loop area tend to simultaneously provide green lights to all north-south traffic and then to all east-west traffic (rather than using more complicated "green wave" progressions), there is no reason to expect significant disruptions to cross traffic from a delay of a few seconds to permit a bus to traverse an intersection.

The key parameter in the design of a TSP scheme is the length of the "window" during which the green cycle would be held for a bus. In the Wilshire-Whittier BRT corridor in Los Angeles, they selected 10% of the signal cycle time. In the Loop Area, the signal cycle time is 75 seconds, and 10% of that would be 7.5 seconds, so we can look at the sensitivity of the results to windows of 5 and 10 seconds to surround this central value.

With relatively similar traffic volumes on most of the north-south and east-west streets in the Loop Area, a first approximation to the traffic signal cycle would be 35 seconds of green, 35 seconds of red and 5 seconds of amber for each direction. For any vehicle approaching an intersection, its probability of green is 35/75. However, a bus with 5 or 10 seconds of signal priority window could extend this to 40 or 45/75 respectively. Each red light avoided in this way saves the bus the length of the red cycle (35 seconds) plus time needed to re-accelerate to speed (perhaps another 10 seconds).

With nine intersections to pass in going across the Loop, each bus has an expected value of 9x35/75 red lights to encounter without signal priority, and each of those red lights will cost an average of 45 seconds of additional travel time. This represents an average traffic signal delay of 189 seconds for a one-way Loop traversal, or 378 seconds for a round trip. If we assume that signal priority is available at seven of those intersections (all except State and Dearborn), then the expected number of red lights is [2x35/75 + 7x30/75] for a 5-second priority window and [2x35/75 +7x25/75] for a 10-second priority window. These represent average traffic signal delays of 336 seconds and 294 seconds respectively for the Loop round trips, or average savings of 42 and 84 seconds respectively.

The observational data reported by UIC implies that red traffic signals were an impediment to buses leaving their stops only 17% of the time. However, the same data reported 39% of the stops being "normal", without indicating whether those also involved red traffic signals or whether the bus drivers simply held the doors open at the stop while waiting for the signal to change in their favor.

The cost of implementing TSP is heavily dependent on what capabilities are already installed on the buses and the local traffic signals before the start of the TSP implementation. However, a general rule of thumb based on experience in Los Angeles and Oakland, CA indicates a cost of about $100 K per mile. Applying this to the four cross-town arterials in the Loop Area would indicate a cost of about $350 K. This can be judged against the time saving benefits in the same ways that precision docking was evaluated in the previous section. In this case, the analysis is based on consideration of the Loop Area as a whole rather than on the basis of each individual bus.

The bus lines that provide cross-town service on the four major arterials under consideration offer services to a variety of other destinations, with service frequencies that vary significantly throughout the day. During the peak periods there are a total of 60 to 90 buses per hour, but during other times of the day the frequency of service is considerably less. If we assume four hours per day with an average of 80 buses per hour, an additional ten hours with an average of 40 buses per hour and five hours with 20 buses per hour, we get a total estimate of 820 cross-town round-trip bus runs per day. [Refined numbers can be derived from detailed review of the bus schedules.] Over the course of a year, this corresponds to 246,000 cross-town round trips.

"Break even" Analysis

Amortizing the TSP system cost of $350 K over a period of 15 years at a discount rate of 7% leads to an annualized cost of $38.4 K. This could be a "break-even" investment based on the following time savings (annually and per bus round trip of the Loop) in Table 3.16:

TABLE 3.16 Time Savings: Annually and Per Bus Round Trip

	Annual Bus Hours Saved	Seconds Saved per Loop Round trip
CTA Direct costs @ $81.64	470	6.9
CTA+10 passengers @ $181.64	211	3.1
CTA+20 passengers @ $281.64	136	2.0
CTA+40 passengers @ $481.64	80	1.2

Sensitivity Analysis Based on Assumed Values of Signal Priority Time Savings
Without knowing exactly how much time will be saved on each cross-town round trip from signal priority, we can still show a sensitivity analysis indicating what the benefits would be at several possible levels of average time saving. The first suggested values for time saving were derived from the analysis reported above, but if those values are questioned, the results can be extrapolated to other levels of time savings, including the much more modest estimate of 10 seconds saved per round trip.

TABLE 3.17 Savings and Benefit-Cost Ratio Findings: Near-Term Transit Signal Priority

Time Saved per Round Trip (s)	CTA Saving	Avg. Pass. Load	Passenger Saving	Annual Saving Total	B/C
42	2870 hr = $234 K	10	$287 K	$521 K	14
42	2870 hr = $234 K	20	$574 K	$808 K	21
42	2870 hr = $234 K	40	$1148 K	$1382 K	36
84	5740 hr = $468 K	10	$574 K	$1042 K	27
84	5740 hr = $468 K	20	$1148 K	$1616 K	42
84	5740 hr = $468 K	40	$2296 K	$2764 K	72
10	683 hr = $56 K	10	$68 K	$124 K	3.2
10	683 hr = $56 K	20	$136 K	$192 K	5.0
10	683 hr = $56 K	40	$272 K	$328 K	8.5

The savings in operating costs to CTA alone are substantial, but when the time of the passengers is added, the value of the savings increases significantly more.

3.5 East-West Underground Monroe Busway — Long-Term Case Study

The subject of our second case study is the long-term plan for the East-West directional transit in the Loop Area. Figure 3.11 shows Monroe Avenue as the corridor of our study, highlighted in yellow with the West Loop Transportation Center also highlighted.

FIGURE 3.11 Location for Underground Monroe Busway (Reference 3-7)

3.5.1 Case Study Corridor

Currently, there are no bus routes on Monroe Ave. Excerpt from the Chicago Central Area Plan: "In the 1970s the City contemplated a subway that would link the west Loop commuter stations to North Michigan Avenue and McCormick Place via Monroe Street. The plan was never realized but the right-of-way was reserved for future transit use." (3-7).

If warranted by future traffic growth, in the long term, an underground bus tunnel has been considered under Monroe Avenue. The underground tunnel would extend between Clinton Street and Michigan Avenue. It would have three lanes, and would provide passengers with the opportunity to connect to CTA's train lines in the Loop area and to Union Station and the West Loop (Ogilvie) Transportation Center on the other side of the Chicago River. The bus tunnel would pass under the river. The tunnel would have four stops underground in the loop area.

Bus routes that currently use Washington – Madison Ave and Adams – Jackson Ave would be consolidated into this bus tunnel. In addition to the routes currently using Washington, Madison Adams, and Jackson Avenues Routes 122 and 123 would be rerouted from Lower Wacker Drive to the Monroe Bus Tunnel as well.

TABLE 3.18 Headways for Bus Routes 122 and 123 During Peak Periods

Bus number	Headway	Travel time	Comment
122 E	AM: 5.5 min **PM: 5min till 6:10**	NA	Illinois Center-Northwestern express
122 W	7:00 – 7:30 8min 7:30 – 8:50 5min 8:50 – 9:25 15min **3:45 – 6:00 5.5 min** **6:00 – 6:20 10min**	NA	Note: the schedule of this route indicated that AM peak hour is 7:30 – 8:50
123 E	5.5 min till 9:05 AM **3:47 – 4:55 4min** **4:55 – 6:08 7min**	NA	Illinois center – Union Express
123 W	7:00 – 7:30 6min 7:30 – 9:20 5 min **3:30 – 4:00 6min** **4:00 – 5:00 4min** **5:00 – 5:55 6 min** **5:55 – 6:20 10min**	NA	Note: the schedule of this route indicated that PM peak hour is **4:00 – 5:00**

TABLE 3.19 CTA Bus Routes 122 and 123 During Peak Periods

East bound	**AM**		**PM**	
	Headway	**Number of buses per hour**	**Headway**	**Number of buses per hour**
122 E	5.5 min	11	5 min	12
123 E	5.5 min	11	5.5 min	11
Total	**2.7 min**	**22**	**2.6 min**	**23**

West bound	**AM**		**PM**	
	Headway	**Number of buses per hour**	**Headway**	**Number of buses per hour**
122 W	5 – 8 min	12 – 7.5	5.5 min	11
123 W	5 – 6 min	12 - 10	4 – 6 min	15 – 10
Total	**2.5 – 3.4 min**	**24 – 17.5**	**2.3 – 2.8 min**	**26 – 21**

TABLE 3.20 Eastbound Bus Routes During Peak Periods

East bound	**AM**		**PM**	
	Headway	**Number of buses per hour**	**Headway**	**Number of buses per hour**
Washington 14, 20, 56, 157	1.9 – 2.4 min	31 – 24.5	1.5 – 2.4 min	40.5 – 25
Jackson 126, 151, 1, 60, 7	1.6 – 2.2 min	37 – 27.5	1.1 – 2.4 min	55 – 24.5
Lower Wacker – East 122 and 123	2.7 min	22	2.6 min	23
Total	0.66 – 0.81 min **40 – 49 sec**	**90 – 74**	0.5 -0.83 min **30 – 50 sec**	**118.5 – 72.5**

TABLE 3.21 Westbound Bus Routes During Peak Periods

West bound	**AM**		**PM**	
	Headway	**Number of buses per hour**	**Headway**	**Number of buses per hour**
Madison 14, 20, 56, 157	1.4 – 2.1 min	44 – 29	2 – 2.8 min	30.5 – 21.5
Adams 126, 151, 1, 60, 7	1.3 – 2.3 min	44.5 – 26	1.6 – 2.7 min	38 – 22
Lower Wacker – West 122 and 123	2.5 – 3.4 min	24 – 17.5	2.3 – 2.8 min	26 – 21
Total	0.53 – 0.83 min **32 – 50 sec**	**112.5 – 72.5**	0.63 – 0.93 min **38 – 56 sec**	**94.5 – 64.5**

If all these routes would be consolidated onto the Monroe underground bus tunnel, assuming that no route will be cancelled and that no change to their operation frequency will be made, there will be 11 routes using the corridor. This would mean

- In the morning peak:
    - East-bound: 74 – 90 buses per hour, or one bus in every 40 – 49 sec
    - West-bound: 72.5 – 118.5 buses per hour, or one bus in every 30 – 50 sec.
- In the afternoon peak:
    - East-bound: 72.5 – 112.5 buses per hour, or one bus in every 32 – 50 sec

- West-bound: 64.5 – 94.5 buses per hour, or one bus in every 38 – 56 sec. [5]

We have no detailed information about the future operation plans for use of this busway, but the three-lane alignment appears to provide for the center lane to be shared by buses traveling in both directions that need to pass buses that have stopped for passenger loading and unloading. The maximum expected operating speed and passenger loadings would largely determine the travel time needed to traverse the busway, in combination with the stopping policy.

For the underground Monroe busway the following CVHAS technologies could technically be applied:

- Automatic speed and spacing control
- Automatic steering control
- Precision docking
- Platooned operation (all the above, plus communication between vehicles)

3.5.2 Evaluation of Long-Term Underground Monroe Busway

The primary CVHAS contributions to be considered with regard to the Monroe Busway are the time saving from precision docking at the stations and the capital cost saving from the use of automatic steering to reduce the width of the lanes.

3.5.2.1 Precision Docking

The precision docking analysis can follow the same general form and most of the same assumptions as the precision docking analysis for the near-term east-west scenario.

Since the underground busway will be new construction, the cost of installing the magnets for reference location markings will be less than the cost of retrofitting them into the surface streets, and should be assumed to be $5 each for 50 magnets at each station. With four stations on each side of the busway plus one at the terminal near Clinton, we would have a total of nine stations, at a cost of $250 each, for a grand total of $1750 in capital facility cost. No costs are allocated for construction of passenger loading platforms, since those are assumed to be needed and constructed for the busway regardless of whether precision docking is used.

Since this scenario is being developed in the long term rather than the near term, the cost of the in-vehicle systems is expected to be considerably less, and should be in the range of

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[5] For comparison, Sound Transit's fact sheet [http://www.soundtransit.org/stbusiness/facts/factsheets/stbusinessJointOpsDTT.htm] notes that in the afternoon peak-hour 130 buses per hour run in the Downtown Seattle Transit Tunnel. DMJM Harris estimated the vehicle throughput of the Downtown Seattle Transit Tunnel at 207 buses per hour (for a scenario where passengers were all seated) and 145 buses per hour (for seated and standing scenario).
[http://www.maggiefimia.com/kcc_site/DMJMHarris%20Report(supplemented).pdf]
[Technical Memorandum, Review and Analysis of Sound Transit Evaluation Of Joint Operation in the Downtown Seattle Transit Tunnel, Technical Revisions and Comments Added November 5, 2001]

approximately $2.5 K per bus. Note that this equipment complement is the same as the equipment needed to provide for automatic steering control when the buses drive through the tunnel, so this equipment also generates the lane width reduction benefits. With the enhanced volume of bus travel that should be stimulated by the improved connectivity and reduced travel time of this new busway, it is assumed that 200 buses would need to be equipped to serve the bus routes using the busway. Equipping these buses with the necessary equipment therefore costs a total of $500 K. Adding in the cost of the roadway magnets at the bus stops raises the initial investment to about $502 K.

The total volume of bus trips using the Monroe Busway should be somewhat higher than the present-day volume of Loop cross-town bus runs. Since those were estimated to be 246,000 round trips per year currently, we can estimate that the Monroe Busway would handle 300,000 or 400,000 annual round trips and check the sensitivity of benefits to those different assumptions. These round trips will generate 2.7 million or 3.6 million annual station docking maneuvers at the nine bus stops.

"Break-even" Analysis

Using a discount rate of 7%, and a bus life of 15 years, the $502 K total cost of implementing precision docking for the Monroe Busway is amortized into an annual cost of $55.1 K. This could be a "break-even" investment based on the following time savings (annually and per bus stop):

TABLE 3.22 Time Savings: Annually and Per Bus Stop

	Annual Hours Saved	Seconds Saved per Stop @ 300K trips	Seconds Saved per Stop @ 400K trips
CTA Direct costs @ $81.64	675	0.89	0.68
CTA+10 passengers @ $181.64	304	0.40	0.31
CTA+20 passengers @ $281.64	196	0.27	0.20
CTA+40 passengers @ $481.64	115	0.16	0.12

Sensitivity Analysis Based on Assumed Docking Time Savings

The cost effectiveness of precision docking in the Monroe Busway could also be estimated by considering several possible values of time saved per bus stop, analogous to the analysis that was reported previously for the near-term east-west surface street scenario. In this case, we consider the effects if precision docking saves 1, 5 or 10 seconds per bus stop, with 300,000 annual round trips:

TABLE 3.23 Savings and Benefit-Cost Ratio Findings: Long-Term Precision Docking

Time Saved per Stop (s)	CTA Saving	Avg. Pass. Load	Passenger Saving	Annual Saving Total	B/C
1	750 hr = $61.2K	10	$75 K	$136 K	2.5
1	750 hr = $61.2K	20	$150 K	$211 K	3.8
1	750 hr = $61.2K	40	$300 K	$361 K	6.6
5	3750 hr = $306 K	10	$375 K	$681 K	12
5	3750 hr = $306 K	20	$750 K	$1056 K	19
5	3750 hr = $306 K	40	$1500 K	$1806 K	33
10	7500 hr = $612 K	10	$750 K	$1362 K	25
10	7500 hr = $612 K	20	$1500 K	$2112 K	38
10	7500 hr = $612 K	40	$3000 K	$3612 K	66

The results would be scaled up by a factor of 1.33 if the total annual round trips were to be 400,000 rather than 300,000.

3.5.2.2 Reduction of Lane Width

The more significant economic benefit from use of CVHAS technologies is expected to arise from the ability of the automatic steering technology to operate a bus at full cruising speed in a lane that is only ten feet wide rather than twelve feet wide. This means that the two main running lanes of the Monroe Busway could each be reduced in width from 12 ft. to 10 ft., with some saving in construction costs. The entire length of the Monroe busway tunnel (about one mile) could therefore be four feet narrower than originally planned. Considering that purely from the point of view of surface area and volume of the construction project, it means that the footprint of the excavation and paving could be reduced by about 21,000 square feet, and with an average depth of excavation of about 15 feet, the volume of the material to be removed could be reduced by about 315,000 cubic feet.

In contrast, the costs associated with providing the automatic steering control for the buses are essentially the same as for the precision docking described in the previous section, plus the addition of reference markers throughout the length of all lanes of the busway. Assuming that this will require three miles of magnet installations at $5 K per mile, we have an additional cost of $15 K, for a total capital cost of $517 K. Note that all but this final $15 K was already accounted for in the docking analysis.

Consultations with tunnel construction experts in both Chicago [Austen Cooney, Kenny Construction Company] and San Francisco [Esa Rasi of Bechtel who was the cost estimator for BART on the San Francisco International Airport extension] have revealed an extreme reluctance to quote specific cost estimates without doing detailed studies of soil conditions and specific tunnel layouts. They have not even been willing to provide estimates of the incremental costs that could be saved from a reduction in width of a shallow cut-and-cover tunnel such as we are suggesting here. This has prevented us from doing the type of bottom-up estimate of savings that we would prefer to do.

In the absence of this kind of information, we are compelled to fall back on "break-even" analysis and analogies to existing tunnels.

"Break-even" Analysis

In this case, we are considering the trade-off between two different capital costs, one for the automatic steering technology and the other for tunnel construction. We are spending $517 K for automatic steering systems and reducing the tunnel construction area by 21,000 square feet. Therefore, if the cost of the tunnel construction is less than $24.62 per square foot, the investment in automatic steering appears cost effective. Alternatively, if we consider volume rather than surface area for the tunnel construction, we are reducing the volume of the excavation by 315,000 cubic feet. Therefore, if the cost of the tunnel construction is less than $1.64 per cubic foot, the investment in automatic steering appears cost effective.

Parametric Variations Based on Comparison with Existing Tunnel

Tunnel construction conditions and methods can vary dramatically, making it difficult to compare them from location to location. The closest analogy to the Monroe Busway among existing facilities in the U.S. appears to be the Seattle bus tunnel, which was completed in 1991. The cost of constructing that tunnel was estimated in current-year dollars to be $1478 per square foot. However, several aspects of its construction would tend to make it more costly than the Monroe Busway:

- Steeply-sloped site, with portions deep underground and therefore deep-bored rather than cut-and-cover construction;
- Right-angle curve in the middle, rather than straight-line construction;
- High-profile cross-section for much of its length, indicating large volume of material removed per unit surface area;
- Huge stations with costly materials (such as polished granite).

Considering these factors, it would be best to assume the cost per square foot of the Monroe Busway to be substantially less than this. If we assumed the maximum likely cost per square foot of the Monroe Busway to be only about 1/3 of the Seattle bus tunnel's cost and then worked down from there, we would see cost savings and B/C ratios associated with the automatic steering control to be along the following lines:

TABLE 3.24 Savings and Benefit-Cost Ratio Findings: Long-Term Tunnel Construction

Cost per Square Foot	Cost Saving	B/C Ratio
$500	$10.5 Million	20.3
$400	$8.4 Million	16.2
$300	$6.3 Million	12.2
$200	$4.2 Million	8.1
$100	$2.1 Million	4.1

3.6 Clinton-Carroll Avenue Busway — Long-Term Alternative

The third case study is on a different corridor: on the North-South Clinton Avenue connected to the East-West Carroll Avenue. Figure 3.11 shows the case study corridor of the Clinton-Carroll busway. We will only examine the long-term possibilities for this corridor. Colors on the figure indicate the traffic environment for this long-term alternative.

Figure 6 shows that the long-term alternative plan for the Clinton-Carroll busway consists of two sections: the underground and grade separated Clinton bus tunnel running in the north-south direction and the partially segregated Carroll busway running in the east-west direction. Therefore, throughout the case study we will deal with these two sections separately.

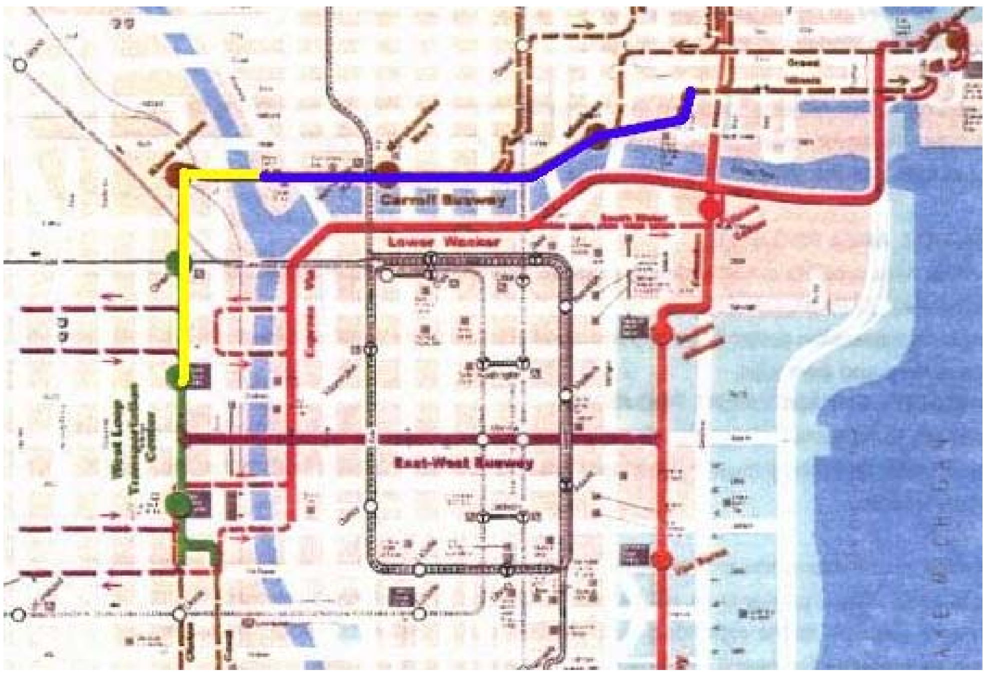

FIGURE 3.12 Location for Clinton-Carroll Avenue Busway (Reference 3-7)

3.6.1 Case Study Corridor

The proposed busway is intended to serve trips that are currently seriously under-served by the existing transit services. This would accommodate linkages between the major commuter rail terminals to the west of the Loop and the entertainment center of the Navy Pier in Lake Michigan, as well as much planned new development in the areas between Michigan Avenue and Navy Pier. Since there is very limited transit service in this corridor today, the present-day baseline is not a very useful basis for comparison of the CVHAS and non-CVHAS alternatives.

3.6.1.1 Clinton Underground Bus Tunnel

This tunnel does not exist yet, but is part of the concept for a major urban transportation corridor combining bus operations with commuter rail and long-distance railroad services, all of which would be located below ground.

We assume that the bus tunnel under Clinton is to be planned similarly to the Monroe bus tunnel. Therefore, in terms of the Clinton bus tunnel we will refer back to the Monroe tunnel (case study #2) and discuss only those aspects that are different from that, while we will discuss the Carroll busway in more detail.

We assume that as a future alternative an underground bus tunnel, similar to that planned for under Monroe Street, would be constructed. However, preliminary plans for such a tunnel have not been developed. Therefore, there is very little information about its layout, profile, and cross-section or about its stops and connections. We assume that the same routes that would use the Carroll Avenue Busway would use the Clinton bus tunnel as well. (The Parsons study examines the option of an underpass under the Metra tracks on Clinton Street. This would be part of the near term plan. On the long-term alternative, studied here, buses would pass under the Metra-owned track in the underground tunnel.)

The Clinton underground bus tunnel and the long-term E-W underground bus tunnel under Monroe Street (our second case study) are identical in terms of what CVHAS technologies would be possible to apply:

- Automatic speed and spacing control
- Automatic steering control
- Precision docking
- Platooned operation (all the above, plus communication between vehicles)

On the Clinton underground bus tunnel (similarly to the Monroe underground bus tunnel):

- Run time on the Clinton corridor between Canal Street and Union Station (from hereon referred to as run time) – measured in seconds
- Throughput of the Clinton corridor between Canal Street and Union Station (from hereon referred to as throughput) – measured in number of buses per hour (or number of passengers per hour)

Furthermore, we anticipate that some infrastructure geometries could change as a result of CVHAS technologies:

- lane width between stops – measured in feet
- median width in between stops – measured in feet, and
- stop geometries – measured in feet, such as stop length, lane and median width.

3.6.1.2 Carroll Avenue Busway

Parsons Transportation Group prepared a study of the Carroll Avenue Busway for the Chicago DOT (3-8). The following information about current conditions is excerpt from this report.

The right-of-way, currently controlled by the Union Pacific railroad, extends from the Chicago River to just west of Rush Street to the south of Kinzie Street. The ROW is generally 24 to 28 feet wide. The corridor is currently used for parking and loading. Traffic is a mix of passenger vehicles and single unit trucks. Parking garages are accessed by crossing the corridor. No through traffic is possible on the ROW currently.

Bus routes that currently serve the market that will be affected by the Carroll transit way project are CTA's routes 120 and 121.

TABLE 3.25 Eastbound Bus Routes 120 and 121 During Peak Periods

East bound	**AM**		**PM**	
	Headway	**Number of buses per hour**	**Headway**	**Number of buses per hour**
120 E	5.5 min		5 min	
121 E	5.5 min		5.5 min	
Total	**2.7 min**		**2.6 min**	

TABLE 3.26 Westbound Bus Routes 120 and 121 During Peak Periods

West bound	**AM**		**PM**	
	Headway	**Number of buses per hour**	**Headway**	**Number of buses per hour**
120 W	5 – 8 min	12 – 7.5	5.5 min	11
121 W	5 – 6 min	12 - 10	4 – 6 min	15 – 10
Total	**2.5 – 3.4 min**	**24 – 17.5**	**2.3 – 2.8 min**	**26 – 21**

However, with the growing level of activity between Michigan Ave. and Navy Pier, as well as the prospect for faster connections to the commuter rail stations west of the Loop, we should assume a significant increase in the frequency of bus departures in the future study baseline year.

Current travel time: Similar travel along Grand and Illinois on existing CTA bus routes are 10-12 minutes during peak periods between Orleans and McClurg. However, this represents only a small portion of the planned new service.

A long-term plan of providing a two-lane roadway through the corridor that is at least partially restricted for buses is explored in our case study. The corridor will remain open to some truck traffic to and from loading facilities and to some vehicular traffic to and from garages. The two-lane bus roadway would extend between a new bridge over the Chicago River at the Orleans ramp and Kinzie Street. For further details on the roadway we refer the reader to the referenced document by Parsons.

One of the goals of the Carroll Avenue project is to reduce transit delays. Therefore, the study recommends traffic signals at the following three intersections:

- Under LaSalle Street
- Between Clark and Dearborn
- Under Dearborn

Signals would be required due to limited sight distance for drivers to be able to see conflicting cross-traffic. Signals would be actuated, with priority given to buses.

One mid-corridor station is recommended by the Parsons study just east of West Street in order to connect to the CTA Brown Line. Here two additional ten-foot wide lanes would be added as off line stops.

<u>Travel time</u> on the future Carroll transit way was estimated by the Parsons study to be 7-8 minutes.

The Parsons study also identified the travel markets the Carroll transit way will serve:

1. Metra (Union and Ogilvie station) to Streeterville/Northwestern Hospital/Navy Pier – currently served by routes 120 and 121 – ridership of about 2,800 on average weekdays (although some may shift to other routes if the 120 and 121 are rerouted)
2. Brown line station to Streeterville – a ridership of 1,000 -1,500 per weekday
3. Brown line station to the West Loop rail stations – ridership not specified
4. Streeterville to the West Loop rail stations – ridership not specified

Based on the above markets identified, the Parsons study suggested several potential new transit routes. Bus operations would be headway based, at 5 minutes in peak periods and 15 minutes off peak. Operating hours would be between 6:00 AM and 8:00 PM.

Special issues were addressed in detail in the Parsons study. Here we address only those that can be helped by CVHAS technologies:

- Internal pedestrian Circulation Bridge of the Merchandise Mart
- Access at the western end (bridge over Chicago River)
- Ramp to parking deck between Wells and La Salle (at proposed bus station)

These are briefly discussed below. More details can be found in the Parsons study.

Internal Circulation Bridge of the Merchandise Mart - Within a section under the Merchandise Mart a walkway crosses the corridor over a raised pedestrian bridge. This bridge serves an internal circulation function within the Merchandise Mart. Available ROW is limited to 18 feet at this section. Vertical clearance is approximately 17-18 feet. Two solutions were explored in the Parsons study:

- Depress the roadway to allow the pedestrian bridge to cross grade separated, allowing enough clearance for the buses.
- Raise the roadway to the level of the pedestrian bridge providing an at-grade crossing. This option would require the reduction of the bus roadway to one lane.

Access at the western end - long-term plan calls for the construction of a new bridge over the Chicago River. This new bridge would offer the advantages of a dedicated facility since buses would not have to use the congested general bridge on Kinzie Street. The Parsons study contains conceptual alternatives to provide this access.

Ramp to parking deck between Wells and La Salle (at proposed bus station) – "Currently, columns supporting a ramp to the parking garage located between Wells and La Salle create a conflict with the potential transit station and bus travel lanes. The upgrade of Carroll to a busway will require the removal or relocation of these columns."

Carroll Busway could benefit from the following CVHAS technologies

- Automatic steering control (Under Merchandise Mart, at the entry points)
- Precision docking
- Some signal pre-emption (SPE) to give priority to buses over exit/entry vehicles on ramps and loading vehicles. Buses would get green every time over parking or loading vehicles, but if there were no buses around they get continuous green. Buses would activate the signal to turn red for the interfering vehicles.

On the Carroll bus way the following performance measures are likely to be affected by CVHAS technologies:

- Run time – measured in seconds
- Safety – measured in the number of crashes

Furthermore, we anticipate that some infrastructure geometries could change as a result of CVHAS technologies:

- lane width – measured in feet
- median width– measured in feet, and
- stop geometries – measured in feet, such as stop length, lane and median width.

3.6.2 Evaluation of Long-Term Clinton-Carroll Avenue Busway

The primary benefits of the CVHAS technologies for the Clinton-Carroll Busway are likely to be from automatic steering control reducing the width of the new bridge over the Chicago River and the underground construction of the bus lanes for the new transportation center along Clinton. There is some lingering doubt about the conditions associated with the pedestrian bridge across the Carroll right of way beneath the Merchandise Mart, and whether the CVHAS technologies could facilitate the coexistence of the pedestrian (and merchandise cart) crossing with the buses using the Busway.

There could also be benefits from precision docking, traffic signal priority and collision warning systems on the portions of the bus routes that share local streets with other traffic on the extensions to Navy Pier, Streeterville and Water Tower Place. However, since these benefits have already been addressed for the near-term cross-town services in the Loop Area, there is no need to repeat the analyses here.

The planning study for the Carroll Avenue Busway has already provided valuable background information about the baseline plans for development of this facility, but many aspects still remain unspecified and therefore need to be assumed in order to evaluate the CVHAS technology applicability. For example, we have to make assumptions about the frequency of bus service that will be offered on the new routes using the Busway and the number of buses that will need to be equipped with the CVHAS technologies.

The Chicago Central Area Plan shows new bus routes to the Navy Pier, Streeterville and Water Tower Place fanning out from the Carroll Busway, but does not specify the level of service on these routes. If we assume these to be high-density services with significant passenger demands, they could run on headways as short as 5 minutes each during the peak periods, which would mean that the Busway would be serving up to 36 buses per hour in each direction. If the round-trip travel time on each of those routes averages 45 minutes, it would be necessary to have nine buses serving each route. With provision for spares, it will probably be necessary to equip about 33 buses to provide this level of transit service. The primary CVHAS technology to consider here is automatic steering control (which also provides precision docking capability). On the long-term planning horizon of this scenario, it should be possible to equip a bus with this type of system for about $2.5 K, leading to a total vehicle cost for CVHAS technology of $82.5 K. The length of busway to equip with reference markers is approximately two miles, which would add another $10 K of initial cost, for a total of about $92 K.

The pedestrian crossing bridge under the Merchandise Mart is a location where the Busway may only be able to accommodate a single lane width without getting into extensive (and costly) construction work to provide a full grade separation between the buses and pedestrians. The busway planning report shows a section of about 210 ft. length having the single lane. This may be adequate at the hypothesized density of bus usage, with 36 buses per hour traveling in each direction. This means that there would be an average of 100 seconds between buses in each direction, which is more than ample time for the buses coming in the opposite direction to clear the single-lane section. It will be necessary to provide a well-designed traffic signal system to control access to the single-lane section and to mediate the usage of the crossing with the pedestrian traffic as well. If the intensity of use of the busway is intended to grow to significantly higher levels, it will be necessary to consider other means of avoiding the pedestrian crossing becoming a bottleneck. This is a case in which the ability of the automatic steering system to operate the bus within a 10-foot lane could make it possible to fit two lanes of bus traffic within a 20-foot clearance rather than the more standard 24-foot clearance at this constrained location. The additional 4 feet could make it possible to work out acceptable provisions for the pedestrian access on both sides of the busway, but this will need a detailed design study and close interactions with the users of the pedestrian crossing. The same increased volumes of bus traffic that would tend to point toward such an approach would also mean that the time slots available for the pedestrians to cross the Busway at grade would become more severely constrained.

The most obvious advantage of use of the automatic steering capability is the opportunity to reduce the width of the busway paving, structures and excavations. The Carroll Busway study already estimated the cost of a new bridge over the Chicago River, to replace a former railroad bridge, based on a unit price of $2,000 per square foot of roadway listed in the Carroll Avenue Busway Study (3-8). Without any additional data regarding this unit price, it was necessary to assume that it is directly proportional to the width of the bridge and not dependent on other cost elements insensitive to a width reduction. Thus reducing the width of this bridge by four feet (from 36 to 32 ft.) would save $2.08 million in construction cost, so on this saving alone we would see a B/C ratio for the $92 K investment in automatic steering of 22.6.

However, it should also be possible to save part of the costs of paving the full length of the new construction on Carroll (where there are currently railroad tracks but poor or no pavement) and part of the costs of the underground construction of the part of the busway on Clinton that extends from Monroe to the new bridge at Carroll (3850 ft.). Saving four feet of width of this underground construction would reduce its surface area by 15,400 ft. Depending on the unit cost per square foot assigned to this construction, the savings could range between an additional $1.54 million (at $100 per square foot) to $7.7 million (at $500 per square foot), following the range of values shown in the previous section for the Monroe Busway. These would obviously add significantly to the B/C ratio for automatic steering, beyond the value gained from the narrower bridge over the river.

These estimates indicate, regardless of the specific unit tunnel construction cost values that are finally selected, that there is likely to be a very high B/C ratio for providing the automatic steering capability to buses using the Carroll Busway.

3.7 Conclusions

3.7.1 Summary of Major Findings

This study investigated the feasibility of implementing CVHAS technologies to improve the performance of bus transit in the Central Area of Chicago. At the outset of the study as we investigated the background of bus transit systems deployment in Chicago's Central Area, we learned and/or concluded that:

There have been two major studies over the past fifteen years investigating ways that public transportation in Chicago's Central Area — its urban core — could be improved. The first study, Chicago's Central Area Circulator Project (CACP), begun in 1987 at the initiation of the Regional Transit Authority, and selected light rail transit as its preferred alternative because it offered speed and capacity advantages over buses for moderate capital costs. However, over the course of the system's planning the cost of the proposed light rail system grew until it became prohibitively expensive to fully engineer and build. By 1990 the CACP was dropped from the regional transportation plan but it continued to be investigated into the mid-1990s.

The second study, the Chicago Central Area Plan includes plans for a variety of transit services that could potentially benefit from use of the CVHAS technologies, in particular, to improve connectivity within the Chicago Central Area, that is, cross-town service across the Loop area, and service between the commuter rail stations to the west of the Loop and the Navy Pier and nearby growing neighborhoods to the northeast. One element of the Central Area Plan is a future East-West Busway that would be built in a shallow tunnel just beneath Monroe Street, consolidating all of the cross-town bus routes in the Loop area where they could be segregated from traffic interference. It would have three lanes, and would provide passengers with the opportunity to connect to rail transit lines in the Loop area and to the commuter rail stations on the other side of the Chicago River. The tunnel would have four stops underground in the Loop Area. A second element of the Central Area Plan is the development of a new transit center along Clinton and Canal Streets, which would be a major underground facility consolidating commuter rail, local rail transit and bus transit lines around the current locations of the major commuter rail terminals. This transit center would be connected to the Navy Pier and its adjacent developing activity centers by a new Carroll Avenue Busway, which would be largely developed along a former railroad right of way just north of the Chicago River, beneath the Merchandise Mart and other major structures. This busway would include the construction of a bridge across the north branch of the Chicago River.

These two primary studies of public transportation in Chicago's Central Area provided the basis for the selection, by Chicago's major public transportation stakeholders, of the three case studies that were performed as part of this project:

- Near term east-west Loop options
- Long term east-west underground "Monroe" busway
- Long term Clinton-Carroll Avenue busway

We performed evaluations of the following CVHAS technologies in the context of these three bus transit case studies: transit signal priority, collision warning, precision docking, and automatic steering control. Based on these evaluation analyses, we find that

- There is a nearly universal ability for each CVHAS application to break even (pay for the system) with minimal time savings required (per stop or per round trip)
- There are consistently large to very large B/C ratios across CVHAS applications accounting for uncertainty in parameter values and lack of complete data
- For the near-term, deployment for collision warning systems appears not to be worth investment
- In the long-term, deployment of collision warning systems is more "borderline" and is within the margin of error for front and rear warning systems based on the uncertainties in the analysis for the long term and the small sample size.

3.7.2 Recommendations and Next Steps

Based on the findings from our evaluation of different CVHAS technologies in the Chicago area, there may also be additional opportunities for transit agencies in Chicago, such as CTA, as they become more familiar with these technologies and their transit applications, to reap other benefits from restructuring routes or revising operations. Such enterprises will have to wait until follow-up work is performed as this is beyond the scope of the current project.

Further study should be considered in the following directions:

- A concerted effort at data collection on the part of both CTA and CDOT so that a more comprehensive and robust analysis of the Chicago bus transit environment in the Loop may be assessed;
    - The following current and/or forecasted data for each bus route along the corridor of interest in order to formulate an accurate base case evaluation under pre-

CVHAS conditions from which a valid comparison with the implementation of CVHAS technologies may be made:

    - Current bus travel times in morning and afternoon peak periods
    - Current bus dwell times at bus stops by time of day (peak and off-peak) to account for passenger boarding and alighting
    - Average bus occupancy levels for weekday (peak and off-peak),
    - Passenger mix including proportion of young and agile, parents with children, elderly and frail, people carrying packages, and wheelchair-bound or on crutches
    - Current and forecasted passenger demand estimates for ridership during different times of day (AM and PM peak, off-peak, daily)
    - Current and forecasted traffic volume per hr during morning and afternoon peak periods - through the entire length of the corridor, preferably by lane or by direction (numbers of vehicles turning left or right, or going straight at intersections)
    - Current fare collection policy split among options (exact amount, pass, smartcard/electronic fare card)
  - The following data for each bus crash for each bus route along the corridor of interest to help formulate an accurate and representative base case assessment under pre-CVHAS conditions for the past three to five years:
    - Action the bus was taking at the time of the crash/incident
    - Point of impact on the bus due to the crash/incident

- Performing a more in-depth examination of (1) the East-West Corridor (underground Monroe busway) and (2) the Clinton-Carroll Avenue busway based on reaction to and acceptance of the Chicago Central Area Plan and the Carroll Avenue Busway Study, respectively, together with the CVHAS evaluation findings documented in this report. This can begin with the writing of summary White Papers as well as arranging for follow-up briefings together with discussions of potential opportunities for next-stage research with Chicago-area transit officials and, if appropriate, the FTA. From the Chicago area, invitees would especially include those who were not able to attend BRT Stakeholder Meeting in December 2003.

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4.0 FREIGHT MOVEMENTS

4.1 Background Information

Chicago is the hub for freight movement in the United States, in part because of its importance as a manufacturing and distribution center, but to a greater extent because it is the one place where all the eastern and western U.S. railroad lines, as well as two Canadian railroads, converge. Chicago is the preferred pass-through city for a majority of railroad freight traffic traveling between the eastern and western U.S. These movements are costly in terms of time, labor, freight-handling facilities, and impacts on all other surface travel in the Chicago region. Innovations that could facilitate freight movement within the region, especially among its major origins and destinations, have the potential to realize major economic benefits.

Goods movement in Chicago is a competitive, customer-driven and 24-hour-a-day business activity. The freight/goods movement industry is a significant piece of Chicago's economic profile accounting for approximately 6% of the gross regional product in 1996 of which intermodal, i.e., rail-highway and vice verse, exchanges comprise approximately 1%. The Metropolitan Planning Organization (MPO) for northeastern Illinois is the Chicago Area Transportation Study (CATS), which has periodically conducted travel surveys of the motor carrier industry. Also, CATS' demand model uses four separate truck trip tables that are linked with the automobile O-D table before and after the assignment stage. The Intermodal Advisory Task Force (IATF), one of 11 CATS Task Forces, has served as the principal medium for freight transportation input to CATS since 1994. Members of IATF represent railroad companies, the trucking industry, freight-forwarding companies, intermodal associations, shippers, and other institutional stakeholders. The IATF has created a substantial body of work in goods movement analysis. Much of it is at www.catsiatf.com.

In 1981, Chicago was the major hub for U.S. railroad traffic and a major transfer point of trailers between individual railroads carrying partial-or completely-cross country trailer-on-flatcar (TOFC) shipments. Rail transfers for TOFC shipments were handicapped by the high volume of trailer traffic at interchange points, a multiplicity of ramps, rail congestion, and difficulty maintaining a sufficient number of flatcars, so these shipments were carried on trucks to their final destinations, which is either another yard or consignee. To address the increased traffic congestion due to truck use on Chicago roads, the Federal Railroad Administration (FRA) commissioned a study (4-1) at that time to investigate the feasibility of constructing a private intermodal terminal roadway on presumed surplus and available rail/highway rights-of-way (ROW) to serve the growing volume of truck traffic as well as to determine the benefits of having the roadway itself.

That study demonstrated the feasibility of an exclusive roadway in terms of the physical ability to construct the facility on available rail right-of-way to connect up to 12 of the major intermodal yards at the time and in terms of the demand for intermodal interchange. The study location was an area approximately 4.7 miles wide by 7.5 miles long on the west and south sides of the city. At the time, interchange of intermodal TOFC was accomplished by transporting the trailer over local roads and highways between the terminals by truck entailing a costly and complex operation of unloading, transferring, and reloading of trailers. Additionally, the local roads and highways used for the interchanges are among the most heavily traveled roads in the region, contributing to more delay to this shipping process.

Solutions for the above problem were found in the 1981 study by performing an alternatives analysis based on the following criteria:

- Ability to minimize use of public streets
- Use of railroad rights-of-way
- Avoidance of locations where street traffic was heavy due to industrial concentrations or expressway access roads, and
- Minimization of initial capital cost and annual operating and maintenance costs

Based on these criteria, the most feasible alternative was a loop passing through or adjacent to the maximum number of TOFC terminals, with spur connections to several terminals not directly on the loop. Not every ramp studied was eventually included in the network. It was proposed that the intermodal roadway be two lanes wherever possible so that maximum operating flexibility could be achieved. Some sections were on public highway (i.e., not on rail ROW). If a single lane were required, it was suggested that adequate traffic controls be installed and that single lanes be only for short distances where the land availability was limited. The total cost of the 18.9-mile intermodal roadway in 1979 dollars was estimated to be $33.3M including construction, right-of-way, and relocation costs. There was never any implementation beyond the study.

The 1981 study focused on cross-town interchange truck movements; however, since then, there have been numerous changes:

- A current effort by rail companies to decrease the volume of such truck movements
- Current intermodal freight movements are increasingly container-on-flatcar (COFC), whereas in 1981 the movements were trailer-on-flat-car (TOFC)
- Freight flow patterns have changed dramatically in the past twenty years. At the time of the 1981 study, the focus was on rail-yard to rail-yard intermodal transfers by truck, and since then there has been growth in yard-to-yard movements by rail as well as growth in truck interchange movements between alternative network nodes, such as warehouse concentrations, industrial parks, and regional points-of-entry on the national highway system.
- Several of the rail yards have closed, while new ones have opened resulting in a shift in the geographical layout of the area's intermodal yards and a change in intermodal freight flow patterns. The area most affected by intermodal freight flows has expanded from 35 sq. miles in 1981 to 1400 sq. miles now.
- Rail ROW availability currently is more limited. For example, some segments considered in the 1981 study are now used by the Chicago Transit Authority's Orange Line.

The remainder of this chapter consists of a discussion of the selection of the alignment that formed the backbone network of nodes and links, that is, rail yards, industrial parks, and regional points of entry and their interconnecting roadways upon which the analysis was performed. After this we present the operational concepts of alternatives for which we conducted a comparative evaluation of benefits and costs. The next two sections describes the methodological approach used followed by the data we used. The following two sections consist of the core of the chapter, presenting the impact analysis and cost-benefit analysis. We offer conclusions and recommendations in the chapter's last section.

4.2 Selection of Alignment

We employed a systematic approach to determine the alignment for the proposed truck-only facility (roadway). Initially, based on information from CATS about the current state of the northeastern Illinois intermodal freight system, we identified a set of major intermodal rail yards, industrial parks/warehouse concentrations and points-of-entry to the region on the national highway system that the facility would serve. We then created connections among these nodes, making use of presumed surplus and available rail/highway rights-of-way (ROW). Two alignments, for the short-term and long-term, were proposed for the truck-only facility.

4.2.1 Identification of Nodes

To identify candidate intermodal freight nodes that could benefit the most from application of dedicated truck lanes, both with and without use of CVHAS technologies, we considered four market categories:

- Market #1: Rail yard to rail yard
- Market #2: Rail yard to/from industrial parks/warehouse concentrations
- Market #3: Rail yard to/from cordon points-of-entry
- Market #4: Cordon points-of-entry to/from industrial parks/warehouse concentrations

Volumes of cross-town rubber-tire yard-to-yard interchange traffic, i.e., Market #1, have been decreasing for the past twenty years and this trend is very likely to continue though Market #1 is unlikely to disappear entirely. Moreover, the interchange traffic generated from two new yards, Joliet (BNSF), and Global III Rochelle (UP), will primarily be steel-wheeled to eastern railroad yards. Therefore, in contrast to the 1981 study, the purpose of the proposed facility is not only to serve Market #1, but also Markets #2 - #4.

Therefore, the nodes in the network should include intermodal terminals (rail yards), industrial parks and points–of-entry. There is a large set of potential nodes from which the final set will be selected, including 21 rail yards, 8 cordon points-of-entry, and 14 industrial parks/warehouse concentrations (See Figure 4.1). We used as primary selection criteria the following: (1) major trip generators and attractors in terms of largest volumes of truck movements, (2) representation of both western (UP and BNSF) and eastern (CSX and NS) U.S. railroads, and (3) a few rail yards along the pathways formed among the primary nodes and cordon points-of-entry as well as consultation with CATS and Chicago-area intermodal freight stakeholders.

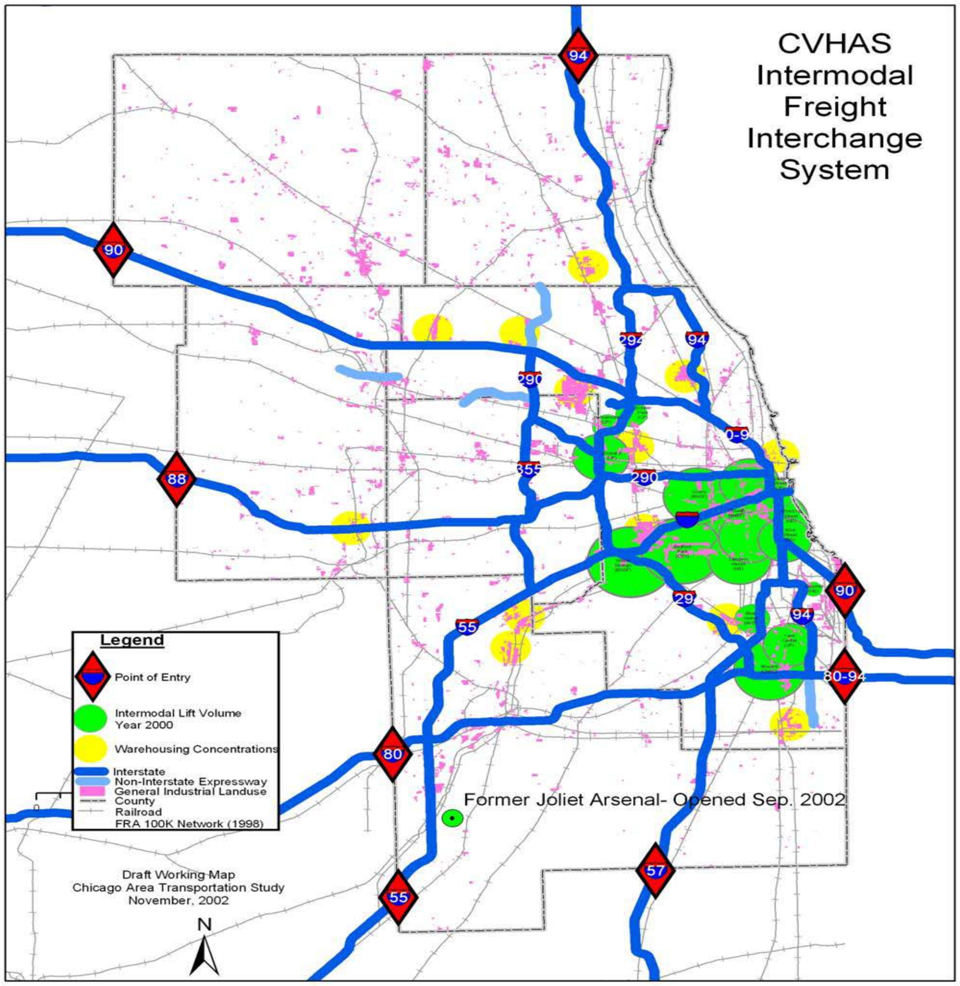

FIGURE 4.1 Northeastern Illinois Freight Interchange System (Source: CATS)

4.2.1.1 Choice of Yards

- Rochelle Global III (UP)
  Rochelle Global III was opened by UP in August 2003 and is situated 75 miles west of Chicago and 25 miles south of Rockford. Rochelle consists of 750 acres and features 720,000 lift capability, a 10-lane automated gate system entrance and will offer customers a 7,200-unit container yard at full build-out (Source: http://www.uprr.com/customers/intermodal/featured/global/)

- Joliet (BNSF)
  As a part of CenterPoint Intermodal Center, Logistics Park, Joliet was opened by BNSF in October 2002, which is 621 acres, 40 miles southwest of Chicago. BNSF says the new facility increases "their Chicago-area intermodal capacity by 400,000 lifts per year, and they've got an option on another 200 acres which give them space for an additional

800,000 lifts." (Source: http://www.illini.utu.org/board/news.html, under "Current Hot Topics")

- Bedford Park (CSX)
  The 3rd largest yard in terms of Year 2000 annual lifts (612,986[6]) and the largest CSX yard.

- 47th/51st Street Yard (NS)
  The sixth largest yard in terms of Year 2000 annual lifts (440,491) and the largest NS yard.

- Corwith (BNSF)
  The largest yard in terms of Year 2000 annual lifts (751,154)

- Willow Springs (BNSF)
  The 2nd largest yard in terms of Year 2000 annual lifts (697,303)

- Cicero (BNSF)
  The fifth largest yard in terms of Year 2000 annual lifts (446,036)

The above three yards (Corwith, Willow Springs and Cicero) all belong to BNSF. With the opening of Joliet, a substantial amount of inbound and outbound intermodal traffic from/to the Pacific Rim transported by BNSF will likely be consolidated at Joliet in the future without reaching these three yards. However, if we compare the capacity of Joliet (400,000 lifts near term, and possibly 1,200,000 long term) and the total annual lifts of these three yards in Year 2000 (1,900,000 lifts), and if we also consider continued market growth, we may foresee that these three yards will still play important roles in the Chicago-area intermodal freight transportation business.

- Global II (UP)
  Currently a major yard with 304,174 Year 2000 annual lifts. However, it is expected that Global III will divert substantial amount of traffic from it. We included this yard because of its current size and it lies along to the alignment connecting the primary nodes.

- 63rd Street (NS)
  Year 2000 annual lifts are 278,203, but it was still selected due to its adjacency to the alignment connecting the primary nodes.

4.2.1.2 Choice of Points of Entry

- Chicago Skyway (East I-90 to Indiana)
  The largest point-of-entry to the Chicago metropolitan area and the heavy-duty truck trips entering and leaving through this point are around 197,000[7] and 136,000 respectively per month in 2002.

[6] The statistics on annual lifts reported here are from Reference 4-2.

- I-55 (South)
  Close to Joliet yard

- I-88 (West)
  Close to Rochelle yard.

4.2.1.3 Choice of Industrial Parks/Warehouse Concentrations

- IP4- Northlake
  A major industrial parks/warehouse concentration with 224,000 and 226,000 heavy-duty truck trips attracted/generated from it.

Note that the above nodes are those to which the proposed truck-only facility will provide direct access or connection. Certainly, other nodes may also be able to make use of the facility, e.g., the following two industrial parks/warehouse concentrations: Bensenville/Elk Grove Village and Hodgkins and one point of entry at I-94 North, although they are not directly connected.

4.2.2 Node-Link Combinations

There were many ways to connect the selected set of nodes. To minimize initial capital cost, presumed available ROWs were one of the major considerations when selecting the alignment. Another major consideration was to keep the total length as short as possible. We made several site visits to the region to investigate the ROW conditions and the findings are documented in Appendix IV.

As Rochelle and Joliet rail yards have recently opened, truck volumes in and out of them as well as their impact on overall regional goods movement are currently not well documented. It is likely to take a few years for the travel demand to and from these two new facilities to become clearly evident. Moreover, due to budget constraints, it is necessary that development of the proposed facility be in stages so as to be able to get started without an enormously expensive up-front investment. Therefore, with significant input from CATS and the intermodal freight stakeholder committee, we developed two types of node-link combinations to investigate: short- and long-term alignments

4.2.2.1 Short-Term Alignment

The short-term network consists of a truck-only facility primarily on presumed surplus and available rail rights-of-way, either adjacent to existing tracks or in air rights, and is identified in Figure 4.2 by nine segments, representing connections among the major selected nodes. The total length is 44.5 miles.

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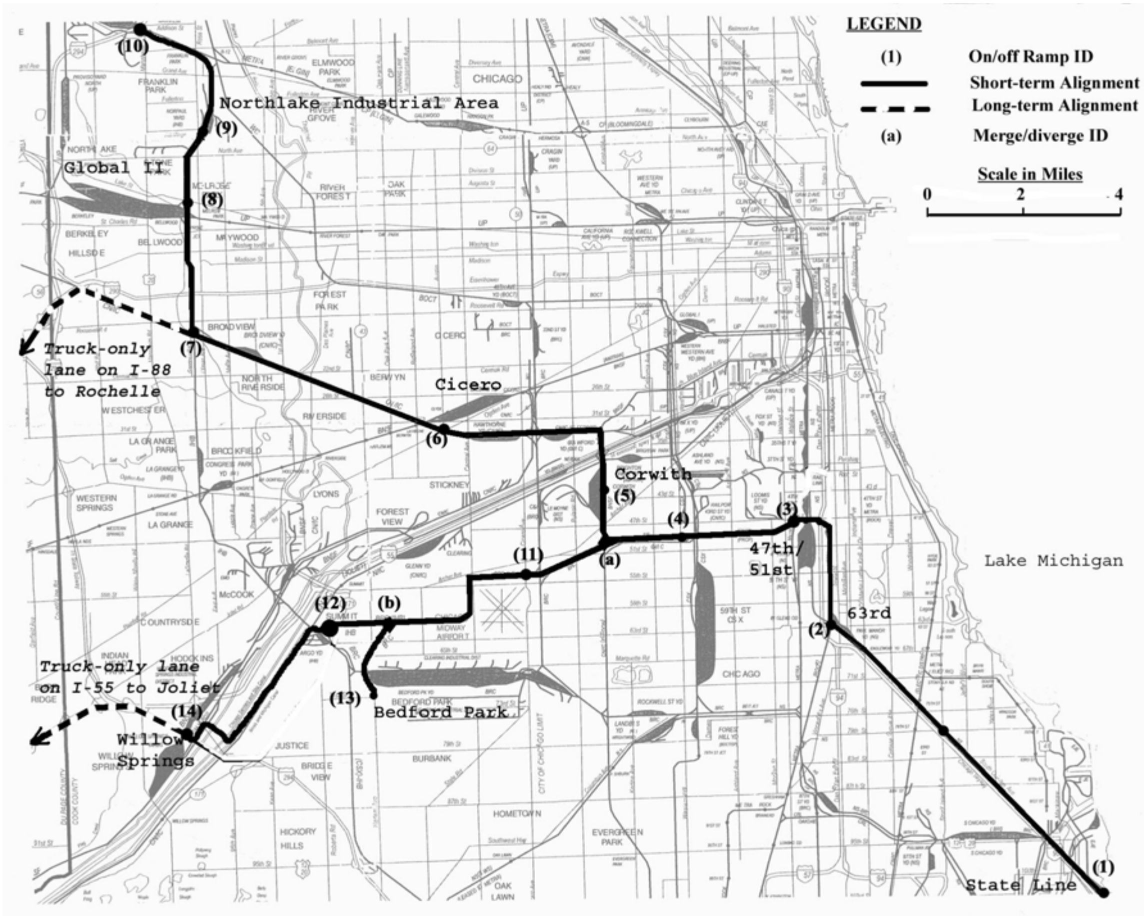
[7] Source: Reference 4-3 and similarly hereinafter.



Note: Indexes (1) and (2) etc represent the on/off ramps that trucks may use to access/egress the truck-only roadway; Indexes (a) and (b) represent locations that the roadway diverges and merges. No truck enters or leaves at those locations.

FIGURE 4.2 The Short Term Alignment

The length of each segment is given in Table 4.1 and the locations of on/off ramps are at following nodes (the on/off ramp IDs are consistent with those in Figure 4.2):

(1) State line
(2) @ 63rd Street
(3) @47th Street
(4) @ Western Ave
(5) @ 41st Street
(6) @ US-34 Ogden Ave
(7) @ Roosevelt Road
(8) @ Lake Street
(9) @ Armitage Ave
(10) @ I-294 around Addison Street
(11) @ US-50
(12) @ Archer Ave
(13) @ 71st Street
(14) @ Sante Fe Drive

Table 4.1 Length of Each Segment in Short Term Alignment

Starting node – ending node	Length (miles)	Segment ID
(1) – (2)	8.0	1
(2) – (3)	3.0	2
(3) – (4)	2.5	3
(4) – (a)	1.5	3
(a) – (5)	1.0	3
(5) – (6)	4.0	4
(6) – (7)	5.0	5
(7) – (8)	3.0	5
(8) – (9)	1.5	6
(9) – (10)	3.0	7
(a) – (11)	1.5	8
(11) – (b)	3.5	8
(b) – (13)	1.5	8
(b) – (12)	1.0	9
(12) – (14)	4.5	9
Total	44.5	-

The detailed description of each segment is as below:

- Segment 1 [nodes (1) – (2)] starts from the Indiana State Line to 63rd Street Yard following the elevated NS ROW east of the Chicago Skyway.

- Segment 2 [nodes (2) – (3)] connects the 63rd Street Yard with the 47th/51st Street Yard, mainly making use of the Metra ROW east of the Dan Ryan Expressway. A new bridge would be needed to cross the Dan Ryan Expressway to get to the 47th/51st Street Yard.

- Segment 3 [nodes (3) –(4) – (a) – (5)] originates at 47th Street Yard and proceeds west along the elevated IHB and CN/IC joint ownership ROW near 49th Street. After crossing the NS and CN/IC trestle and Western Avenue, the roadway continues further west and then north to reach Corwith Yard along the ROW beside the CTA, NS and CN/IC tracks.

- Segment 4 [nodes (5) – (6)] starts from north of Corwith to Cicero along the ROW adjacent to CN/IC tracks.

- Segment 5 [nodes (6) – (7) – (8)] proceeds further west along CN/IC tracks (ex-CC&P), and turns north at the junction between CN/IC and IHB. It follows IHB to Global II Yard.

- Segment 6 [nodes (8) – (9)] continues along the IHB tracks and reaches the Northlake industrial area around Norpaul Yard.

- Segment 7 [nodes (9) – (10)] proceeds north along IHB and then turns west at the junction between IHB and Metra. It continues along Metra and eventually merges to I-294 around Addison Street.

- Segment 8 [nodes (a) – (11) – (b) – (13)] starts from the junction between BRC, CN/IC and BNSF tracks and proceeds west along the ROW adjacent to BRC(IHB) tracks to the gate of Bedford Park Yard located at 71st Street.

- Segment 9 [nodes (b) – (12) – (14)] originates at the junction between BRC and IHB, and proceeds further west along IHB tracks to Argo Yard. After passing it, the roadway turns southwest continues along the CN/IC close to the canals or making use of the towpath and then crosses the canals with a new bridge to Willow Springs Yard.

A preliminary alignment design for the branch from the State Line to Corwith Yard can be found in Appendix V.

4.2.2.2 Long-Term Alignment

The long-term alignment consists of the short-term alignment plus the recently opened Rochelle and Joliet yards, and the Cordon Points-of-Entry on I-88 (@ Rochelle) and I-55 (@ Joliet), and associated routes linking them with the short-term alignment. The alignment is shown in Figure 4.3 and is also partially shown in dotted lines in Figure 4.2.

The links connecting Rochelle and Joliet yards with the short-term alignment are proposed to be truck-only lanes along I-88 and I-55 respectively. The IDOT IRIS database shows that it is feasible to add two additional lanes on the existing ROWs of both interstate highways.

The total length of the long-term alignment is approximately 145 miles.

The long-term alignment attempts to accommodate the traffic generated by the two newly opened yards, Rochelle and Joliet. Considering their annual lift capabilities and the marketing plans by UP and BNSF, it is expected that these two yards will have significant impact on the intermodal freight movement pattern in the Chicago metropolitan area. However, as aforementioned, it is not clear now how, when and to what extent the impact would occur. As we do not have enough information to make reasonable forecasts for these impacts, we focused our quantitative analysis on the short-term alignment for which there was more complete data such as O-D flows.

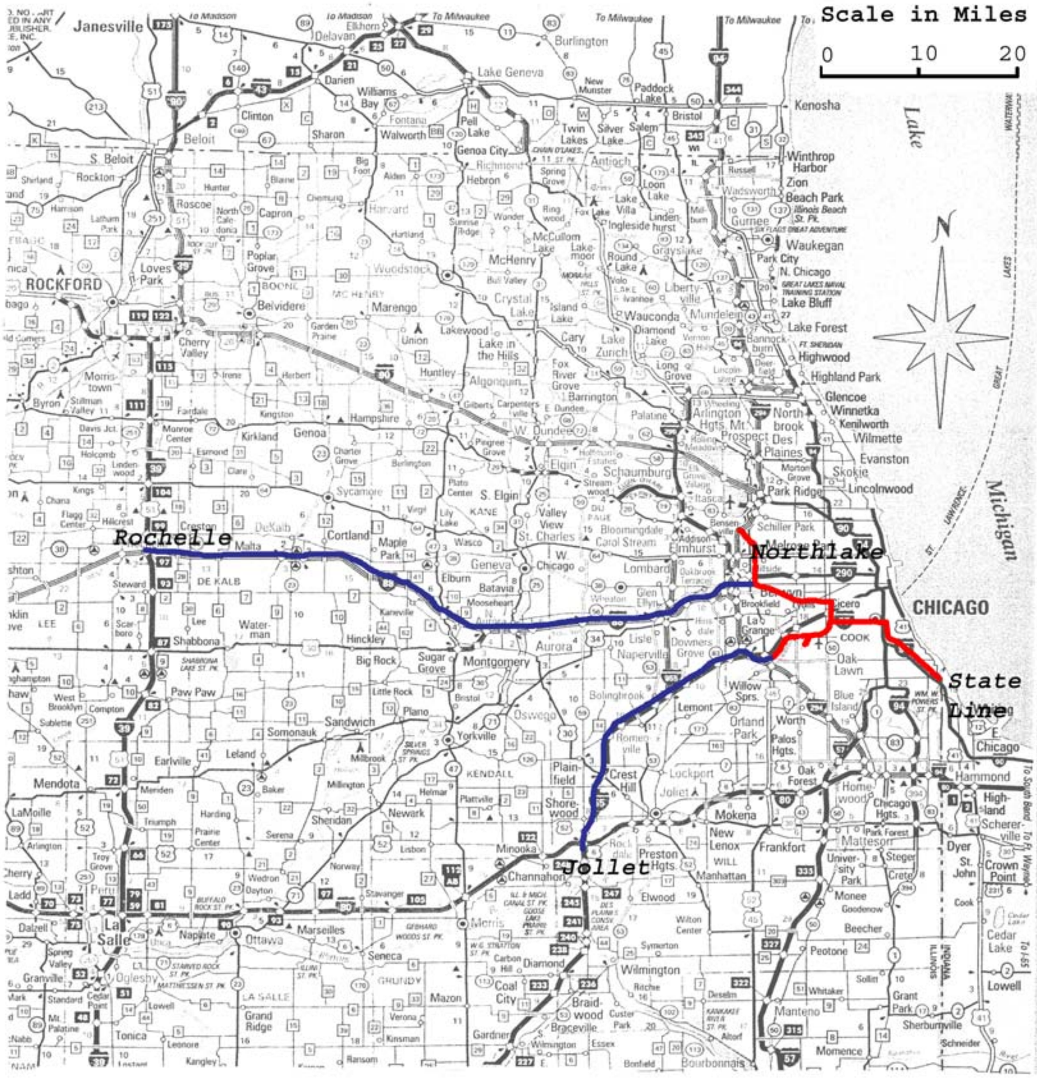


FIGURE 4.3 The Long-Term Alignment

4.3 Concept of Operations

4.3.1 Operational Concept Designs

The following list consists of candidate alternatives that we have considered including in subsequent analyses for the short-term alignment. We have listed the maximum possible set of alternatives to be as systematic and complete as possible so no alternative is overlooked. However, some alternatives will be seen in the discussion below to be infeasible or otherwise inappropriate and removed from further consideration and this process of elimination will move us toward a short list of candidate alternatives for which we will perform comparative analyses across alternatives.

1. Baseline (Do Nothing): This alternative is without CVHAS technologies and no truck-only facilities, however, it should include all infrastructure changes to the regional network that are either already programmed or planned for as part of CATS' Long Range Plans. For example, there are already plans for highway lane additions to several interstates that are part of our alignments, namely, I-55 and I-88. These additional lanes will, at least, in the short term, enhance roadway capacity and reduce the need to add truck-only lanes along such roadway segments.

2. Truck-only Facility without CVHAS Technologies: There are two sub-alternatives here to consider depending on what types of trucks are allowed to use the facility. We refer to trucks as *intermodal* if either their origins or destinations are intermodal rail yards; otherwise, trucks are called *non-intermodal*, and generally refer to the local Chicago-area or cross-border heavy-duty trucks.

   2.a Restricted to intermodal trucks only
   2.b Open to all trucks whether intermodal or non-intermodal

   There are a few tradeoffs to consider in determining whether to include both Alternatives 2.a and 2.b for further consideration. First, Alternative 2.b should help with financing the facility if user fees are employed to help pay for it and would allow all trucks to use the facility and thus draw more truck traffic from the general use roadway facilities than Alternative 2.a would and should result in more travel time reduction on the general use lanes than for Alternative 2.a. While in Alternative 2.b, the truck-only facility allows more trucks on than in Alternative 2.a, it is not likely that 2.b would result in such a large truck volume that the truck lane got congested, if a certain amount of toll is imposed. Alternative 2.b provides a greater opportunity for an improved investment picture because it draws from a much larger pool of potential users of the facility. There would likely be construction cost differences between the alternatives; 2.b would require additional on/off ramps to accommodate and better serve non-intermodal trucks. However, such added costs would be relatively small compared with the overall construction cost of the roadway; moreover, the roadway would have to be built for both 2.a and 2.b. For a truck-only facility, there are major safety-related benefits stemming from the separation of truck/non-truck traffic. Traffic safety statistics show that a significant majority of two-vehicle crashes involving a truck and another vehicle, approximately 74%, are caused by drivers of the other vehicles who make maneuvers that trucks are not able to respond to. However, currently no authoritative and quantitative data is available on these safety-related benefits, leaving us with only congestion-related benefits to investigate.

   Based on this, we recommended removing Alternative 2.a from further consideration.

3. Truck-only Facility with CVHAS Technologies: There are three primary sub-alternatives to consider depending on what types of CVHAS technologies to include: a. Collision warning, b. Collision warning plus automatic steering and c. Collision warning, automatic steering plus automatic speed and spacing control. For each such CVHAS technology category the types of trucks permitted on the facility (intermodal or all trucks) could also vary. Certain

levels of market penetration of CVHAS-equipped intermodal trucks (and potentially non-intermodal trucks as well) will have to be assumed.

3.a Collision Warning (CW)
3.a.1 Equipped intermodal trucks only
This alternative does not make much sense as this alternative imposes two restrictions on use of the truck-only facility (only equipped and intermodal trucks allowed), which would limit the volume of truck traffic on the facility. There are no safety-related reasons to segregate equipped and non-equipped trucks for collision warning technology and separating them provides no derived incremental benefits over the alternative in which they use the same lane, such as reduced lane width (thus reduced construction costs). We recommended deleting this alternative from further consideration.
3.a.2 Equipped trucks, whether intermodal or not
3.a.3 Equipped intermodal trucks and non-equipped/non-intermodal trucks
This alternative also does not make sense and begs the question: If we allow non-equipped/non-intermodal trucks on the facility, why restrict the intermodal trucks to be equipped-only? We recommended deleting this alternative from further consideration.
3.a.4 Intermodal trucks only, whether equipped or not
3.a.5 All trucks: intermodal or non-intermodal, equipped or not

As previously stated, there are no safety-related reasons why CW-equipped and non-CW-equipped trucks couldn't share the same facility. The primary potential benefits associated with Collision Warning are safety-related, yet also, as previously stated, there are major safety-related benefits from the separation of trucks from other vehicles via the truck-only facility. However, while truck-only facilities exist as well as collision warning systems, no safety-related analyses and associated data, including impacts on number of crashes, injuries, injury severity, fatalities, etc., have been conducted for these[8]. Without such baseline analyses there is no existing case for comparison purposes and we recommend not performing the safety-related analyses, thus removing Alternative 3.a and all its sub-alternatives from further consideration.

3.b Collision Warning and Automatic Steering
3.b.1 Equipped intermodal trucks only
3.b.2 Equipped trucks, whether intermodal or not
3.b.3 Equipped intermodal trucks and non-equipped/non-intermodal trucks (This alternative really doesn't make sense and begs the following question: If we allow non-equipped/non-intermodal trucks, on the facility, why restrict the intermodal trucks to be equipped-only? We recommended deleting this alternative from further consideration.
3.b.4 Intermodal trucks only whether equipped or not
3.b.5 All trucks (intermodal or non-intermodal), equipped or not

[8] Battelle is conducting independent operational test evaluation on trucks running on mixed flow lanes as part of the Intelligent Vehicle Initiative program.

There are no safety-related reasons why trucks equipped with these technologies and non-equipped trucks couldn't share the same facility. Again, the primary potential benefits with these CVHAS technologies would be safety-related. As previously stated, no safety-related analyses and associated data have been conducted for these previous safety studies to use for comparison purposes and this argues for not performing the safety-related analyses. There is, however, a construction cost savings tradeoff argument in favor of keeping Alternatives 3.b.1 and 3.b.2, because of lane width reductions resulting from automatic steering. However, Alternatives 3.b.2 and 3.b.5 are preferred to 3.b.1 and 3.b.4, respectively based on the congestion-related benefits argument made in sub-section 2 for truck-only facilities without CVHAS technologies. Thus we recommend keeping only Alternatives 3.b.2 and 3.b.5 for further investigation. Moreover, Alternative 3.b.5 is essentially equivalent to Alternative 2.b because even with automatic steering in 3.b.5, this alternative is open to all trucks and thus there would be no construction cost savings as lane widths would not be narrowed.

- 3.c Collision warning, automatic steering, plus automatic speed and spacing control
- 3.c.1 Equipped trucks only (intermodal or non-intermodal), fully automated trucks in 2-3[9] truck platoons if warranted with drivers in each vehicle (no staging area needed)
- 3.c.2 Equipped trucks only (intermodal or non-intermodal), fully automated trucks in 3 truck platoons with no driver onboard in the following trucks.

Alternative 3.c.2 will need a staging area at each on/off ramp in order to assemble/disassemble truck platoons and allow drivers to get off/on the following trucks. For a lower level of automation, which will probably be implemented in the near term, the staging area could be as large as 63,000 square feet (14 lanes for the 14 destinations*3 trucks per platoon*80 foot truck length*15 foot lane width). It is generally hard, if not impossible to find enough space to accommodate the staging areas in the Chicago urban area, where the short-term alignment is located. Moreover, because the average distance of truck travel is relatively short in the short-term alignment, the costs of constructing the staging areas and crew scheduling may not be compensated by the benefits of labor-savings. Therefore, for the short-term alignment, we recommended only considering Alternative 3.c.1. For the long-term alignment, with much longer trip lengths, fewer access locations, and a lower-density environment with lower land costs, the staging area concept should be re-examined.

Note that at each entry point to an automated truck lane, there should be a "check in" location, analogous to the toll booths at entry points to "closed" toll roads. At the "check in", a simple wireless communication link is established between the entering truck and the roadside, for the truck to state its intended destination and to verify that its key onboard systems are in proper working order (not only the automation equipment, but also basics such as adequate tire pressure and fuel level). Access to the truck lane would only be granted to trucks that successfully pass the "check in" inquiry. At each exit point from the automated truck lane there should be a "check out"

[9] Diminishing returns with respect to productivity set in for platoons longer than three trucks.

location. The "check out" function is needed to verify that the driver is ready and able to resume control of the truck before it leaves the automated facility. If the driver is not able to prove readiness, the truck should be automatically stopped at a parking space provided for the purpose, in order to ensure that safety hazards are not created on the adjacent public roads or in the adjacent terminals by unprepared drivers.

The deployment issue is very important to the success of Alternative 3.c.1. Because it would likely take time and money for the industry to equip its trucks with the CVHAS technologies, the market penetration of fully automated trucks is not expected to be high in the early years. Immediate deployment of Alternative 3.c.1 would not fully realize the potential benefits of the proposed facility. Therefore, we considered two scenarios under Alternative 3.c.1:

3.c.1.1 Immediate deployment of full automation in 2-3 truck platoons if warranted,
3.c.1.2 Truck-only facility without requiring CVHAS technologies before a certain year to be determined and after that converting the facility to be an automated truck-way (automatic steering, speed and spacing control with 2 or 3 truck platoons)

4.3.2 Recommended Alternative Operational Concepts

In summary, in addition to a baseline case with no new truck lanes and an alternative with new truck lanes using only conventional technologies, against which to measure the impacts of CVHAS technology applications, we selected three additional CVHAS operational concepts for evaluation, for a total of five:

1. Baseline concept (do nothing, no CVHAS technologies, no truck-only facilities)
2. Truck-only facility without CVHAS technologies, open to all trucks
3. Truck-only facility with CVHAS technologies (automatic steering) for equipped trucks only
4. Truck-only facility with CVHAS technologies (automatic steering, automatic speed and spacing control with 2 or 3 truck platoons if warranted) for equipped trucks only.
5. Truck-only facility without CVHAS technologies open to all trucks before a certain year to-be-determined and after that converting the facility to be an automated truck-way (automatic steering, speed and spacing control with 2 or 3 truck platoons)

   It should be noted that prior to the to-be-determined year when Alternative 5 is converted to be fully automated, Alternative 5 is equivalent to Alternative 2.

4.4 Methodology

The major purpose of the analyses was to assess the feasibility of each CVHAS operational concept in the Chicago intermodal freight market. More precisely, we attempted to evaluate the impacts of each alternative, and investigate whether the positive impacts outweighed the negative impacts, and then recommended the most promising alternative for a further investment or engineering study.

There are two principal types of socio-economic evaluation methods: cost-benefit analysis (CBA) and multi-criteria analysis (MCA). The CBA estimates the ratio (or difference) of the benefits to the costs of a capital investment considering a specific time period and spatial dimension. Both benefits and costs incurred in future years will be discounted at a specific interest rate. The reliability of the results of CBA increases with the proportion of the system impacts that can be quantified. In contrast to CBA, MCA can deal with discretionary or intangible impacts that cannot reasonably be expressed in monetary units. Different criteria in MCA can be combined to determine a single value. Common approaches of MCA include the econometric approach and the mathematical programming approach (4-4).

In the United States, CBA is recommended to use for evaluation of transportation projects, although MCA variations and other informal methods are often used at the regional level (4-5). Therefore, we employed CBA to evaluate the socio-economic impacts of the selected CVHAS operational concepts.

The ultimate goal of CBA is to ensure that society's resources are put to their most highly-valued uses. All impacts are evaluated from a macroscopic or high-level perspective. Note that the vast portion of impacts is transfers, in which individuals may gain or lose but society is unaffected in the aggregate. The most obvious type of transfer is financial or monetary, such as changes in user fees or taxes used to finance construction, but also jobs resulting from construction and operation. The transfers do not make society as a whole better off or worse off, but they affect the distribution of benefits, and thus have important equity considerations. We did not deal with distributional (equity) issues in our analyses because some major components, such as financing issues, are beyond of the scope of this study and are not clear at the current stage.

The CBA is based on many assumptions that are made as to the values of numerous parameters, which are described in later sections. To account for the variability in these parameter values, we will also perform parametric or sensitivity analyses in order to test the validity of our assumptions and the robustness of our conclusions.

4.5 Data Needs and Sources

The following list summarizes the major data we needed to perform the evaluation and the corresponding sources where we obtained the data.

- Background information about Chicago intermodal freight
  CATS, IDOT, CDOT and the Intermodal Freight Stakeholder Advisory Committee

- Intermodal rail yard conditions in northeastern Illinois
  CATS, IDOT and the Intermodal Freight Stakeholder Advisory Committee

- Chicago Regional Transportation Plan
  CATS

- Railway ROW conditions
  CATS, the stakeholder advisory committee, and site visits by the team

- Highway ROW conditions
  IDOT

- Regional heavy-duty truck travel demand and road network conditions
  CATS

- Construction costs on major highway projects in Chicago area
  IDOT

4.6 Impact Analysis

The primary areas where the impact of CVHAS technology implementation could be experienced and benefits derived are in the areas of (1) traffic and congestion mitigation and travel time benefits and (2) safety, with benefits in the reduction of crashes, injuries, injury severity, property damage, loss of use of trucks, and fatalities; and (3) reduced fuel consumption and pollutant emissions. The impact analyses were performed at a macroscopic level.

4.6.1 Traffic Impacts

As the new truck-only facility provides an alternative truck route in the impacted area, some trucks will divert from their current routes to the new facility and experience time savings. Moreover, the trucks and passenger cars that continue to use existing routes will also enjoy time savings due to congestion mitigation. CATS ran its travel forecasting-models, with input from the project team, to estimate traffic impacts of the proposed truck-only roadway on the Chicago regional traffic flow pattern.

The CATS travel forecasting models represent a classical "four-step" process of trip generation, distribution, mode choice, and assignment, developed and improved upon since 1956, now built upon EMME/2 and ARC/INFO. The present CATS region, for analysis purposes, includes the counties of Lake, McHenry, Cook, DuPage, Kankakee, Kane, Kendall, Grundy, and Will in Illinois, and Lake County in Indiana and parts of other Illinois, Indiana and Wisconsin counties bordering the region.

Due to limited resources and the study's macroscopic nature, only a time-of-day traffic assignment procedure was performed, meaning that the analysis reflects only the impacts of rerouting traffic, but not the induced demand effects of redistribution. CATS' time of day assignment procedure incorporates features such as multiclass and capacity constrained equilibrium assignment. It splits into eight time periods the final highway trip table from the iterated process. Separate assignments estimate highway vehicle-miles and travel speeds for eight time periods during the day, and results of the separate period assignments are accumulated into daily volumes.

In the CATS models, the original truck trip generation model was based on an older truck survey that does not reflect a trend towards more heavy trucks and more light trucks, with decreasing numbers of medium-sized trucks. CATS has recently assembled a Year 2002 intermodal heavy-duty truck O-D matrix, including 21 intermodal rail yards, 8 points-of-entry to the CATS region along the national highway system and 14 industrial park/warehouse concentrations (4-3). The original heavy-duty truck trip table in the CATS models was adjusted by raising trip production rates for any traffic analysis zone that contains an intermodal ramp, and increasing the heavy truck trip table by 25% overall.

Road network coding was also adjusted in order to perform the analysis. The heavy-duty truck mode was removed from roadway links where physical conditions prohibit use by heavy trucks. Two rules were applied for this adjustment. First, links with inadequate (less than 13' 6") vertical clearance for large vehicles, mainly locations where the street passes under the railroad system, were edited to exclude such vehicles. Second the heavy truck mode was also removed from links if these three conditions were simultaneously met: driving lanes of less than or equal to 10' width, one directional driving lane (one-way or two-lane street) and parking allowed.

Only Alternative 1 (no construction) and Alternative 2 (truck-only roadway without any CVHAS technologies) were tested with the CATS models. The impacts of other alternatives were estimated from the modeling results of Alternative 2. Therefore, the truckway was coded as a two-lane expressway with a 65 mph posted speed and 12-foot lanes. Where it was connected to the existing mixed-flow expressways (I-55, I-90, I-294), expressway-to-expressway ramps were coded. Each node with on/off ramps is also associated with a freight location served by the facility. At these points, centroid connector links were coded directly from the truckway to the zone with a 30 mph speed limit and no capacity constraint.

Tolling is one of the key factors affecting the overall traffic impacts in the region and the financial feasibility of the proposed facility. There exist several toll roads in northeastern Illinois, such as the Skyway, I-94/I-294 Tri-State Tollway, I-90 Northwest Tollway, I-355 South Tollway, I-88 between I-39 and Rock Falls. It is a complex exercise to determine an appropriate toll rate that maximizes socio-economic benefits and maintains a promising financial sustainability. Such an exercise is beyond the scope of this study. In contrast, two tolling scenarios were applied in the tests. One is no toll imposed on the facility and the other is to apply tolls of $1.25 each on Segments 1, 3, 4 and 7. The toll rate was determined not to pay for the road, but rather mimic the current toll level of state tollways. The toll rate we set is less than that on the Skyway and is comparable to those on the I-94/I-294 Tri-State Tollway. The Skyway has the highest single charge for any toll road in the state (1.20 per axle), and a 5-axle truck would pay $6.00 for a single trip (7.8 miles, $0.77 per mile). The Tri-State charges tolls according to vehicle class, which are somewhat different for different locations. A 5-axle truck from Indiana to Northlake would pay $5.00 via the Tri-State Tollway. In our toll scenario, toll-collecting locations would be on Segments 1, 3, 4, and 7, and a toll of $1.25 should be paid each time a truck passes any of them, that is, if a truck travels from Indiana to Northlake via the new facility, it would pay $5.00 in total (32.5 miles, $0.15 per mile), the same it would pay if traveling via the Tri-State Tollway.

Although the modeling year was 1999, with some adjustments made to the heavy truck trip table and the roadway network based on current conditions, we assumed the results represent the conditions at the near-term assessment Year 2005.

Table 4.2 presents facility performance results of Alternative 2 under no-toll scenario, including daily vehicle volume (bi-directional), vehicle-miles-traveled (VMT), vehicle-hours-traveled (VHT) and average travel speed (mph) for defined segments.

TABLE 4.2 Truck Facility Daily Statistics under No-Toll Scenario

Segment #	Volume in Vehicles	Vehicle Miles Traveled	Vehicle Hours Traveled	Average Travel Speed
1	15,010	120,080	3,111	39
2	17,118	51,354	1,758	29
3	15,554	77,770	1,839	42
4	16,213	64,852	1,517	43
5	15,537	124,297	2,962	42
6	12,852	19,278	360	54
7	11,649	34,948	570	61
8	6,810	51,076	749	68
9	4,623	20,805	289	72

Table 4.3 presents network statistics for the private auto class of vehicles and the heavy truck class with no-toll scenario. VMT on all facilities includes the freeways and expressways, while VMT on freeways and expressways is presented separately. One can be subtracted from the other to find VMT for only non-freeway/expressway facilities. Also, the truckway was coded as an expressway, so the figures from the truckway (above) can be subtracted from freeway/expressway in the build scenario to calculate non-truckway statistics. VHT can be manipulated the same way.

TABLE 4.3 Network Statistics under No-Toll Scenario

	VMT		VHT	
	All Facilities	Free/Expressway	All Facilities	Free/Expressway
Private Auto No-build	159,644,571	40,545,003	7,319,636	1,325,469
Private Auto Build	159,615,066	40,881,503	7,254,060	1,317,786
Difference	-0.0%	0.8%	-0.9%	-0.6%
	All Facilities	Free/Expressway	All Facilities	Free/Expressway
Heavy Truck No-build	6,741,155	4,264,104	204,843	94,617
Heavy Truck Build	6,773,692	4,415,266	198,339	94,660
Difference	0.5%	3.5%	-3.2%	0.0%

From Table 4.2, it can be found that the proposed truckway with one-lane in each direction would get congested once it starts operation, particularly Segments 1 to 5 [10]. Two major re-

[10] This is based on the hourly-lane capacity of approximately 680 heavy-duty trucks (Highway Capacity Manual, 2000).

routings would occur. Some trucks are diverted from the Skyway to the proposed truckway. And some trucks traveling between Indiana and the Northlake direction are avoiding several toll plazas on I-294 by using the proposed truckway instead of coming across on 80/94.

Table 4.4 presents facility performance results of Alternative 2 with toll, including daily vehicle volume, VMT and VHT and average travel speed for defined segments.

TABLE 4.4 Truck Facility Daily Statistics with Toll Scenario

Segment #	Volume in Vehicles	Vehicle Miles Traveled	Vehicle Hours Traveled	Average Travel Speed
1	10,484	83,872	1,557	54
2	13,974	41,921	953	44
3	10,385	51,923	853	61
4	10,012	40,046	616	65
5	12,543	100,347	1,827	55
6	10,014	15,021	235	64
7	7,381	22,143	319	69
8	6,578	49,334	726	68
9	4,821	21,693	304	71

Table 4.5 presents network statistics for the private auto class of vehicles and the heavy truck class with toll.

TABLE 4.5 Network Statistics with Toll Scenario

	VMT		VHT	
	All Facilities	Free/Expressway	All Facilities	Free/Expressway
Private Auto No-build	159,644,571	40,545,003	7,319,636	1,325,469
Private Auto Build w/Toll	159,635,502	40,826,589	7,268,434	1,323,007
Difference	-0.0%	0.7%	-0.7%	-0.2%
	All Facilities	Free/Expressway	All Facilities	Free/Expressway
Heavy Truck No-build	6,741,155	4,264,104	204,843	94,617
Heavy Truck Build w/Toll	6,765,553	4,367,236	196,986	91,325
Difference	0.4%	2.4%	-3.8%	-3.5%

For the toll scenario, we conclude that the capacity of one truck lane in each direction (Alternative 2) is adequate for the predicted truck traffic in Year 2005. Although financing issues of the proposed facility are beyond of the scope of the study, we present a quick calculation here. The levied tolls would generate the revenue of $13M at Year 2005 and consequently a total amount of $200M in Year 2003 dollar over the evaluation period of 20 years, if we took into account traffic growth presented below. The generated revenue would pay for 25% of the cost of the proposed truck-only roadway, including construction, ROW and annual operation and maintenance cost presented in Section 4.7.1. Because road pricing is a promising way to finance the truck-only facility, we performed the following analyses based on the results with a toll levied. That is to say, hereinafter, the traffic impacts of Alternative 2 are characterized by Tables 4.4 and 4.5.

Note that the statistics documented in the above tables are 24-hour averages, which were calculated from the eight time period assignments by the CATS models. Certainly, the primary VHT savings are concentrated in the peak hours. Any realistic toll structure would have to capture this value to the truckers through a dynamic pricing structure, which again, is beyond the scope of this project.

Another thing to note is that the multi-class equilibrium assignment in the CATS models is based on "auto vehicle equivalents", where B-plate and light trucks are both one auto vehicle equivalent, and medium trucks are two vehicle equivalents and heavy trucks are three auto vehicle equivalents. The time penalty by toll is not dependent upon what vehicle class it is applied to. Moreover, the CATS models used a particular volume-delay function for toll links, which goes beyond a simple conversion of dollars paid in toll to minutes based on a single assumed value of time. The time penalty associated with the toll of $1.25 on the collected segment was between 2.60 and 18.89 minutes, depending on the locations, direction, and time period of the day. It implies that the values of travel time vary between $3.97 and $28.83 per hour (for auto vehicle equivalents, not for trucks).

The traffic volumes for Alternatives 3 and 4 would be much lower than those in Table 3, because it takes time and money for the industry to equip their trucks with the CVHAS technologies. In the absence of a specific forecasting model for the adoption of these new technologies, we assumed levels of market penetration at the beginning of the project, for example, 15% for automatic steering in Alternative 3 and 10% for automatic steering, automatic speed and spacing control in Alternative 4[11]. With the assumed market penetrations, traffic prediction for Alternatives 3 and 4 can be easily calculated and are presented in Table 4.6.

TABLE 4.6 Predicted Daily Truck Facility Traffic Volumes for Alternatives 3 and 4

Segment #	1	2	3	4	5	6	7	8	9
Alternative 3	1573	2096	1558	1502	1881	1502	1107	987	723
Alternative 4	1048	1397	1039	1001	1254	1001	738	658	482

[11] Market penetration and its growth over time clearly need to be considered here. It would have been too simplistic to assume a 100% market penetration of these technology systems for these alternatives. Nevertheless, while the selection of these market penetration percentages is somewhat arbitrary, choosing smaller percentages will have only resulted in a worse performance for these two alternatives relative to the baseline (See Section 4.7.3).

Note that with the growth of the market penetration of CVHAS equipped trucks in the following years, traffic volumes for Alternative 3 and 4 will increase consequently. The growth of the market penetration is discussed in Section 4.7.1.5.

By referring to the historic annual growth rates of intermodal truck movements in the Chicago area: 3.7% from 1978 to 1996, 5.6% from 1996 to 2000 and the annual growth rate of VMT by trucks in Illinois: 1.5% from 1997 to 2002, we selected future growth rates for traffic volumes on the new facility as 2% from 2005 to 2015, and 1% from 2016 to 2025. Consequently, in Alternative 2 traffic volumes of several segments of the facility will be beyond their capacities in 2015, and thus a second lane in each direction would be added on these segments by that time.

Alternative 5 was designed as more deployment-staging oriented. According to the traffic prediction for Alternative 2, the year to convert the truck-only facility to automated operation would be 2015. We expect that the cost of CVHAS equipment will be reduced significantly by then, as described in the next section. Therefore, it is safer to assume the market penetration of CVHAS-equipped trucks is 80% in 2015. Furthermore, a second lane will not be needed at Alternative 5 because fully automated operation in 2 or 3 truck platoons can increase link capacity significantly. Estimates of the theoretical capacity (pipeline capacity) of a single lane automated highway system have been made in a previous study (4-6). Accounting for flow interruptions or merge disturbances, we determined the adjusted or derated capacity of an automated truck lane as in Table 4.7.

TABLE 4.7 Automated Truck Lane Capacity

	Speed: meters per second [miles per hour]		
Platoon size (No. of trucks)	20 m/s [45 mph]	25 m/s [56 mph]	30 m/s [67mph]
1	920	820	770
2	1290	1260	1250
3	1490	1570	1570

Note that the increase in lane capacity does not scale directly with the platoon size or operating speed, and is indeed relatively insensitive to operating speed. More importantly, there is very little capacity advantage to operating platoons longer than three trucks, while the longer platoons would actually make it more difficult for entering trucks to find gaps in which to merge into the traffic stream. Hence, we do not consider cases with platoons having more than three trucks each.

In summary, with the traffic impact analysis results, we finalized the operational concept alternatives as follows:

- Alternative 1
    - Baseline concept (no CVHAS technologies, no truck-only facilities).
- Alternative 2
    - Truck-only facility without CVHAS technologies, open to all trucks;

- One standard 12-foot lane in each direction before Year 2015, and a second lane added on Segments 1-6 by Year 2015.

Alternative 3
- Truck-only facility with CVHAS technologies (automatic steering) for equipped trucks only;
- One 10-foot lane in each direction. Automatic steering control makes it possible for equipped trucks to follow lanes very accurately. For maximum-width trucks of 9 feet, lanes need only be 10 feet wide rather than the standard 12 feet.

- Alternative 4
    - Truck-only facility with fully automated CVHAS technologies (automatic steering, automatic speed and spacing control with 2 or 3 truck platoons if warranted) for equipped trucks only;
    - One 10-foot lane in each direction.
- Alternative 5
    - Truck-only facility without CVHAS technologies before Year 2015;
    - At Year 2015, upgrading the facility to be an automated truck-way (automatic steering, speed and spacing control with 2 or 3 truck platoons);
    - One standard 12-foot lane in each direction.

Again, recall that prior to Year 2015 when Alternative 5 is converted to be fully automated, Alternative 5 is equivalent to Alternative 2. In each of the above cases, the roadway widths include shoulders on both sides, in addition to the specified lanes.

4.6.2 Safety Impacts

For a truck-only facility with CVHAS technologies, safety-related benefits stem from the separation of truck/non-truck traffic and the technologies as well. Traffic safety statistics show that a significant majority of two-vehicle crashes involving trucks and another vehicle, approximately 74%, are caused by drivers of the other vehicles, who make maneuvers that trucks are not able to respond to (4-7). The CVHAS collision warning technologies will no doubt reduce some kinds of crashes and result in some safety-related benefits. However, sufficient data are not available at this time to support quantitative estimates of the safety benefits, so those are not included here.

4.6.3 Fuel Consumption/Emission Impacts

Combinations of on-road and wind tunnel tests have shown that operating trucks in automated close-formation platoons can save 15%-20% of fuel consumption when they are cruising at highway speeds, compared to operating at the same speeds individually. The automated trucks would maintain those high speeds continuously on the automated lane. Additionally, there are fuel savings because trucks on urban arterials experience stop-and-go traffic rather than higher-speed cruising. This effect has been quantified in research at the University of California at Riverside that has measured fuel consumption of a representative mix of modern Class-8 trucks (produced from 1998-2004), loaded to a gross vehicle weight of 60,000 lb., of about 5.5 miles per gallon when the truck is cruising at constant speed of 60 mph. Driving in congested traffic at an average speed of 30 mph leads to a decline to 4 miles per gallon. Following a California Air Resources Board driving cycle that includes a lot of stop-and-go cycles and an average speed of 18 mph, leads to a further decline to about 3.6 miles per gallon. These effects are illustrated in Figure 4.4.

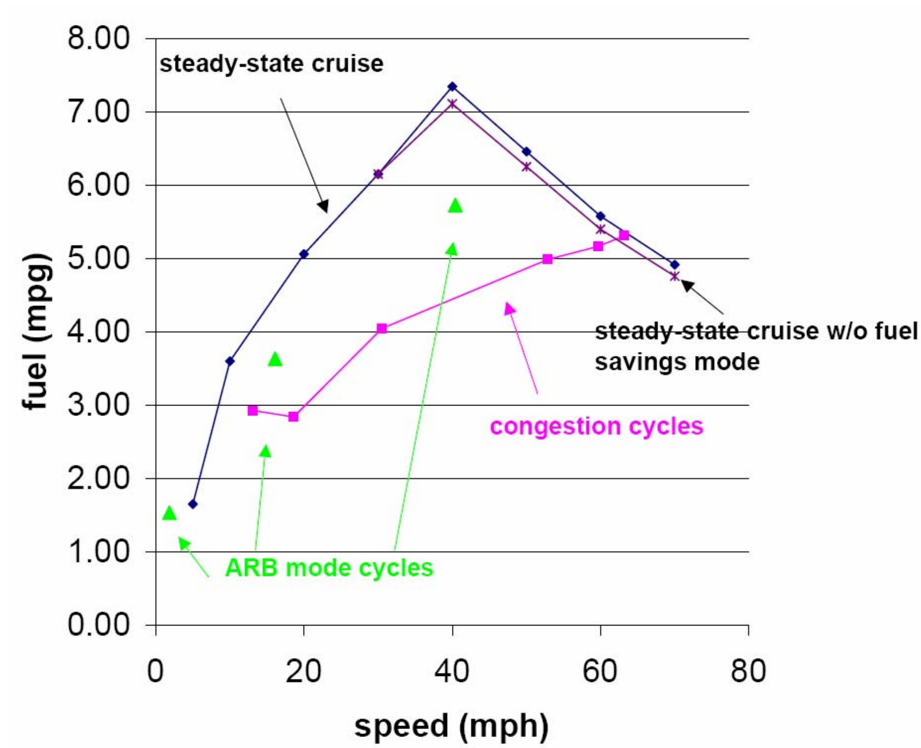


FIGURE 4.4 Fuel Consumption of Trucks (Source: Reference 4-9)

The same drag reductions producing fuel savings also contribute to reducing emissions from trucks. Carbon dioxide (greenhouse) gas reductions are directly proportional to fuel consumption reductions. The contributions for regulated pollutants are the subject of current experiments and are not yet known for heavy diesels of the types used in trucks, although they have been found to be substantial for the Otto-cycle engines used in passenger vehicles.

The proposed facility may also reduce emissions from trucks and other vehicles resulting from congestion mitigation. However, in this study, we did not examine these impacts but rather leave it to subsequent environmental studies. Note that integrating emissions costs into the cost-benefit evaluation does not have a major impact on project feasibility (4-5).

4.7 Cost-Benefit Analysis

This section presents a cost-benefit analysis (CBA) for the alternative operational concepts. The CBA period was 20 years (2005 – 2025). As recommended by the Office of Management and Budget, an annual discount rate of seven percent was used in the CBA.

4.7.1 Cost Estimation

The costs associated with each alternative were calculated, considering the following primary cost categories:

- Construction costs of truck-only roadway
- Right-of-way costs
- Annual operation and maintenance facility cost
- CVHAS equipment and installation costs (facility)
- CVHAS equipment and installation costs (in-vehicle units)

4.7.1.1 Construction Costs

In view of the macroscopic nature of this feasibility study, a simplified approach was employed to estimate the construction costs. We made several site visits to investigate the ROW conditions (See Appendix IV for detailed findings). Based on the construction cost statistics in the Chicago area, the unit construction cost per lane mile was determined for each specific segment. Consequently, multiplying the unit cost by the length of each segment yielded the construction cost for each segment and total cost for the proposed facility.

Figure 4.5 presents the inflation-adjusted cost per lane mile for major Chicago area highway engineering and construction projects prepared by CATS in 2002. For example, the unit construction cost for Elgin-O'Hare (1991) is \$6.9M per lane mile; Kennedy reconstruction (1992), \$6.7M; Tri-State add-lanes/reconstruction (1993), \$7M and Stevenson reconstruction (1999), \$7.1M. These projects involved reconstruction of heavily-used highways while open for public use, and were considerably more complex than the proposed creation of new truck lanes on lightly-used or vacant rights-of-way.

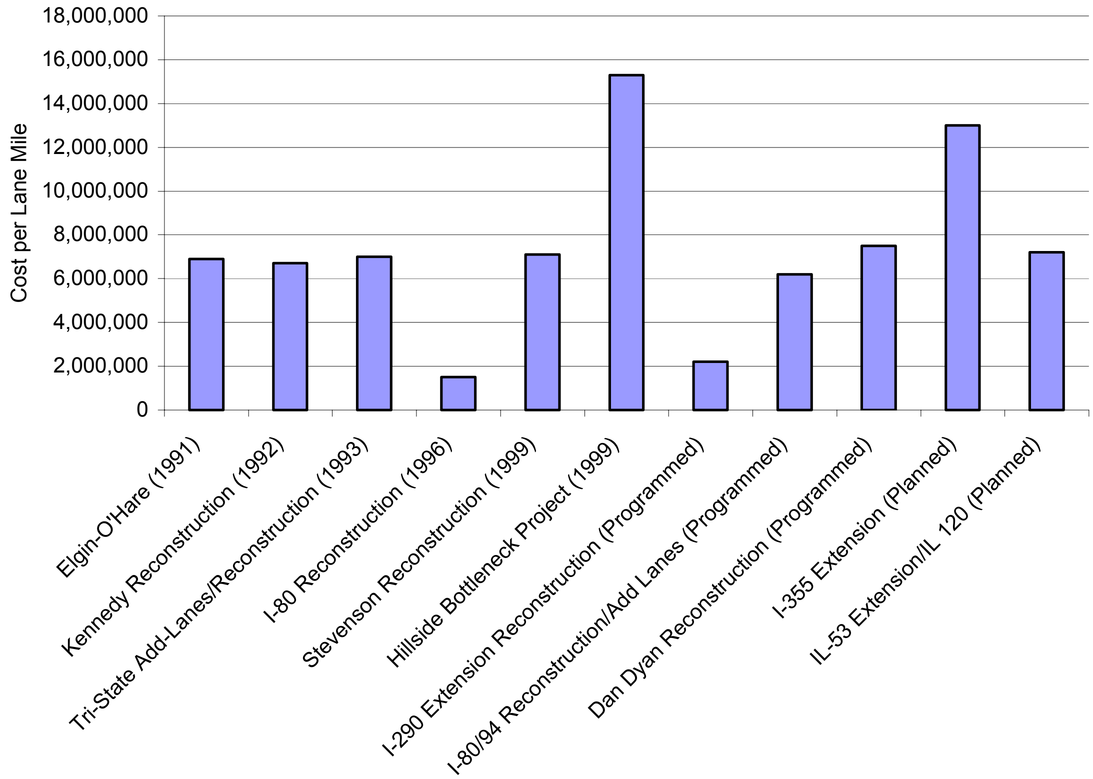


FIGURE 4.5 Inflation-Adjusted Cost per Lane Mile for Major Chicago Area Highway Engineering and Construction Projects (Source: CATS 2030 Regional Transportation Plan Development Process: http://www.sp2030.com/)

Based on site visits to the proposed alignment and the above data, we determined unit roadway construction costs for each specific segment, ranging from $1.5M per lane-mile to $6.5M per lane mile, depending on their ROW conditions. In each segment, certain number of bridges with different lengths may be needed, for example, to cross the Calumet River, the Dan Ryan Expressway, railroad trestles, canals or local streets. Therefore, we also determined a unit bridge construction cost as $20M per lane mile, but with the special exception that the high-clearance bridge needed over the Calumet River would cost $60 M per lane mile. Table 4.8 presents unit construction cost for each segment of the near-term truckway at the Interstate standard (12-foot lane).

TABLE 4.8 Construction Cost Estimation of Truck-Only Facility

Segment #	Length (mile)		Unit cost ($ million per lane mile)	
	Highway	Bridge	Highway	Bridge
1	7.8	0.2	1.5	60
2	2.7	0.3	1.5	20
3	4.7	0.3	2.0	20
4	3.9	0.1	6.5	20
5	7.9	0.1	6.5	20
6	1.4	0.1	6.5	20
7	2.9	0.1	6.5	20
8	6.4	0.1	6.5	20
9	5.2	0.3	5.0	20
Total	42.9	1.6	-	-

As aforementioned, with automatic steering control, lane width could be reduced to 10 feet. Moreover, conventional highway alignments are based on drivers' sight distances at expected operating speeds. Automated vehicles are not subject to the same kinds of limitations, so it is possible to accommodate tighter curves and sight lines otherwise unacceptable for conventionally driven vehicles. With these considerations, we assumed the unit construction costs of roadways and bridges would be reduced eight percent and five percent, respectively, when calculating total construction costs for alternatives with automatic steering and full automation.

The following considerations have been made when estimating the total construction cost for each alternative:

- Alternative 2
  - A second lane added in Year 2015 and the cost expressed in 2003 value with a seven percent annual discount rate.
- Alternative 3
  - Percentage of saving on unit construction cost due to the reduced lane width: 8% for highway; 5% for bridge;
  - No second lane added.
- Alternative 4
  - Percentage of saving on unit construction cost due to the reduced lane width: 8% for highway; 5% for bridge;
  - No second lane added.
- Alternative 5
  - Standard 12-foot lane, no cost-saving;
  - No second lane added.

The estimates of total cost are summarized in Table 4.9.

TABLE 4.9 Total Construction Cost for Each Alternative (Year 2003 Dollars)

	Alternative 2	Alternative 3	Alternative 4	Alternative 5
Number of Lanes per Direction	1 (before 2015), 2 (after 2015)	1	1	1
Lane Width (feet)	12	10	10	12
Total Construction Costs ($)	716,164,244	439,216,000	439,216,000	474,800,000

4.7.1.2 Right-of-Way Costs

The cost of industrial space (land alone) in Chicago-Cook County averages $3.93 per square foot ($42.30 per square meter) net (4-10). We estimated the width of ROW requirement for each alternative. Multiplying the ROW width by the unit cost and total length yielded the total ROW costs. For Alternative 2, although a second lane in each direction would be added in the future, the ROWs were assumed to be purchased at the beginning of the construction. Therefore, the width of ROW for Segments 1-6 at Alternative 2 is 80 feet (2 feet barrier, 4 feet left shoulder, 2*12 feet lane, and 10 feet for the right shoulder in each direction). Consequently, the widths for Alternative 3, 4 and 5 are 52, 52, and 56 feet respectively.

Table 4.10 reports the total ROW cost for each alternative.

TABLE 4.10 Right-of-Way Cost for Each Alternative (Year 2003 Dollars)

	Alternative 2	Alternative 3	Alternative 4	Alternative 5
Total Width of ROW (ft)	80/56	52	52	56
Total ROW Costs ($)	73,871,424	48,016,426	48,016,426	51,709,997

4.7.1.3 Annual Operation and Maintenance of Facility Cost

Operation and maintenance (O&M) costs were calculated as a percentage of total project cost estimated at 3% - 4% of construction costs over a 20-year period (4-11). For Alternative 3, 4 and 5 (after 2015), the O&M cost would be 10% -15% higher, because of maintenance of electronics and instruments and more frequent pavement rehabilitations. For Alternative 2 and 5 before 2015, the annual O&M costs were both $1.4M. After then, they were $2.8M and 1.6M respectively. For Alternative 3 and 4, the annual O&M costs were $1.5M and $1.6M respectively.

4.7.1.4 CVHAS Equipment and Installation Costs (Facility)

Automatic steering and full automation need roadway reference markings, for example, permanent magnets installed in the pavement so that vehicle positions can be measured relative to the markings. For new construction, the installation of these magnets should add about $5000 per lane mile. For retrofits into existing pavement, the cost of installation was assumed to be

$10,000 per lane mile. Note that these costs will decrease over time as mass production techniques for magnet installation are developed.

For full automation, vehicle-roadway wireless communications will be also needed, and will probably be based on the next generation of dedicated short-range communications (DSRC) in the 5.9 GHz band. These devices are currently under development and are not yet commercially available, but it is likely that the roadside units will cost no more than $5000 each (and potentially much less than that with volume production in the long-term). One roadside unit will be needed at each on-ramp and off-ramp and then periodically along the automated lane, at a spacing of about 300m.

We note below the following factor when calculating the CVHAS facility cost:

- Alternative 5
    - Full automation operation at Year 2015 and the cost expressed in 2003 value with a seven percent annual discount rate.

Table 4.11 presents the total CVHAS facility cost for each alternative.

TABLE 4.11 CVHAS Facility Cost for Each Alternative (Year 2003 Dollars)

	Alternative 2	Alternative 3	Alternative 4	Alternative 5
CVHAS Facility Costs ($)	0	445,000	1,638,342	1,665,700

Note that there may be other CVHAS facility requirements, such as a control center and its hardware and software. It is reasonable to assume that the traffic management functions for the automated truck facility will be handled at the existing regional transportation management center, together with the rest of the primary highway network. It may be necessary to provide an additional workstation at the center, specific to the automated truck facility, but the cost of this is likely to be very small relative to the other costs of the new facility and thus it is not explicitly computed in the analyses here.

4.7.1.5 CVHAS Equipment and Installation Costs (In-vehicle Unit)

It is key to recognize that the costs would be significantly different in the near term (when annual production of vehicles would only be in the hundreds) and the longer term (when it could be in the range of ten thousand). So the cost estimates presented in Table 4.12 were estimated under both assumptions. The costs are the incremental costs associated with the addition of CVHAS capabilities to trucks. In all cases, we have assumed modern trucks that already have electronically controlled engines and in-vehicle data buses. The underlying component technology on trucks is advancing for reasons unrelated to CVHAS, and it was assumed, based on discussions with the largest truck manufacturer in the world, that “by wire” actuation systems will be readily available on conventional trucks within the “long-term” planning horizon for this project.

TABLE 4.12 Cost Estimation for In-Vehicle Units

	Automatic steering control	
Cost generators	Near-term unit cost ($1000)	Long-term unit cost ($1000)
Steering actuator	2.5	0.5
Magnetic sensors	5	1
Computer and interfaces	5	1
Installation/integration	0.5	0.2
Sub-total	13	2.7
	Additional costs for full automation	
Forward ranging sensor(s)	2.5	0.5
Wireless communication	0.5	0.1
Brake actuation	5	1
Driver interface	1	Assume included
Installation/integration	1	0.3
Total	23	4.6

The following assumptions/considerations were made when estimating the total in-vehicle unit costs:

- For calculating the costs of in-vehicle units for automatic steering control and full automation before 2015, we used the approximate near-term unit costs of $13K and $25K respectively while after 2015, we used the approximate long-term cost of $3K and $5K; Between Year 2005 and 2015, we applied a simple linear scaling down of the costs over time so that they continuously changed from the near-term cost to the lower long-term cost. The change of costs per vehicle over time is shown as Figure 4.6.

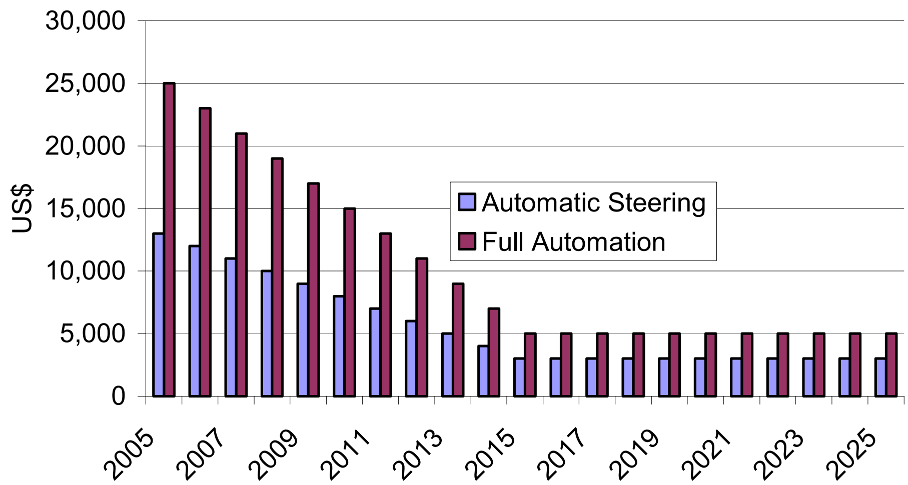


FIGURE 4.6 Change of CVHAS Equipped Cost per Vehicle over Time

- It was estimated from the CATS regional models that there would be 37,000 truck trips using the new truck-only facility at Year 2005. Based on discussions with CATS, we assumed that there are, on average, two daily truck trips, and estimated there to be a total of 18,500 trucks to be equipped.

- For Alternative 3, the level of market penetration was assumed to be 15% in Year 2005, and would increase annually 15% more in the following three years and 10% more after that until reaching 80%, an assumed saturated level at Year 2010. Consequently, the number of equipped trucks would increase at the same rate as the market penetration grew, and after 2010, it would increase in the following years at the same growth rate as the traffic growth rate previously reported in Section 4.6.1 as 2% from 2010 to 2015, and 1% from 2015 to 2025. The assumed population growth of automatic steering equipped trucks is illustrated in Figure 4.7

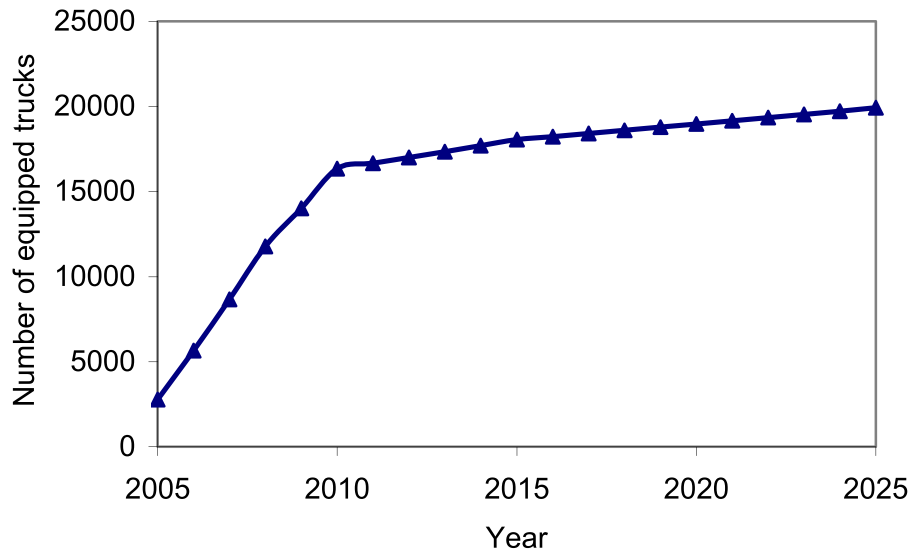


FIGURE 4.7 Assumed Growth of Automatic Steering Equipped Trucks

- For Alternative 4, the level of market penetration was assumed to be 10% at Year 2005, and it would increase annually 15% in the following three years and 5% more after that until reaching 80% at Year 2013. The number of equipped trucks would increase at the same rate as the market penetration would grow, and after Year 2013, it would increase in the following years at the same growth rate as the traffic growth rate previously reported in Section 4.6.1 as 2% from 2013 to 2015, and 1% from 2015 to 2025. The assumed population growth of full automation trucks is shown as Figure 4.8.

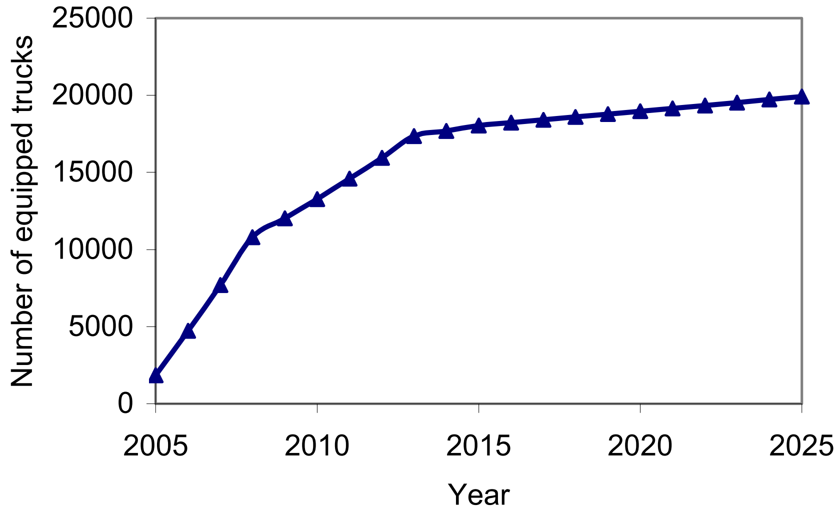


FIGURE 4.8 Assumed Growth of Full Automation Trucks

- For Alternative 5, the level of market penetration was assumed to be 80% at Year 2015, and the number of equipped trucks increased in the following years at the same traffic growth rate as 1%.
- We assumed a 10-year truck life and thus included a replacement cost of in-truck equipment after the truck wears out.

Table 4.13 presents the resulting total CVHAS in-vehicle unit cost for each alternative.

TABLE 4.13 CVHAS In-Vehicle Equipment Cost for Each Alternative (Year 2003 Dollars)

	Alternative 2	Alternative 3	Alternative 4	Alternative 5
CVHAS In-Vehicle Costs ($)	0	165,038,739	300,196,641	40,259,968

4.7.2 Benefit Estimation

As aforementioned, we only considered benefits of travel time savings and reductions of fuel consumption. We did not consider the safety and environmental benefits discussed in the last section as well as the reduced maintenance costs of surface streets.

4.7.2.1 Travel Time Savings

From Table 4.5, it can be calculated that, for Alternative 2 the total network travel time savings for passenger cars and trucks are 13,824,540 and 2,123,390 hours, respectively, at Year 2005. By applying the value of travel time of $16 /hour for passenger cars recommended in (4-12) and $65 /hour for heavy-duty trucks (based on discussions with CATS), we estimated the annual time saving benefits as US$ 221,192,640 and 137,890,350 respectively in Year 2005.

For the other Alternatives, travel time savings were estimated by multiplying the corresponding levels of market penetrations at Year 2005.

We acknowledge that the above linear scaling of time savings is not a realistic assumption, because the change of the total travel time of a network does not scale directly with the capacity it has. In fact, the linear scaling may underestimate the actual benefits, as shown in Figure 4.9. Therefore, it is safe to make this assumption in the sense that our conclusion about the cost-effectiveness of each alternative presented later in this chapter will not be invalidated by relaxing this assumption.

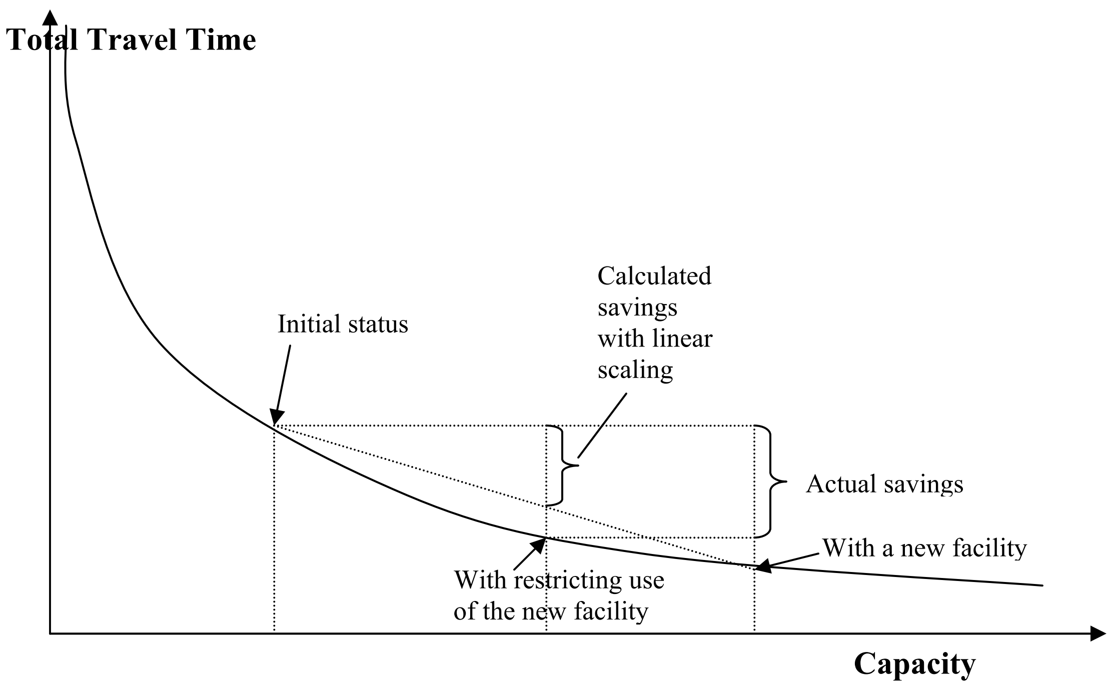


FIGURE 4.9 Actual Time Savings vs. Calculated Savings with Linear Scaling

Due to limited resources, we did not run CATS' travel forecast models to estimate the network impacts of the proposed facility in the future years, for example, 2010 or 2015. We simply assumed the following trends for the timesaving benefits:

- For Alternatives 2 and 5 (before 2015), the corresponding benefits decreased at an annual rate of 5% in the following years, considering the growth of the traffic demand.
- For Alternative 3, the corresponding benefits increased annually at the same rate as the growth rate of market penetration before Year 2010 when the level of market penetration became saturated. After that, the benefits were assumed not to change.
- For Alternative 4, the corresponding benefits increased annually at the same rate as the growth rate of market penetration before Year 2013. After that, the benefits increased annually 2% from 2013 to 2015 and 1% from 2015 to 2025, considering the characteristics of automated operations.

- For Alternative 5 (after 2015), the corresponding benefits increased 1% annually from 2015 to 2025, considering the characteristics of automated operations.

Table 4.14 presents the resulting present value in Year 2003 of the travel time savings for each alternative, compared to the baseline case of no new truck facility.

TABLE 4.14 Travel Time Savings for Each Alternative (Year 2003 Dollars)

	Alternative 2	Alternative 3	Alternative 4	Alternative 5
Travel time savings ($)	2,938,473,072	2,185,796,310	1,931,338,450	2,981,926,571
- portion for all trucks	1,128,393,969	839,360,890	741,647,313	1,145,080,413
- portion for intermodal trucks[12]	214,394,854	159,478,569	140,912,989	217,565,278

The benefits of time savings for intermodal trucks presented above are a simple first-cut estimate. This portion of the benefits is comparatively small, because rubber-tired cross-town transfers between intermodal rail terminals are a shrinking (though not vanishing) segment of the Chicago trucking market, and increasing percentages of yard to yard transfers are now being handled by rail. However, with this new truck-only facility, rubber-tired cross-town transfers could resurge and more time savings for intermodal trucks could be expected.

4.7.2.2 Reductions in Fuel Consumption

Recall that there are two sources for the decrease in fuel consumption: avoiding stop-and-go traffic on urban arterials and aerodynamic drag reductions from automated close-formation platoons.

Based on the empirical data presented in Reference 4-9, we estimated the reductions of fuel consumption of heavy-duty trucks due to avoiding stop and go traffic.

From Table 4.5, it can be calculated that with the introduction of Alternative 2, VMT of heavy-duty trucks on non-expressway/freeway facilities decreased by 78,734 miles while on expressway/freeway facilities it increased by 103,132 miles. The average travel speeds can also be calculated to be 23 mph and 46 mph on these two types of facilities, corresponding to the fuel consumption rates of 4.2 miles per gallon at ARB mode cycles and 6.6 miles per gallon at steady-state cruise without fuel savings mode. The unit price of diesel fuel was $1.50 /gallon[13]. Consequently, the annual fuel savings was estimated as $842,435 at Year 2005 for Alternative 2.

For the other Alternatives, fuel cost savings were estimated by multiplying the corresponding levels of market penetrations. Furthermore, we assumed the trends for fuel savings to be consistent with those used to estimate travel time savings (See Section 4.7.2.1).

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[12] Either their origins or destinations are intermodal rail yards.
[13] An average value taken over Chicago-area diesel prices obtained by means of an Internet search.

In evaluating Alternatives 4 and 5, additional reductions were calculated by assuming 15% savings of fuel consumption due to automated close-formation platoons (4-8). These savings also increased in the following years at the same growth rate of market penetration and traffic volume.

Table 4.15 presents the resulting fuel savings for each alternative.

TABLE 4.15 Reduction of Fuel Consumption for Each Alternative, Compared to Baseline Case with No Truck Facility

	Alternative 2	Alternative 3	Alternative 4	Alternative 5
Fuel Savings ($)	6,893,874	5,128,039	46,257,595	24,505,307

4.7.3 Comparison of Costs and Benefits

The evaluation results for the alternative operational concepts are presented in Table 4.16 with entries expressed in present value (2003) terms.

TABLE 4.16 Evaluation Results of the Alternative Operational Concepts

	Alternative 2	Alternative 3	Alternative 4	Alternative 5
Cost Components				
Construction costs	716,164,244	439,216,000	439,216,000	474,800,000
ROW costs	73,871,424	48,016,426	48,016,426	51,709,997
Annual O&M	21,941,915	17,391,021	18,550,423	15,544,330
CVHAS costs (facility)	0	445,000	1,638,342	1,665,700
CVHAS costs (vehicle)	0	165,038,739	300,196,641	40,259,968
Total	811,977,583	670,107,186	807,617,831	583,979,994
Benefit Components				
Travel time savings	2,938,473,072	2,185,796,310	1,931,338,450	2,981,926,571
Reduction of fuel consumption	6,893,874	5,128,039	46,257,595	24,505,307
Total	2,945,366,946	2,190,924,349	1,977,596,045	3,006,431,878
B/C ratio	3.63	3.27	2.45	5.15

In calculating the B/C ratios in Table 4.16, we assumed that the residual values of all the alternatives after 20 years (the CBA time period) were each zero. Because of limited levels of market penetration of CVHAS equipped trucks in Alternative 3 and 4, the truck-only facility was not fully utilized and thus these two alternatives are somewhat inferior to Alternative 2. It implies that, compared with the conventional truck-only lane (Alternative 2), the incremental costs of these alternatives outweigh the incremental benefits, causing an incremental B/C ratio that is less than one. However, note that the total costs of the CVHAS alternatives (3-5), including the vehicle costs, are all lower than the total costs of the truck-only facility without use of CVHAS technologies (Alternative 2).

Alternative 5 was evaluated as the best since it deployed CVHAS technologies at a later time, when the costs of the in-vehicle equipment were lower and the traffic volumes higher. The incremental CVHAS B/C ratio is 7.57. Therefore, the deployment-staging issue is very important for a successful implementation of CVHAS. We recommended Alternative 5 for further investigation.

4.7.4 Sensitivity Analyses

The CBA presented above was based on many assumptions. Therefore it is necessary to perform sensitivity analyses relative to particular parameters in order to verify the above conclusions. Because Alternative 5 was recommended for further investigation, we focused our attention on this operational concept and performed sensitivity analyses to test the reliability of the previous conclusion about it. We did not intend to determine which parameter or assumption the CBA presented above is most sensitive to.

We identified the factors that appeared to have significant impact on the evaluation outcome such as construction costs, CVHAS in-vehicle unit cost, and travel time savings. These factors are uncertain, and we performed the CBA based on our best estimate of the values of these factors. There is no doubt that any deviation from our estimate will affect the analysis outcome, and we thus conducted sensitivity analyses on these three factors. Other factors, such as annual discount rate and ROW unit cost will certainly affect the analysis outcome, but their influence was considered secondary here.

In order to investigate the impact of the uncertainty of these factors on the evaluation outcome, we determined ranges of values that these factors could assume in a conservative (pessimistic) manner:

- Construction costs

  The unit construction costs are presented in Table 4.8, which were determined by referring to the statistical data and conducting site visits. We assumed that the unit cost could be up to 20% lower or up to 100% higher.

- CVHAS in-vehicle unit costs

  The CVHAS in-vehicle unit costs are presented in Table 4.12. For calculating the costs of Alternative 5, we used the approximate long-term cost of $5K. Here we assumed that this cost could be increased to the approximate near-term unit cost of $25K or decreased to 20% less.

- Travel time savings

  A lot of parameters could be attributed to the uncertainty of travel time savings, such as the accuracy of predicted traffic volume, level of market penetration assumed, and value of travel time used. We did not differentiate their impacts but assumed that total travel time savings could be reduced by 67% or increased by 20%.

It can be found that in the worst possible scenario (two times the unit construction cost, $25K CVHAS in-vehicle unit cost, and one-third travel time savings), Alternative 5 would become infeasible because its B/C ratio would decline to 0.86. This warrants a further examination of the reliability and robustness of the feasibility of Alternative 5. For this purpose, we performed a Monte-Carlo analysis to see how these three factors affect Alternative 5's B/C ratio, where unit construction cost, CVHAS in-vehicle unit cost, and travel time savings were assumed to be uniformly distributed between their varying ranges described as above, and they were independent from each other.

Figure 4.10 presented the B/C ratios resulting from the Monte-Carlo analysis, with a sample size of 2000.

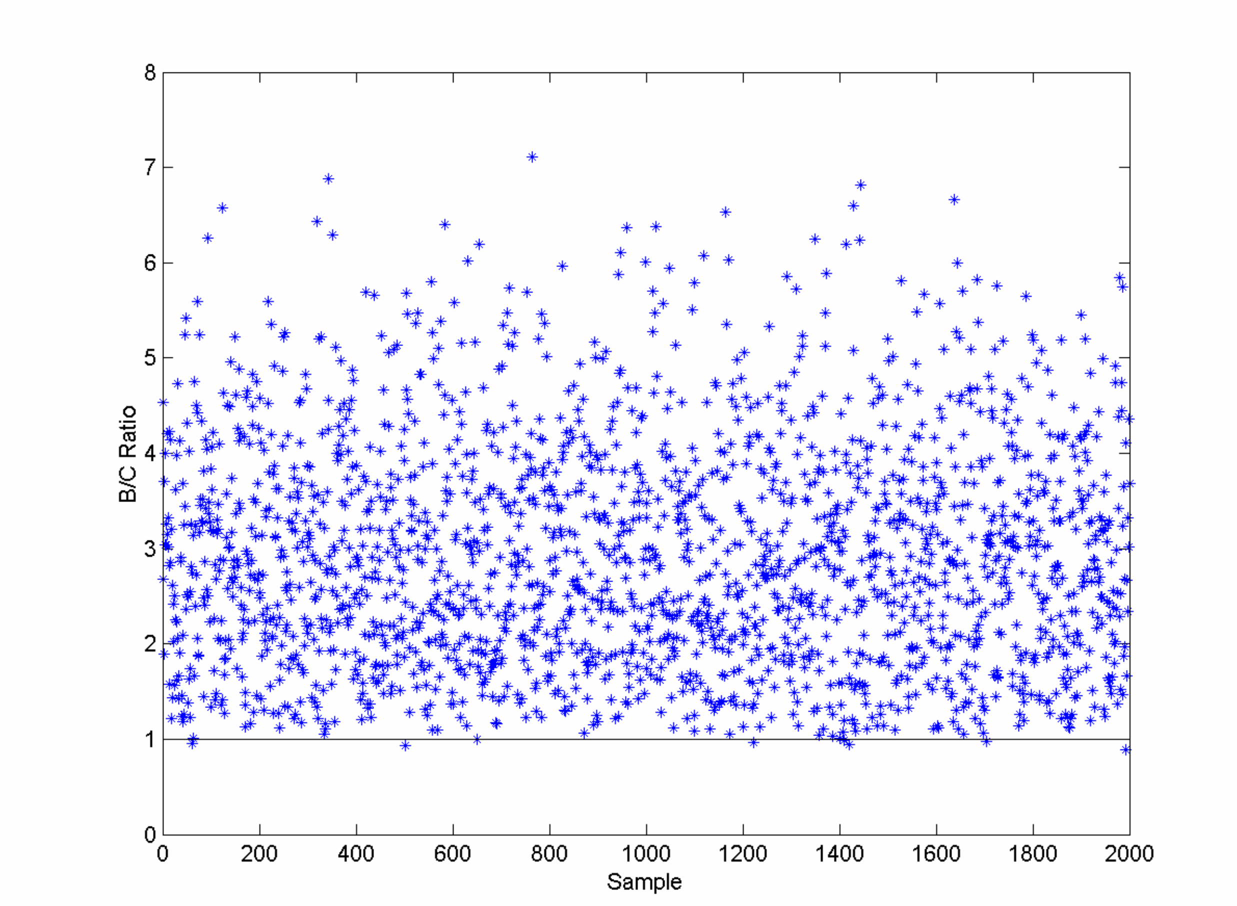

FIGURE 4.10 B/C Ratios of Alternative 5 Compared to the Do-Nothing Alternative in the Monte-Carlo Analysis

It can be found that there were only eight cases over 2000 samples that the B/C ratio of Alternative 5 is less than one. We conducted a *t*-test to test the null hypothesis that "the B/C ratio of Alternative 5 is less or equal to one". The resultant *t*-value was 74.1. Even at the 0.1% significance level, with 1999 degrees of freedom, we rejected the null hypothesis. Therefore, the *t*-test shows that Alternative 5 is economically feasible, compared to the baseline case with no truck facility, and this conclusion is reliable and robust.

The above Monte-Carlo analysis validated the robustness of the feasibility of Alternative 5 with respect to the do-nothing baseline. It is also of interest to show the comparison with conventional truck-only facility (Alternative 2) to highlight the difference based on use of CVHAS technologies, given that a truck-only facility is going to be developed. Therefore, we performed another sensitivity analysis to investigate the impact of the uncertainty on the incremental B/C ratio, compared to Alternative 2.

The major uncertain factors associated with the incremental B/C ratios were identified as below. Again, we determined ranges of values that these factors could assume in a conservative manner.

- Saving of construction costs

  One of major incremental benefits of Alternative 5 over Alternative 2 is the saving of construction costs because a second lane would not be added in Segments 1-6. However, this second lane might not be needed in Alternative 2 if actual traffic volume was much lower than predicted. We assumed this condition had a probability of 20% to occur.

- CVHAS in-vehicle unit costs

  Similarly as above, we assumed that this cost could be increased to the approximate near-term unit cost of $25K or decreased to 20% less.

- Market penetration

  The level of market penetration would affect both incremental costs and benefits. For the estimation of Alternative 5, we used 80% at Year 2015. Here we assumed that this level could be increased to 90% or decreased to 50%.

A Monte-Carlo analysis was conducted to see how these three factors affect Alternative 5's incremental B/C ratio, where saving of construction costs was assumed to binomially distributed, and CVHAS in-vehicle unit cost and market penetration uniformly distributed between their varying ranges described as above, and they were independent from each other.

Figure 4.11 presented the incremental B/C ratios resulting from the Monte-Carlo analysis, with a sample size of 2000.

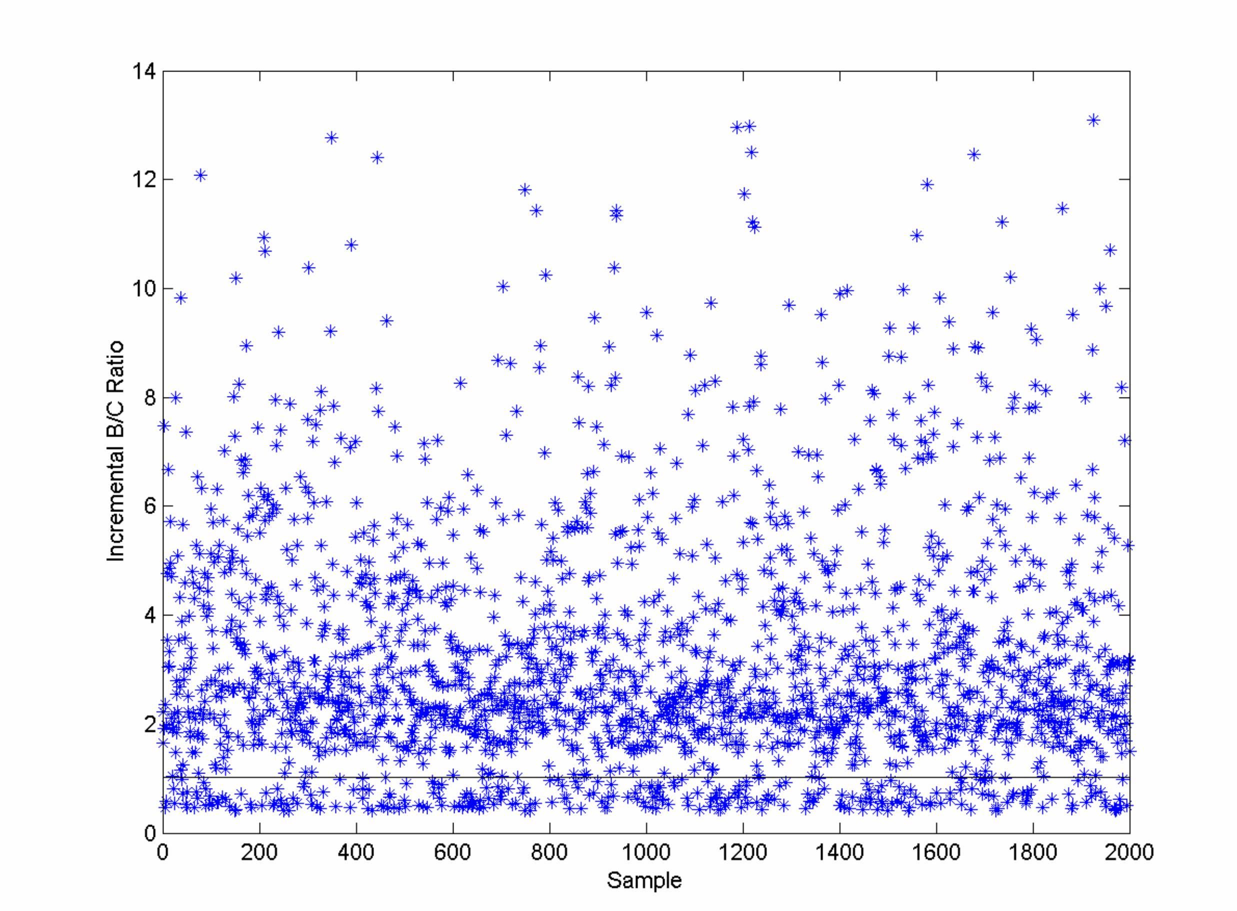

FIGURE 4.11 B/C Ratios of Alternative 5 Compared to Alternative 2 (Conventional Truck Only Facility) in the Monte-Carlo Analysis

It can be found that there were 289 cases over 2000 samples that the incremental B/C ratio of Alternative 5 is less than one. We conducted a *t*-test to test the null hypothesis that "the incremental B/C ratio of Alternative 5 is less or equal to one". The resultant *t*-value was 43.9. Even at the 0.1% significance level, with 1999 degrees of freedom, we rejected the null hypothesis. Therefore, the *t*-test implies that application of CVHAS technologies does improve the performance of a conventional truck-only facility, and this conclusion is also reliable and robust.

4.8 Conclusions

4.8.1 Summary of Major Findings

This study investigated the feasibility of implementing CVHAS technologies to improve the performance of the freight movement system in the metropolitan Chicago area. At the outset of the study, we learned and/or concluded that:

- The target market of the 1981 study, cross-town rubber-tire railroad yard-to-yard interchange traffic, has been decreasing for the past twenty years and this trend is very likely to continue though this market is unlikely to disappear entirely.

- Since 1981, several of the rail yards have closed while new ones have opened resulting in a considerably larger geographical layout of the Chicago area's intermodal yards and changed intermodal freight flow patterns.
- The proposed facility needs to spread in a larger area, serving not only yard-to-yard interchange, but also yard to/from industrial parks/warehouse concentrations, yard to/from cordon points-of-entry and cordon points-of-entry to/from industrial parks/warehouse concentrations.
- Two newly-opened yards, Rochelle and Joliet, are expected to impose significant impacts on the intermodal freight movement pattern in the Chicago metropolitan area. However, it is not clear at this moment how, when, and to what extent the impacts would occur.
- Two alignments, short and long-term could be selected for the new facility. The short-term alignment consists of a truck-only roadway primarily on presumed surplus and available rail rights-of-way, either adjacent to existing tracks or in air rights. The long-term alignment consists of the short-term alignment plus truck-only lanes along I-88 and I-55 to Rochelle and Joliet, respectively.
- In addition to a baseline case with no new truck lanes and an alternative with new truck lanes using only conventional technologies, three additional CVHAS operational concepts were considered for the short-term alignment.

Based on our impact and cost-benefit analyses, we find that

- Compared with the baseline, all of the four alternatives should be economically feasible, and the B/C ratios are in the range between 2.61 and 5.32.
- Because of limited levels of market penetration of CVHAS equipped trucks in Alternative 3 and 4, the truck-only facility was not fully utilized and thus these two alternatives are slightly inferior to Alternative 2. It implies that, compared with the conventional truck-only lane (Alternative 2), the incremental costs of these alternatives outweigh the incremental benefits, causing an incremental B/C ratio that is less than one.
- Alternative 5 was evaluated as the best because it deployed CVHAS technologies later, when their costs were lower and the traffic volumes larger. The incremental CVHAS B/C ratio is 7.57 relative to the truck-only lane without CVHAS technologies.
- Sensitivity analyses show Alternative 5 is robustly feasible, compared to both the do-nothing alternative and the conventional truck-only facility alternative.
- Our study showed that CVHAS technologies are able to help improve the performance of the intermodal freight system. However, the times and ways of deploying CVHAS technologies play important roles for their efficiency and success.

4.8.2 Recommendations and Next Steps

We recommended Alternative 5 for further investigation, which is a conventional truck-only facility open to all trucks before 2015 and then converted to an automated truck highway open only to automated trucks.

Further study should be conducted in the following directions:

- Creating a time-staged model of market penetration of CVHAS, considering that the growth of adoption of CVHAS is determined by the benefits gained from the technologies and the costs;
- Performing major investment or environmental impact studies for Alternative 5;
- Investigating the impacts of Rochelle and Joliet on overall regional goods movement and evaluating the long-term alignment and the corresponding operational concepts;
- Examining the concept of automated truck platoons with no drivers in the following vehicles for the long-term alignment case, with fewer nodes at larger separations.
- Testing some other networks. For example, a network with addressing the full range of regional truck accessibility needs from the start, and considering the opportunities for developing truck lanes, both with and without CVHAS technologies, in other parts of the Chicago region, unconstrained by the locations of intermodal terminals and railroad rights of way.

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APPENDIX I
AUTOMATION TECHNOLOGIES AND CONCEPTS

1. Overview of Automation

Automation seeks to improve upon the benefits of BRT by providing several advanced capabilities, which can improve bus operations significantly, including:

- Automatic speed and spacing control
- Automatic steering control
- Precision docking
- Collision warning
- Fully automated vehicle operation

This resulting system will from now be referred to as Automated Bus Rapid Transit (ABRT).

The CVHAS technologies that make ABRT possible are finally reaching the level of maturity where actual implementation is becoming a viable possibility. Additionally, work has been done on how to fully integrate the technologies into previously existing public transportation systems to maximize the performance of the system. The following sections elucidate these concepts as well as how CVHAS technologies work.

2. Components of Automation

The capability of a vehicle to operate safely and reliably without any human control requires the simultaneous and integrated functioning of several different systems [14]. These systems must also have the ability to function independently and in cooperation with a human driver, when traffic conditions preclude the possibility of fully automated operation. Their basic properties and abilities are described below; the enabling technologies will be explained later.

2.1 Adaptive Cruise Control

Adaptive Cruise Control (ACC) is an enhancement of the standard form of cruise control you would find on just about any vehicle sold today. The thing that separates ACC is that it uses forward-looking sensors to track the vehicle ahead and slow down when necessary to keep a safe distance. Automatic control of the throttle increases or decreases the speed, as well as some gentle actuation of breaking. The following distance from the vehicle in front may be adjustable to account for differing weather conditions and driver preference.

2.2 Frontal Collision Warning

Frontal collision warning uses supplementary logic hardware and sensing elements in addition to ACC in order to determine if the vehicle ahead is closing in at a rate too fast to avoid a collision without some degree of rapid braking. In the future, it may also have the ability to detect other types of foreign objects, such as people or animals, which similarly present dangerous situation. When the system determines that a collision could be imminent, the driver is warned through some auditory and perhaps visual means. There could also be different levels of warning, each designed to elicit a different level of response from the driver.

Although this system could offer some additional reaction time and increase overall driving safety, there are some practical issues to be considered. First of all, if the system is overly sensitive and is constantly warning the driver of an impending collision, the driver will grow tired of the system and turn it off. On the other hand, if the driver is expecting a warning for that extra reaction time and none is given, a collision could easily result. Second, the driver must be fully aware of the system and accustomed to how it works in order to react to a warning. The bottom line is that a frontal collision warning does not alleviate the need for the driver to have full awareness, but can nonetheless increase safety and help avoid accidents.

Transit buses operating in an urban environment such as the Chicago central area are confronted with more complicated driving conditions than vehicles operating on interstate highways, the application for which commercially-available collision warning systems have been developed. The commercially-available systems cannot contend effectively with the diversity of hazards, over a wide forward field of view, which must be addressed in the urban transit application. Frequent turns around corners put street furniture into the sensor field of view and generate false alarms, which are distracting and annoying to drivers. In order to address these problems, PATH is developing and field testing a transit bus forward collision warning system under the U.S. DOT – sponsored Intelligent Vehicle Initiative (IVI) program. This system is being combined with a side collision warning system under development by Carnegie-Mellon University, and the combined warning systems will be tested by drivers in San Mateo County, California and in Pittsburgh during 2004.

2.3 Frontal Collision Avoidance

Frontal collision avoidance takes frontal collision warning a major step forward by automatically (and perhaps strongly) applying the brakes to avoid what the system has determined to be an imminent collision. It could work in cooperation with the collision warning system to first alert the driver if a potential collision has been detected, and then only apply the brakes strongly when the situation becomes critical.

This system faces even more serious safety issues than the frontal collision warning system. If the system even occasionally detects critical situations when there is none and applies rapid braking, then the driver will quickly become frustrated with the system and turn it off. Even worse, this could potentially even lead to a collision when there would not have been one otherwise. For example, suppose a vehicle from the adjacent lane abruptly “cuts-off” a vehicle with a collision avoidance system, resulting in unnecessary hard braking and a rear-end collision with the vehicle behind. Not only could this put people at risk, but also could be a liability for the product manufacturer and bus operator. Such potentially dangerous situations necessitate that the system be thoroughly tested before being used on the road.

2.4 Side-Looking Collision Warning

Side-looking collision warning is very similar to frontal collision warning except that the sensors are located on the side of the vehicle and the collision warning logic is slightly different. The system works in two ways. First, when the driver puts on the turning signal, it warns if there are any vehicles in the corresponding lane. Second, if a vehicle from one of the adjacent lanes is coming too close, the system can give a warning to the driver. This could happen if either driver is veering far off from the center of the lane by accident, or perhaps changing lanes without checking to make sure that the lane is free.

Although this system could suffer from the same sensitivity issue as the frontal collision warning system, it's likely to be less severe due to the closer proximity of the vehicles. A greater concern is that the driver will become too dependent on the system and refrain from manually checking for the presence of other vehicles before lane changing. Not only could this be dangerous even when the vehicle is equipped with a side-looking collision warning system, but could also encourage a bad habit when driving in vehicles not equipped with the system. However, it is generally agreed that the overall benefits should outweigh these concerns.

2.5 Side-Looking Collision Avoidance

Side-looking collision avoidance expands upon side-looking collision warning by giving the system the ability to automatically react and avoid a collision when deemed necessary. In this case, however, steering control would be the necessary course of action instead of braking. For example, if the driver is trying to change lanes without seeing that another vehicle is in the way and does not respond to warnings, a "stiffening" of the steering wheel could result to prevent a collision. Just as with frontal collision avoidance, the system would have to be coupled with a warning system so that action is only taken if the driver first fails to react to a warning.

The main danger of this system would be a situation where the artificial "stiffening" of the wheel described above prevents the driver from reacting properly to an emergency situation. Therefore, the driver must be able to quickly and easily override this system whenever necessary.

2.6 Lane Keeping

Lane keeping is the ability for the vehicle to sense the center of the lane and automatically control the steering to continuously keep the vehicle precisely aligned. For the system to be sufficiently reliable and accurate, there must be some type of compatible infrastructure in the roadway, such as painted lane marker stripes, embedded magnets, magnetic tape, or radar reflectors. The system can either be used merely as a lane-departure warning service, or potentially could offer automatic steering control.

For the case of lane-departure warning, the system would be a safety benefit both to those who use it and those who don't, since all vehicles on the road are in danger when another vehicle accidentally exits its lane. It would be an especially great benefit to drivers who travel for extended periods of time, such as bus drivers. For the case of fully automatic steering control, although it's more powerful, it's also more likely to encourage the driver to become inattentive, and therefore must be used with caution. With regards to transit bus operation, however, automatic steering control can provide numerous benefits, as it would allow buses to operate in a similar manner to light rail, including the use of precision docking.

2.7 Combined ACC, Collision Avoidance, and Lane Keeping in a Busway

As long as there is virtually no risk of interactions with regular traffic or pedestrians, as is the case within a dedicated busway, ACC and lane keeping can safely be combined to provide fully automated vehicle control. Collision warning/avoidance could still be utilized as a backup safety system, but ideally there should be no need for it to be used. Of course, bus stops would necessitate that the speed of the bus not be constant and some type of *speed control* be used. The lane keeping system could provide an easy way to do this, depending on the exact nature of the technology used (discussed later). The ACC system would only need to be used if the buses were off schedule for some reason, and two of them managed to come within close proximity of one another. In this instance, the ACC system would assure the there is sufficient inter-vehicle spacing.

3. Levels of Automation

Before learning of the different CVHAS technologies that can be used in ABRT, it is helpful to distinguish between the different types of roadway being traversed. There are considered to be three different types of roadway, each which allows the bus to operate in different degrees of automation:

1. Mixed traffic flow
2. Bus lanes
3. Busways

Although it may eventually be possible to have fully automated operations in all conditions, including mixed traffic, the technology currently is insufficient for such a task. Therefore, different road conditions require the technology to be utilized in different ways, as explained in the following sections.

3.1 CVHAS in Mixed Traffic Flow

In mixed traffic flow, buses operate in city streets along with general traffic, including pedestrians, bicyclists, and emergency vehicles. The chaotic and unpredictable nature of such conditions completely precludes using automated vehicle control. However, CVHAS technologies can still be used for the tasks of precision docking, traffic signal priority, and collision warning. Indeed, this is where the collision warning systems could potentially provide the biggest safety benefit, since lane changing, making sharp turns and inattentive pedestrians are constant hazards here.

3.2 CVHAS in Bus Lanes

As explained in Section 2.3, bus lanes are lanes, which are separated from general traffic by either a physical barrier or lane makings as a means to reduce interactions with other vehicles and pedestrians, thereby diminishing both the frequency and significance of delays. In cases where the bus lane is grade-separated from the mixed-traffic and sidewalk, automatic steering control may be utilized. Special circumstances and emergency situations can simply be handled by the bus driver resuming control of the steering wheel and taking whatever actions are necessary.

3.3 CVHAS in Busways

As explained in Section 2.2, busways are special roadways, which are reserved for exclusive use by buses, resulting in absolutely no interaction with regular traffic and unprecedented safety. Since the risk of running into unauthorized vehicles and pedestrians is nearly zero, CVHAS technologies can be used to their full extent to provide fully automated vehicle operation. Although there is still a need for a bus driver to handle emergency situations, enforce payment of fares, and resume control once the busway has ended, the bulk of driving operations inside the busway can be completely automated.

3.4 CVHAS Technologies

An effective automated bus design integrates several different technologies to achieve a system that is safe and reliable at all times, as well as being practical and cost-effective. Some of these technologies are needed solely for the task of automation, while others can also be found in traditional BRT systems. Specifically, lateral and longitudinal control is normally handled entirely by the bus driver. Automation makes it possible for these tasks to be handled through the use of various types of sensing technology in conjunction with an on-board computer. Those technologies are discussed in the preceding sections.

4.1 Lateral Control

Lateral control is a fundamental and essential consideration upon which any automated bus relies. This is what allows the bus to precisely follow along the center of the lane with much more accuracy than any human could achieve. However, the technology must not only be accurate, but also reliable, affordable, and safe. There are currently three prospective technologies, which fit these requirements and thus merit consideration. These technologies include:

1. Discrete Magnetic Guidance System
2. Magnetic Stripe Lateral Guidance System
3. Optical guidance

All of these technologies are similar in that they are designed to simply have the bus follow a lane-marker system implanted in the road along a lane. However, they differ greatly in terms of exactly what that system is composed of, as well as having different strengths and weaknesses.

4.1.1 PATH's Magnetic Guidance System

The Magnetic Guidance System (MGS) was designed by PATH (Partners for Advanced Transit and Highways) researchers specifically for the tasks of guidance and control (Figure I.1). The system is composed of two basic parts: a series of magnets embedded in the road, and a pair of vehicle-borne sensing and processing units, installed in the front and rear of the bus. The simple, permanent magnets are implanted in the center lane of the road, generally spaced apart by a distance of about 1 meter. As the bus travels over the markers, they are consecutively read in a manner, which ensures that the bus will stay aligned with the center of the lane. Over the past 10 years, studies have proven that the system can offer consistent and accurate performance:

- Lateral position accuracy of 0.5 cm
- Longitudinal position accuracy of 5 cm
- Reliable under realistic environmental conditions
- Fail-safe

Failure to detect a magnet, or even several magnets, should not seriously affect the performance of the system. By alternating the polarity of the magnets (north-up vs. south-up), a binary code is created which indicates upcoming roadway characteristics. The system also can be used as a reliable and precise AVL system, through simple "counting" of the magnets.

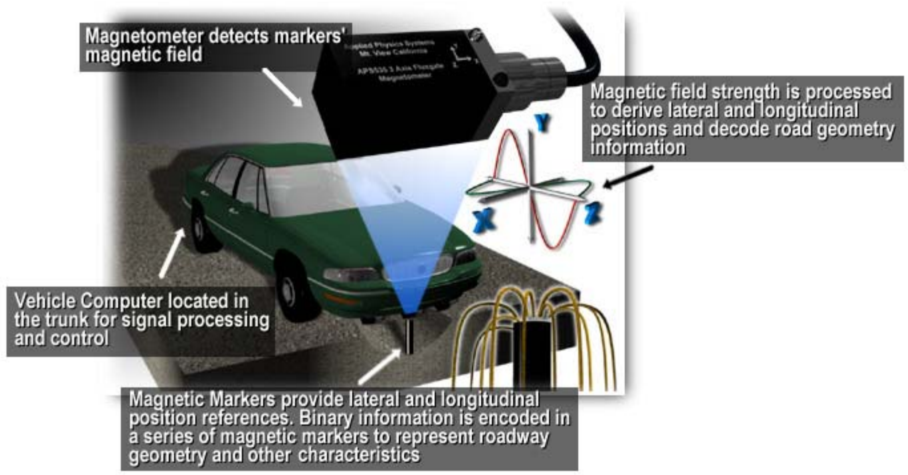


FIGURE I.1 PATH's Magnetic Guidance System

The magnetic markers are made out of ferrite, a ceramic material, with a 2.4 cm diameter, 10 cm length, and a price as low as 90¢ each. However, certain locations where rebar is close to the surface may require the use of special Neodymium magnets. These magnets are 2.5 cm in diameter, 2.5 cm in length, and cost less than $10 each. The final cost to install the magnets per mile in a single lane is estimated to be below $10,000, and can be reduced further once the installation process is automated (Figure I.2).

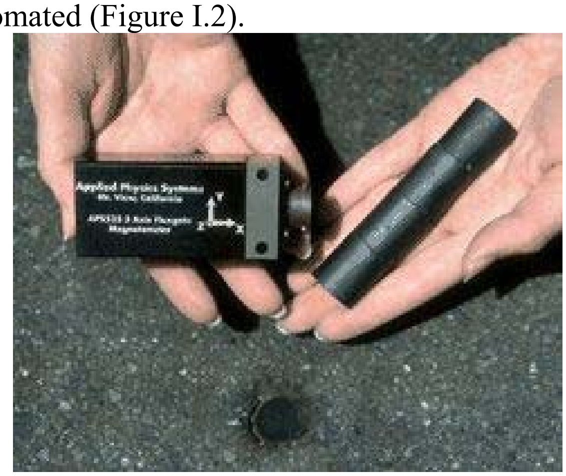


FIGURE I.2 3 Axis Fluxgate Magnetometer & Ceramic Magnet

The magnetic marker guidance system has been under development since 1989, and has been successfully used for automatic steering control at a variety of international demonstrations:

- Automatic steering of passenger cars at highway speeds and low-speed maneuvering at National Automated Highway Systems Consortium Demo '97 in San Diego, CA, August 1997;
- Automatic steering of passenger cars at highway speeds and low-speed precision maneuvering at Demo 98 in Rijnwoude, Netherlands, June 1998;
- Automatic steering of a truck for the Combi-Road project demonstration in Ridderkerk, Netherlands, June 1998;

- Precision docking of a passenger car at Demo 99 in East Liberty, Ohio, July 1999 (Figure I.3);
- Steering guidance, lane departure warning and lane departure avoidance under diverse weather conditions at Demo 2000 in Tsukuba, Japan, November 2000.

More recently, it has been used for precision docking of a transit bus at demonstrations in Washington DC and San Diego in June and August, 2003. These demonstrations showed the ability to reliably approach the bus stop and to dock at the stop with a gap of only 1 cm between the edge of the bus and the loading platform, which is closer than most rail transit systems can achieve, making it easy for a wheelchair to roll on and off the bus.

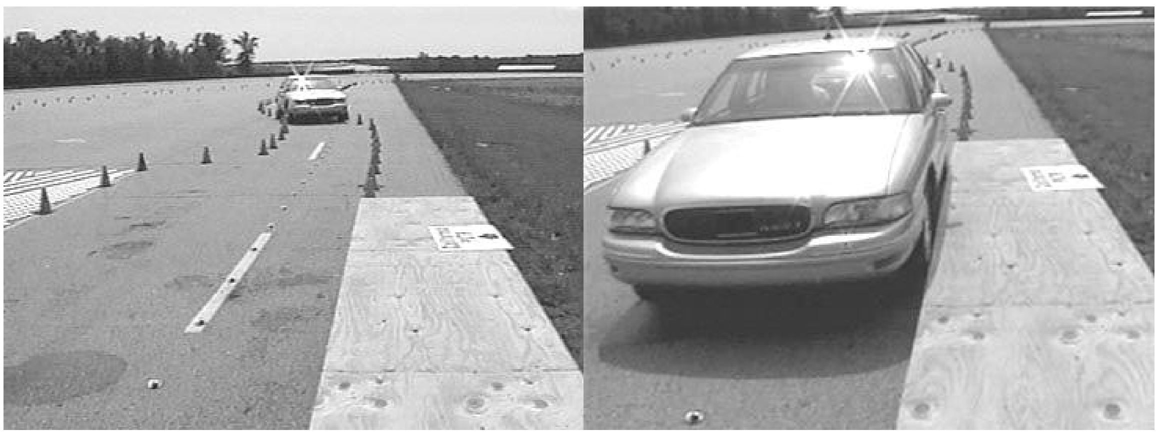


FIGURE I.3 Demonstration of PATH's Magnetic Guidance System at Demo '99

4.1.2 3M's Lateral Guidance System

3M has developed a similar type of technology to that of PATH, called the Lateral Guidance System. The main difference is that 3M uses a continuous magnetic tape, as opposed to discrete magnetic markers, which the sensing electronics is designed to read and stay aligned with through communication with the steering actuator (Figure I.4 and I.5). The system is composed of three parts: the magnetic marking tape, sensing electronics, and the operator interface. Like PATH's magnetic markers, this system also promises to provide the absolute positional information of the bus. The sensors and interface cost about $5,000 to $10,000 and the cost of the tape is $3 to $5 per foot, but is no longer commercially available.

FIGURE I.4 3M's Lateral Guidance System

This system has also been demonstrated, proving that the technology works and offering some competition for PATH's MGS.

FIGURE I.5: Demonstration of 3M's Lateral Guidance System at Demo '99

4.1.3 Optical Guidance

The third prospective lateral guidance technology involves an optical guidance system, developed by IRISBUS and MATRA transport international. With this system, a camera mounted behind the windscreen reads lines painted on the road, which indicate the route to follow. The image is processed to detect any course deviation, which is immediately corrected by a motor on the steering column. The image processing software linked to the dashboard camera continuously compares the bus' trajectory with the stripes painted on the roadway, looking about 100 feet ahead. Before the motor on the steering column makes each adjustment to keep the bus on course, the software checks with sensors on the steering column and on the front axle that measure the angle of the bus' wheels to ensure that the adjustment will work as intended. This system allows the vehicle to follow the programmed route within a tolerance of a few centimeters and can function even if only one-third of the stripes are visible (Figure I.6) [18], [19].

The main drawback of this system is that snowy weather conditions could limit the effectiveness of the system in the winter months. However, optical guidance could serve as an additional, redundant system to be used in conjunction with one of the magnetic guidance systems.

FIGURE I.6 An optically guided CIVIS bus

4.1.4 Precision Docking

If buses can be stopped within one or two centimeters from the curb or loading platform, it becomes possible to load and unload passengers similarly to a rail transit vehicle, both reducing dwell times and improving accessibility for handicapped passengers and those using mobility aids (Figure I.7). It is nearly impossible to expect bus drivers to achieve such accuracy reliably and continuously. Not only would it be unreliable and stressful for the bus driver, but could also lead to passenger discomfort and maintenance issues when the bus wheels scuff the curb. The solution is to use one of the lateral control technologies previously described. With several years of experiments having been performed by researchers at PATH, the accuracy of precision docking is very well established.

FIGURE I.7 Precision docking

4.2 Cooperative Adaptive Cruise Control

Adaptive cruise control (ACC) has been developed as a driving comfort and convenience feature for passenger cars and trucks, and is now commercially available on a variety of vehicles (but with limited numbers sold to date). Its performance is limited by the limited ability of the forward ranging sensors (radar or laser) to reliably track preceding vehicles, and it is therefore unlikely to produce any significant improvements in traffic flow volume, stability or safety. However, if the ACC sensor is augmented with a wireless communication link between vehicles the performance could be enhanced significantly. This is the concept of Cooperative Adaptive Cruise Control (CACC).

CACC makes it possible for each vehicle to communicate its precise location, speed, acceleration and operating condition to the vehicle(s) behind it so that they can respond more quickly and accurately to its maneuvers. This improved information about the behavior of the leading vehicle should make it possible for the following vehicle to drive closer to the leader and provide a smoother ride to the passengers, while also improving its ability to respond safely to any anomalies in the behavior of the leader. With the CACC improvements, it becomes possible to shorten the inter-vehicle separations by enough that the traffic flow volume per lane can be increased significantly. However, this is only practical if most of the vehicles in the lane are equipped with the CACC communication capability, which means that it is most suitable for use in dedicated bus lanes, rather than on buses that operate mixed with other vehicles.

For the future dedicated bus lane applications of the Monroe East-West underground busway or the underground busway level of the future Clinton/Canal pair, CACC could make it possible to provide a passenger-carrying capacity comparable to heavy rail transit, while retaining the low vehicle cost and operating flexibility of buses. PATH has tested vehicles operating in close-formation automated platoons using wireless communications to coordinate vehicle maneuvers. Passenger cars have been operated at a speed of 60 mph with separations as close as 4 m (13 ft.), while a pair of tractor-trailer trucks was recently tested at a separation of 3 m (10 ft.) at a speed of 50 mph. PATH's test buses have been operated as close as 15 m (50 ft.) to each other at about 50 mph (Figure I.8). Using this more conservative separation and speed, and assuming a three-bus platoon (two 40-foot buses with 37 seats and one 60-foot articulated bus with 50 seats), plus a safety separation of 60 m (200 ft.) between platoons, one lane of busway could accommodate up to 70,000 seats per hour. This exceeds the seating capacity currently provided on any CTA line, and makes the automated BRT service fully competitive with rail for the highest-capacity applications.

FIGURE I.8 A 3-Bus Platoon, San Diego, California, August 2003

5. Safety Issues

The CVHAS technologies are intended to enhance the safety of vehicle operations, but it is difficult to quantify their precise safety effects because safety problems are rare events and it requires extensive data collection over a long period of time and large number of vehicles in order to produce reliable estimates of safety improvements. The large majority of road vehicle crashes that occur today (in the range of 90%) are caused by driver errors, so technologies that can reduce or eliminate these errors should enhance safety unless they produce new kinds of driver errors or faults of their own.

The assessment of safety issues is closely related to the extent to which the CVHAS equipped buses are mixed with non-equipped vehicles, pedestrians and other hazards. The state of the art of CVHAS technologies does not permit automation of vehicle driving in mixed traffic environments, but only in dedicated lanes that are protected from intrusions by other vehicles or pedestrians (analogous to rail transit rights of way). This should be expected to remain the case for the foreseeable future as well, for a variety of technical reasons.

5.1 Safety Issues in Mixed Traffic

The primary opportunity for CVHAS technologies to improve safety in mixed traffic is by providing the bus driver with warnings of potentially unsafe conditions so that the driver can respond effectively. This would especially involve forward and side collision warnings, so that the driver can be alerted to a hazard before he or she might otherwise notice it, especially if distracted from normal driving alertness by passengers or other disturbances.

Precision docking offers a possibility of an additional safety improvement. If the automatic steering control system that does the docking relieves the driver of the workload associated with trying to accurately position the bus adjacent to the curb or loading platform, it gives the driver an opportunity to focus attention ahead of the bus, to watch out for pedestrians who might stray in front of the bus and be better able to stop without hitting them.

5.2 Safety Issues in Busways

In a dedicated busway, it becomes possible to provide partial (steering) or complete (steering, speed and spacing) automatic control of the driving of the bus. The segregation of the busway from other traffic already provides protection against intrusions by other vehicles, debris and pedestrians. The CVHAS automation systems also provide for more accurate steering, speed and spacing control than drivers can typically accomplish, and these systems are not vulnerable to fatigue or distraction the way drivers may be. However, the technology cannot be made absolutely perfect, so it also needs its own fault detection systems to identify problems and stop the bus or alert the driver when it may be necessary to resume manual control. The safety of the automated driving will have to be proven by extensive testing, and will depend on the specifics of the system hardware and software design and implementation, so it cannot be predicted *a priori*.

APPENDIX II

PRESENT CONDITION OF CARROLL AVENUE RIGHT-OF-WAY


321 N. CLARK ST.


WABASH AV

APPENDIX III

DESCRIPTION AND ASSESSMENT OF FIELD DATA COLLECTION FOR EAST-WEST AT-GRADE SHORT-TERM ALTERNATIVE

For the field data collection, a stopwatch was used to note the times throughout the trials. The stopwatch was run continuously throughout each trial, and the time was noted at three separate times during each bus stop. For bus stop *i*, we have:

1. The bus opens it doors – $t_{open,i}$
2. The bus closes its doors – $t_{close,i}$
3. The bus starts moving – $t_{move,i}$

Using this method, travel time, boarding time, and idle time can be computed for each stop as follows. For bus stop *i*, we have:

1. Travel time to the stop = $t_{open,i} - t_{move,i-1}$
2. Boarding time at the stop = $t_{close,i} - t_{open,i}$
3. Idle time at the stop – $t_{move,i} - t_{close,i}$

Also at each stop, any observations of factors affecting the quality of the service were noted. These observations included:

- Buses waiting for the preceding bus in the stop ahead to leave
- Red lights forcing the bus to remain at the stop
- Illegally parked vehicles affecting bus service
- Other (nature of disturbance was recorded)

Data was generally taken during morning and evening peak hours of operation – 7:00 to 9:00 AM and 4:00 to 6:00 PM. The stopwatch was started when the bus started moving at the first stop, denoted Stop 0.

In order to help interpret the data, several useful quantities were computed for each line, based on an averaging of the trial runs. Those quantities include:

1) Productivity – a measure of the ratio of the ridership on the route to the number of buses serving the route times the number of hours they operate.

$$\text{productivity} = \frac{\text{ridership}}{\text{number of buses} * \text{hours of operation}}$$

2) Average overall speed – the distance traveled on the route divided by the total time elapsed during the route (boarding and idle time included).
3) Average traveling speed – the distance traveled on the route divided by the sum of the travel times for each stop (boarding and idle time not included).
4) Average idle time – the average amount of time the bus was idle per stop.
5) Passenger flow rate – the sum of passengers boarding and alighting the bus divided by the boarding time. The units are seconds per passenger.
6) Passengers on/off – the average number of passengers the boarded and alighted the bus per stop.
7) Observational statistics – a breakdown of how frequently each of the different types of disturbances occurred during the route.

The results are presented in the following sections.

The table below summarizes the results of the data collection.

Results of data collection

	Number of trials	Productivity $\left[\frac{passengers}{hour * bus}\right]$	Average overall speed [*MPH*]	Average traveling speed [*MPH*]	Average idle time [*seconds*]	Passenger flow rate *[passengers/second]*	Passengers on $\left[\frac{passengers}{stop}\right]$	Passengers off $\left[\frac{passengers}{stop}\right]$
Line 157	10	161	5.19	10.80	17.6	4.79	4.21	2.34
Line 20	5	125	5.14	10.67	18.5	3.77	3.38	4.49
Line 126	7	160	5.27	11.48	17.4	4.01	4.38	3.30
Line 1	5	202	4.15	12.29	24.1	4.01	7.80	3.89
Total		162	4.94	11.31	19.4	4.15	4.94	3.51

The results of the data collection reflect the extent of the demand of these bus routes during peak hours, as the productivity for each is particularly high. To get a feeling for just how high these numbers are, they can be compared to the overall weekday average for each line (for the entire routes – not just Madison-Washington and Adams-Jackson). These numbers can be found in the *Bus Ridership by Route* (August, 2003) report, prepared by the CTA.

Productivity

	CTA data	Collected data
Line 157	37	161
Line 20	60	125
Line 126	38	160
Line 1	46	202

There are three reasons why the CTA numbers are so much lower than the collected data:

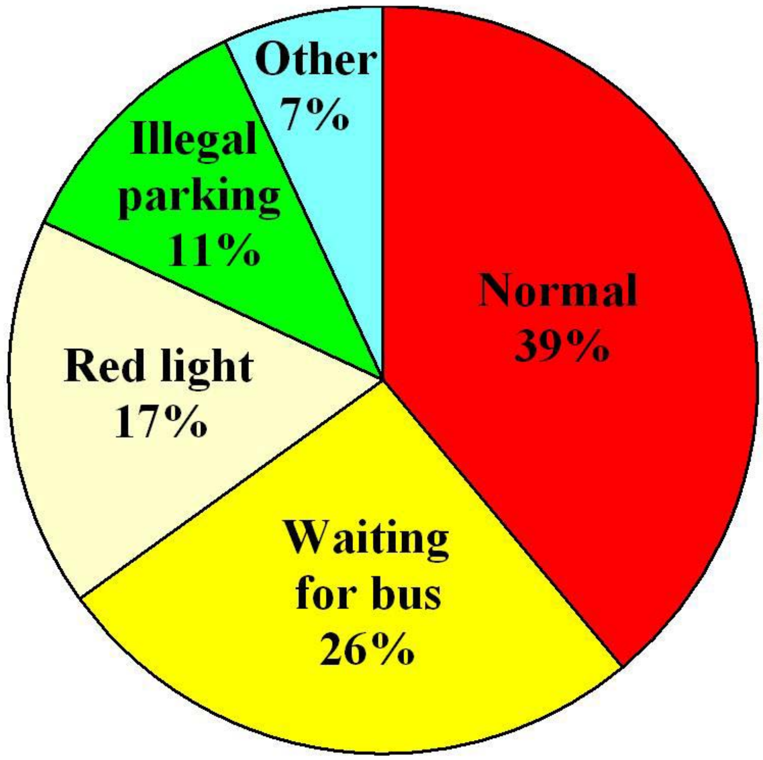
1. The data was collected during peak hours, when the demand for public transit is by far the highest, while the CTA data was collected throughout all hours of operation.
2. The data was collected in the heart of the Chicago Loop, while the CTA data was collected over the entire bus routes.
3. The region of each line where data was collected contains very frequent bus stops, occurring at approximately every two blocks. This certainly inflates the results, as productivity is traditionally computed over the *entire* route, where stops are much more infrequent.

While the three reasons above explain the high numbers that were obtained for productivity, they also elucidate the reasons why these sections are being studied. The high demand which these lines experience in the Loop can give us a taste of what to expect with the new routes being proposed.

Looking at the average overall speed and average traveling speed, we can see that the former is less than half of the latter. The obvious conclusion is that the buses actually spend more time at the stops than traveling on the road. This underscores how much time is spent at the bus stops in these busy areas, and indicates that there may be a lot of room for improvement. As should now be expected, the average idle time is also very high at 19.4 seconds.

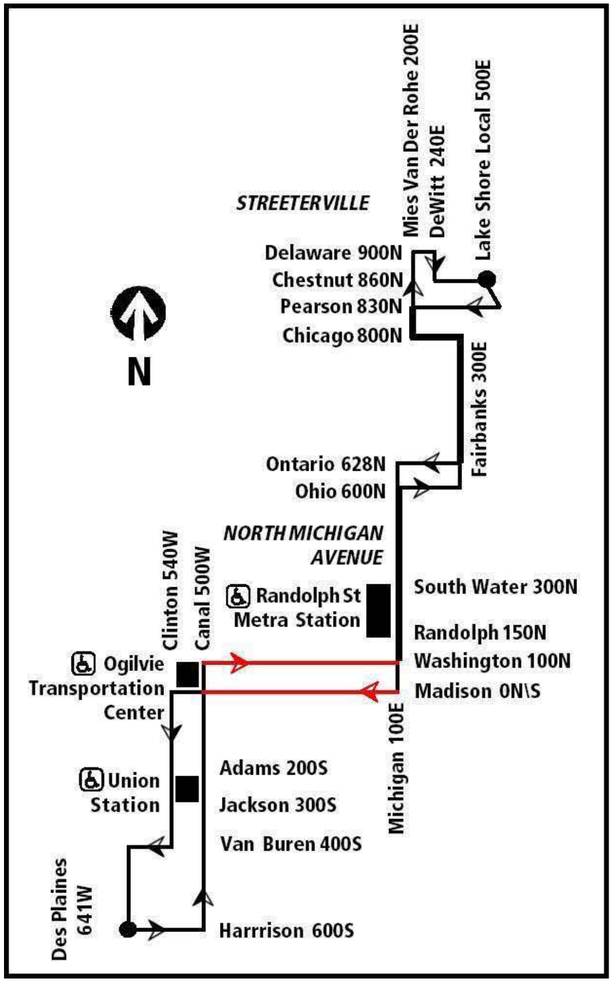
The passenger flow rate turned out to be 4.15 seconds per passenger – about what would be expected for a typical bus service. The average number of passengers boarding and alighting per stop turned out to be 4.94 and 3.91, respectively. These figures will help us to gauge the benefits that can be obtained through the implementation of CVHAS.

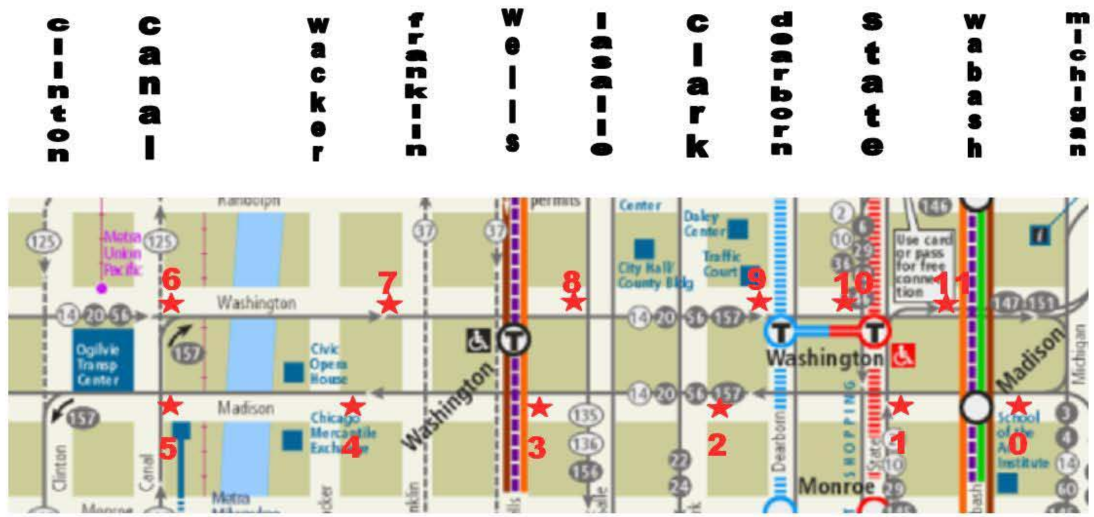
The final type of data taken was observational statistics, and the results are summarized in the pie chart below.



The results reveal the extent to which these various types of disturbances can affect the bus service, with 61% of the stops encountering an interruption of one type or another. The most common problem was the bus having to wait for another bus in the stop ahead to leave, generally increasing travel times. While this problem is almost impossible to avoid, it could be certainly minimized by improving schedule adherence and decreasing boarding/idle times. The second most significant type of disturbance was a red light preventing the bus from leaving the stop and increasing idle time. The only way to address this is by improving signal timing or traffic signal priority. Illegal parking also was an issue, but could be completely eliminated with the East-West Bus Lanes. While there were other types of service interruption, they represent only a small portion of the problem at only 7%. They included pedestrians getting in the way of the stop, the bus stopping a significant distance away from the stop, and people asking the bus driver questions.

Route 157 Map





A bus traveling southbound starts at stop 0 in the Loop Area, proceeds through stops 1 though 5 and leaves the Loop Area toward South on Clinton Street. A bus traveling north reaches the loop area at stop 6, then proceeds through stops 7 though 11 and leaves the Loop Area toward North on Michigan.

Sample of the original raw data collected from field:

Stop	t_{open}		t_{close}		t_{move}		Passengers on	Passengers off	Observations
1	1	7	1	56	2	29	7	3	Bus Waiting
2	3	31	3	44	4	0	3	0	Bus Waiting
3	5	19	6	18	6	41	6	1	Normal
4	7	2	7	50	8	5	6	4	Normal
5	8	38	8	58	9	4	2	5	Red light
6	----------	----------	----------	----------	---------	----------	----------	----------	----------
7	0	21	1	06	1	30	6	0	Normal
8	2	15	2	51	3	02	4	3	Bus Waiting
9	3	43	3	59	4	27	3	2	Red light
10	4	55	5	29	5	40	6	4	Illegal parking
11	6	04					8	2	Other

Trial 1, Madison-Washington Line 157

For the West bound direction (stops 1 through 5) data set it is clear that the clock was started at stop 0. No other data was taken at this stop. For the East bound direction, the clock was started at stop 6, but no other data was collected at this stop.

Analysis of the above data (Trial 1, Madison-Washington Line 157):

Madison	West bound		test 1			Time to next stop	passengers		Observations		Excl	Incl.
stop	T open	dwell time	T close	idle	T move		on	off		bus waiting	49	49
1	67	49	116	33	149	62	7	3	Bus Waiting	normal	38	38
2	211	13	224	16	240	79	3	0	Bus Waiting	red light	0	6
3	319	59	378	23	401	21	6	1	Normal	illegally parked	0	0
4	422	48	470	15	485	33	6	4	Normal	other:	0	0
5	**518**	20	538	6	544		2	5	Red light			
	262	Total dwell: 169		Total idle 87	262							
		Total dwell: 189		Total idle 93							**Excl**	
6	**Washington**	**East bound**				21				bus waiting	11	
7	21	45	66	24	90	45	6	0	Normal	normal	24	
8	135	36	171	11	182	41	4	3	Bus Waiting	red light	28	
9	223	16	239	28	267	28	3	2	Red light	illegally parked	11	
10	295	34	329	11	340	24	6	4	Illegal parking	Other	0	
11	**364**	-364	0	0	0		8	2	Other			
	159	Total dwell: 131		Total idle 74								

Explanation by columns:

1. Stop id number
2. Time bus opened the door [sec] – data
3. Dwell time at stop [sec] – calculated: (Time bus closed the door) – (Time bus opened the door)
4. Time bus closed the door [sec] – data
5. Idle time [sec] – calculated: (Time bus moved on) – (Time bus closed the door)
6. Time bus moved on from stop [sec] – data
7. Time to next stop [sec] – calculated: (Time bus moved on from stop "i" to "i+1")
8. Number of passengers boarding and alighting – data
9. Observation of interference with bus (reason for idle time) – data
    a. "Bus waiting" – bus bunching, bus's path is blocked by another bus.
    b. "red light" – since most of these stops are near side on occasions that bus needs to wait for green light after it finished loading
    c. "illegal parking" – a vehicle blocked the buses path.
    d. "other" - pedestrians getting in the way of the stop, the bus stopping a significant distance away from the stop, and people asking the bus driver questions

Yellow indicates additional data collected on westbound that are not matched by eastbound data collection

Additional section: columns

10. reason for idle time – data
11. idle time totaled by reason per direction for route [sec] if extra data excluded – calculated
12. idle time totaled by reason per direction for route [sec] if extra data included – calculated

Blue color indicates where data is missing.
Grey color indicates set of data that includes additional (yellow) data.

Explanation by cells:

- Data in second column in thick-bordered cell – travel time [sec] from first time observation to last time observation for each direction. These are excluding the additional data collected for stop 5.
- Data in sixth column in thick-bordered cell – travel time [sec] from first time observation to last time observation, only for west bound direction. Includes additional data collected for stop 5. Could not be calculated for eastbound direction due to missing data for stop 11 (blue cells).
- Total dwell and idle time are in cells as indicated. Grey indicates that additional data was included.
- Numbers in dashed lined cells are total time spent moving from first time observation to last time observation. Grey (for west bound) indicates that additional data was included. Note that the shaded (inclusive) total time spent moving has to be the same as the exclusive total time spent moving (here 262 sec.).

Having analyzed all 10 tests for route 157 as presented above our results for the route:

Route 157

route: Madison, West Bound	exclusive sec	exclusive min	exclusive %	inclusive sec	inclusive min	inclusive %
average travel time between stop 1 and 5	432.6	7:12	100.0	480.8	8:01	100.0
average moving time per route, inclusive	216.2	3:36	50.0	216.2	3:40	45.0
average idle time per route, average over runs	77.9	1:18	18.0	96.8	1:37	20.1
total dwell time per route, average over runs	138.5	2:19	32.0	167.8	2:48	34.9
			100.0			100.0

route: Washington, East Bound	sec	min	%	
average travel time between stop 7 and 11	454.7	7:35	100	there is no inclusive
average moving time per route, inclusive	233.0	3:53	51.24	because there is no data
average idle time per route, average over runs	76.1	1:16	16.74	
total dwell time per route, average over runs	145.6	2:26	32.02	
			100.00	

Route 157 and such limited data set cannot be statistically significant. Never the less this is all the data we have. It seems that on both Madison (between Wabash and Canal), and on Washington (between Canal and Wabash) buses spend 45-50% of their time moving, about 20% of their time idling and about 30% at stops. These numbers were 1/3-1/3-1/3 for the Wilshire-Wittier corridor in Los Angeles before applying signal priority. It seems that this route does not have a great need for signal priority.

Individual stops: Time is In sec

stop	average dwell time	average idle time	average pass on	average pass off	Average pass movement
1	32.0	22.1	4.4	2.1	6.5
2	37.6	18.2	5.1	2.6	7.7
3	32.4	20.9	2.7	2.1	4.8
4	36.5	16.7	3.2	2.5	5.7
5	29.3	18.9	3.5	2.0	5.5
stop					
7	35.3	20.0	5.1	1.7	6.8
8	37.1	13.9	4.6	3.2	7.8
9	38.0	21.0	4.8	2.7	7.5
10	35.2	21.2	3.8	2.3	6.1
11	No data	No data	4.9	2.2	7.1

reason for idle per stop Route 157

stop	**1**	**2**	**3**	**4**	**5**
bus waiting	1	7	6	2	0
normal	6	2	3	7	3
red light	2	0	0	1	4
illegal parking	1	0	0	0	2
other	0	1	1	0	1
sum	10	10	10	10	10
stop	**7**	**8**	**9**	**10**	**11**
bus waiting	4	2	3	1	4
normal	2	3	3	3	2
red light	0	3	2	1	1
illegal parking	2	2	2	1	1
other	2	0	0	4	2
sum	10	10	10	10	10

The main reason for idle time seems to be bus bunching – indicated by numbers in red showing that the most frequent reason for idle at stop is that the bus's path is being blocked by another bus. Red light does not seem to be a significant reason for idle.

there is data on the occasions and delay
and the reasons for it

reason for idle per route per direction

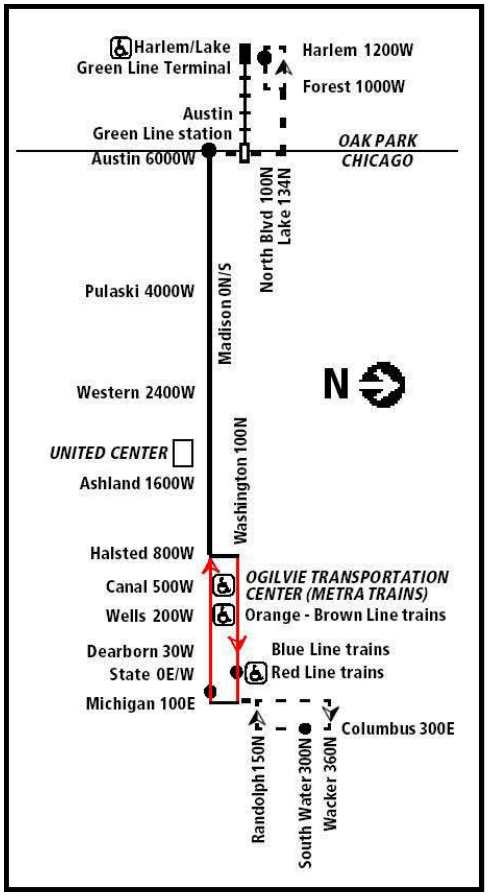
Madison	number	exclusive % of occasions	sec	% of total idle time	number	inclusive % of occasions	sec	% of total idle time
bus waiting	16	40	34.7	44.54	16	32	34.7	35.85
normal	18	45	33.4	42.88	21	42	41.7	43.08
red light	3	7.5	4.3	5.52	7	14	12.0	12.40
illegal parking	1	2.5	3.0	3.85	3	6	5.6	5.79
other	2	5	2.5	3.21	3	6	2.8	2.89
sum	40	100	77.9	100.00	50	100	96.8	100.00
Washington	East bound	%				%		
bus waiting	10	25	17.5	23.00	14	28		
normal	11	27.5	25.2	33.11	13	26		
red light	6	15	8.6	11.30	7	14		
illegal parking	7	17.5	8.8	11.56	8	16		
other	6	15	16.0	21.02	8	16		
sum	40	100	76.1	100.00	50	100		

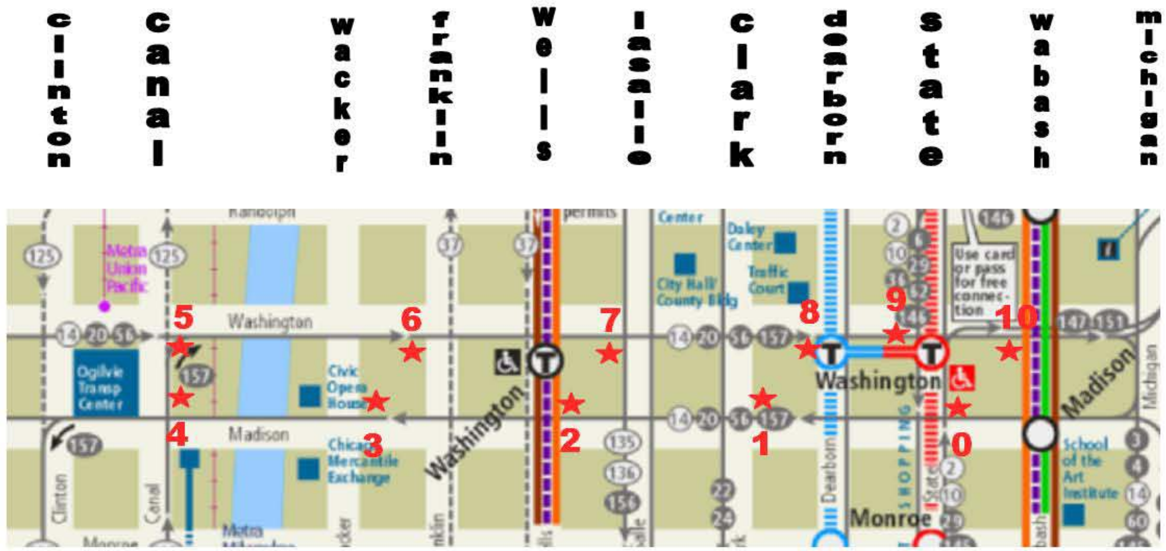
there is do data on

how much time was spent idling
at these occasions for these
reasons

This table reinforces our previous observation that the main reason for idling is bus bunching, not red lights.

Route 20 Map


Harlem/Lake
Green Line Terminal
Harlem 1200W
Forest 1000W
Austin
Green Line station
Austin 6000W
OAK PARK
CHICAGO
North Blvd 100N
Lake 134N
Pulaski 4000W
Madison 0N/S
Western 2400W
N
UNITED CENTER
Ashland 1600W
Washington 100N
Halsted 800W
Canal 500W
OGILVIE TRANSPORTATION CENTER (METRA TRAINS)
Wells 200W
Orange - Brown Line trains
Dearborn 30W
Blue Line trains
State 0E/W
Red Line trains
Michigan 100E
Columbus 300E
Randolph 150N
South Water 300N
Wacker 360N


clinton
canal
wacker
franklin
wells
lasalle
clark
dearborn
state
wabash
michigan
Washington
Madison
Monroe
Ogilvie Transp Center
Civic Opera House
Chicago Mercantile Exchange
City Hall County Bldg
Daley Center
Traffic Court
Use card or pass for free connection
School of the Art Institute
0
1
2
3
4
5
6
7
8
9
10

A bus traveling west bound travels on Madison, switches to Washington through Halsted, reaches the loop area at stop 5 (for route 157 this stop was numbered 6), proceeds through stops 6 though 10. Turns right onto Michigan, travels on block on Michigan and turns right onto Madison. The first stop on Madison the bus reaches is stop 0 (this stop was numbered 1 from route 157). The bus traveling west bound on Madison proceeds through stops 1 through 4 and leaves the Loop Area toward West on Madison.

Sample of the original raw data from the field:

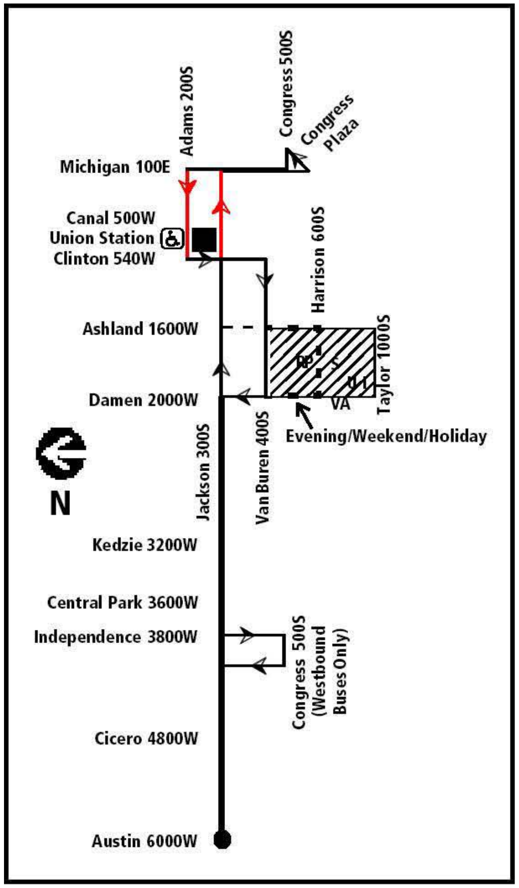
Stop	t_{open}		t_{close}		t_{move}		Passengers on	Passengers off	Observations
1	0	33	1	14	1	29	2	3	Bus Waiting
2	2	21	2	56	3	17	9	1	Bus Waiting
3	4	21	5	18	5	38	8	0	Normal
4	6	12	6	52	7	05	5	0	Normal
5	8	02					2	8	Red light
6	----------	----------	----------	----------	----------	----------	----------	----------	----------
7	1	01	1	19	1	31	1	2	Normal
8	2	20	2	29	2	52	1	1	Bus Waiting
9	3	01	3	25	3	57	0	1	Red light
10	4	15	4	38	4	40	0	17	Illegal parking

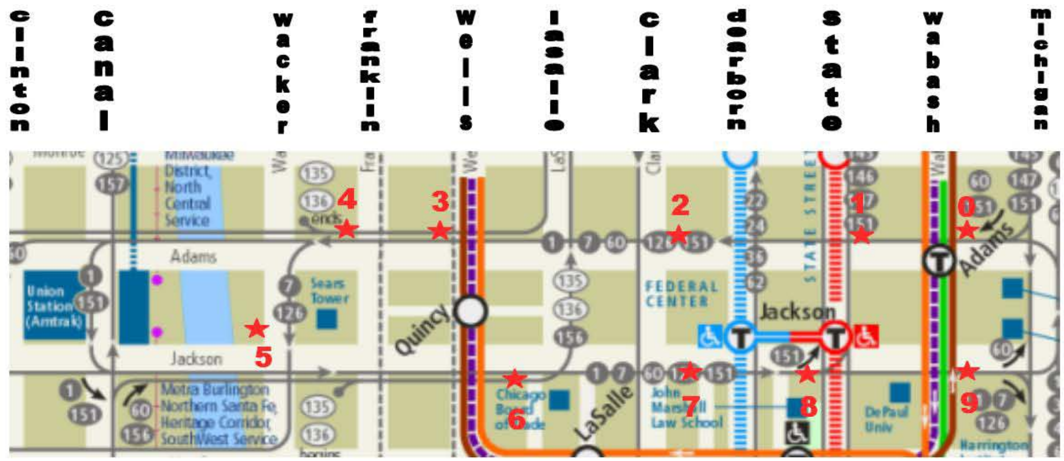
Trial 1, Madison-Washington Line 20

For the West bound direction (stops 1 through 5) data set it is clear that the clock was started at stop 0. No other data was taken at this stop. For the East bound direction, the clock was started at stop 6 – according to the data set, but no other data was taken at this stop. We don't know why not.

There is a problem: the data presented in the table does not fit the route the bus travels. The bus does not go from stop 4 to 5 as the data indicates. Stop 6 is not a starting stop for the bus on this route in the loop area as the data indicates, however, at this time the discrepancy in the data can not be explained. Therefore, this data set could not be used further.

Route 126 Map





A bus leaving Congress Plaza travels on Michigan north bound. It takes a left onto Adams and starts at stop 0. It progresses through stops 1 though 4 on Adams. Here there is a discrepancy: 1.) According to the colorful map it turns left onto Wacker Drive, travels south, crosses Jackson, turns right onto Van Buren to go West. 2.). According to the black and white map it proceeds on Adams, turns left onto Clinton, travels south, crosses Jackson, turns right onto Van Buren to go West. This discrepancy does not matter because they stopped data collection at stop 4, which is still on Adams. A bus coming from the west toward the loop area arrives on Jackson, and proceeds on Jackson all the way to Michigan. This bus first reached stop 6 and proceeds through 7 to 9. It is not clear when the bus stops at stop 5. Not is it clear where the time measurement was started for stop 6. It is possible, and this is what we will assume when analyzing the data, that it was started at stop 5.

Sample of the original raw data from field collection:

Stop	t_{open}		t_{close}		t_{move}		Passengers on	Passengers off	Observations
1	0	24	0	42	0	49	3	8	Bus Waiting
2	1	43	2	5	2	12	4	3	Red light
3	2	28	3	15	3	31	2	8	Illegal parking
4	4	47	5	19	5	34	3	3	Normal
5	----------	----------	----------	----------	----------	----------	----------	----------	----------
6	1	10	1	45	1	53	5	4	Other
7	2	52	3	44	3	45	2	5	Normal
8	4	44	5	12	5	42	1	2	Normal
9	6	30	7	15	7	31	2	6	Normal

Trial 1, Adams-Jackson Line 126

For the West bound direction (stops 1 through 4) data set it is clear that the clock was started at stop 0. No other data was collected at this stop. For the eastbound direction, we assume that the clock was started at stop 5. No other data was taken at this stop. We don't know why not. Data was collected on 7 runs, however, trial six has data missing; therefore we did not use that data set. We used only 6 trials in our analysis.

Analysis of data:

Route 126

route: Adams West Bound	sec	min	%
average travel time between stop 1 and 4	346.8	5:46	100
average moving time per route, inclusive	152.3	2:32	43.92
average idle time per route, average over runs	69.7	1:10	20.09
total dwell time per route, average over runs	124.8	2:05	35.99
			100.00

route: Jackson East-Bound	sec	min	%
average travel time between stop 6 and 9	335.8	5:35	100
average moving time per route, inclusive	110.7	1:51	32.95
average idle time per route, average over runs	65.7	1:06	19.55
total dwell time per route, average over runs	159.5	2:39	47.49
			100.00

Statistics for Individual stops:

time in seconds

stop	average dwell time	average idle time	average pass on	average pass off	average pass movement	average time per passenger
1	26.5	13.5	3.8	4.5	8.3	3.2
2	28.7	21.0	4.2	3.3	7.5	3.8
3	40.8	16.8	5.3	3.2	8.5	4.8
4	28.8	18.3	4.2	2.8	7.0	4.1
5						
6	39.5	15.0	4.8	3.3	8.2	4.8
7	46.2	15.2	5.8	4.5	10.3	4.5
8	32.5	19.2	3.3	2.5	5.8	5.6
9	41.3	16.3	4.0	4.0	8.0	5.2

Route 126 and such small data set cannot be statistically significant representation of the transit conditions on Adams – Jackson arterials. Never the less, this data set seems to indicate that this route does not have significant need for signal priority on Adams. On Jackson the data set indicated very high amount of time (48% of total run time) spent at stops. It would be interesting to collect more data to see whether this really is the case. The average passenger movement is consistently high for this route in this direction. The more passengers use the system, the higher the dwell time is.

reason for idle per stop within 6 runs

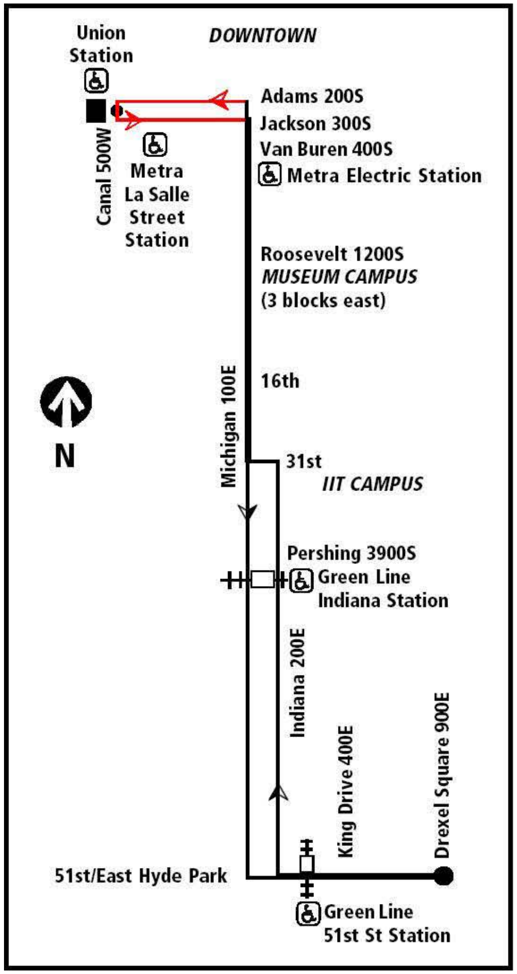
	number of occasions				
stop	**1**	**2**	**3**	**4**	Adams
bus waiting	2	4	3	1	
normal	3	1	1	3	
red light	0	1	1	1	
illegal parking	1	0	1	1	
other	0	0	0	0	
sum	6	6	6	6	
stop	**6**	**7**	**8**	**9**	Jackson
bus waiting	0	2	1	2	
normal	4	1	3	2	
red light	1	2	1	0	
illegal parking	0	1	0	2	
other	1	0	1	0	
sum	6	6	6	6	

reason for idle per route per direction

Adams	number	% of occasion	seconds	% of total idle per route
bus waiting	10	41.7	30.7	44.0
normal	8	33.3	23.5	33.7
red light	3	12.5	9.7	13.9
illegal parking	3	12.5	5.8	8.4
other	0	0.0	0.0	0.0
sum	24	100.0	69.7	100.0
Jackson				
bus waiting	5	20.8	12.0	18.3
normal	10	41.7	31.3	47.7
red light	4	16.7	11.2	17.0
illegal parking	3	12.5	5.8	8.9
other	2	8.3	5.3	8.1
sum	24	100.0	65.7	100.0

Idling does not seem to be very significant for this route. But if anything, bus bunching is the greatest cause for idling.

Route 1 Map



Union Station
DOWNTOWN
Adams 200S
Jackson 300S
Van Buren 400S
Metra Electric Station
Canal 500W
Metra La Salle Street Station
Roosevelt 1200S
MUSEUM CAMPUS
(3 blocks east)
16th
N
Michigan 100E
31st
IIT CAMPUS
Pershing 3900S
Green Line Indiana Station
Indiana 200E
King Drive 400E
Drexel Square 900E
51st/East Hyde Park
Green Line 51st St Station

clinton
canal
wacker
franklin
wells
lasalle
clark
dearborn
state
wabash
michigan
Adams
Jackson
Quincy
LaSalle
FEDERAL CENTER
Sears Tower
Union Station (Amtrak)
Chicago Board of Trade
John Marshall Law School
DePaul Univ
Metra Burlington Northern Santa Fe, Heritage Corridor, SouthWest Service
Milwaukee District, North Central Service
0
1
2
3
4
5
6
7
8

A bus traveling northbound on Michigan reaches stop 0 first on Adams. It progresses through stops 1 and 2 on Adams, turns left on Canal, has a stop (3) on Canal, turns left onto Jackson. It travels eastbound on Jackson reaching stop 4 first on Jackson, then travels through stops 5 through 8 (at stop 8 no data was collected on dwell time), turned left onto Michigan and leaves the loop area traveling south on Michigan.

Sample of the original raw data from field collection:

Stop	t_{open}		t_{close}		t_{move}		Passengers on	Passengers off	Observations
0	1	23	2	03	2	27	3	2	Normal
1	3	46	3	59	3	59	4	2	Bus Waiting
2	6	43	7	13	7	21	0	17	Red light
3	7	52	8	39	8	46	11	0	Illegal parking
4	10	02	11	56	12	05	23	0	Normal
5	13	42	15	10	15	40	12	0	Normal
6	16	43	17	45	18	05	10	2	Other
7	18	30	19	31	19	31	7	8	Normal
8	20	20					2	4	Normal

Trial 1, Adams-Jackson Line 1

Problem with this data is set is that we don't know where the clock was started to get the arrival time (or t_{open}) for stop 0. We cannot just simple renumber the stops so that 0 would be 1 because we do not know the location of where the clock started. Therefore, for every run we will have to subtract the value of t_{open} of stop 1 from every time value, or assume where it might have been started. Inconsistently with the previous data sets, in this data set there are data collected for stop 0. Unfortunately, no data was collected for stop 8 (similarly to the data set of Route 157, stop 11 that caused the complication in the analysis of that data set).

In addition, we broke up the circular route into West and East directions at stop 3 to remain somewhat consistent to the previous two data sets. All this manipulation to make the data set usable and somewhat consistent resulted in a starting data set for our analysis that is as presented here: Our revised starting "raw" data for Route 1:

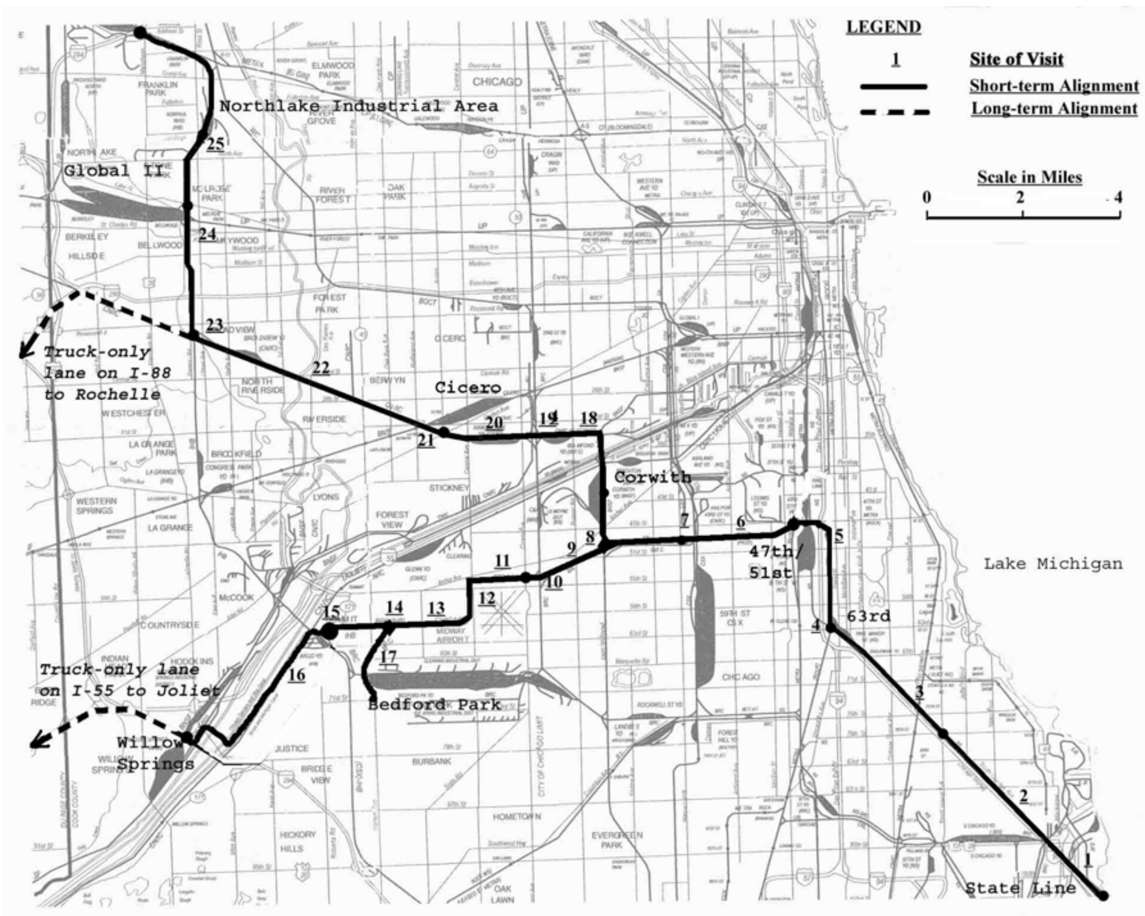
Stop	t_{open}		t_{close}		t_{move}		Passengers on	Passengers off	Observations
0	1	23	2	03	2	27	3	2	Normal
1	3	46	3	59	3	59	4	2	Bus Waiting
2	6	43	7	13	7	21	0	17	Red light
3	7	52	8	39	8	46	11	0	Illegal parking
3'					8	46			
4	10	02	11	56	12	05	23	0	Normal
5	13	42	15	10	15	40	12	0	Normal
6	16	43	17	45	18	05	10	2	Other
7	18	30	19	31	19	31	7	8	Normal
8	20	20					2	4	Normal

APPENDIX IV

RIGHT-OF-WAY CONDITIONS OF SHORT-TERM ALIGNMENT

Presumed available rail rights-of-way (ROW) are one of the major considerations when selecting the short-term alignment. The photos taken by the team from site visits have been assembled in this Appendix and show the ROW conditions of the proposed short-term alignment. The ROW information was also used to estimate the construction cost.

The following figure presents the proposed short-term alignment as well as the sites where the team visited and took the photos.



Generally speaking, there exist presumed surplus and available rail ROW, either elevated (e.g., Sites 2, 3, 5, 6, 7, 20,21, and 24) or at grade (e.g., Sites 4, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 22 and 23). On these segments, the proposed truck-only roadway could be adjacent to existing tracks, either elevated or at grade, depending on the ROW conditions. Elevated structures or bridges would be needed, for example, to cross the Calumet River, the Dan Ryan Expressway, railroad trestles, canals or local streets (e.g., Sites 11, 12, 13, 17, 18 and 22). In some places, existing rail trestle bridges would have to be removed (e.g. Site 6) or expanded (e.g., Site 7 and 21).

For those segments where there is no available rail ROW or existing ROW may not be able to accommodate two truck-only lanes (e.g., Sites 9, 15, 20, 24, 25), the proposed roadway could be in air rights. Air rights may be required from the property owners on either or both sides of the tracks.

Site-1

Site-2

Site-3

Site-4

Site-5

Site-6

Site-7

Note: one of the spans over the CSX has been knocked out

Site-8

Site-9

Site-10

Site-11

Site-12

Site-13

Site-14

Site-15

Site-16

Site-17

Site-18

Site-19

Site-20

Site-21

Note: bridges would be needed to cross the local street or rail tracks.

Site-22

Site-23

Site-24

Site-25

APPENDIX V

DETAILED ALIGNMENT DESIGN FOR SELECTED SEGMENTS

This appendix presents an alignment design for one portion of our proposed short-term alignment, namely, from State Line to Corwith Yard that corresponds to Segments 1 through 3 in the main report. The State Line to Corwith portion was further divided into ten separate and individual sections in this Appendix.

1. Section Descriptions

Section 1: Corwith to St. Louis Avenue

This section emerges out of the Burlington Northern Santa Fe (BNSF) Corwith Yard and connects it with the ROW identified as being parallel to 49th Street. There exist three rail tracks in total on this section, two of which are owned by BNSF and the remaining one by Norfolk Southern (NS). The geography of the section is such that the three tracks after coming out of the BNSF Corwith Yard, head south and veer eastward toward its end on Saint Louis Avenue, to join and follow the path identified to link it with the 49th Street parallel right-of-way identified. Furthermore there is also potential for the use of aerial rights and on-ground rights for this section. Both BNSF and NS have aerial rights over their tracks to a certain height so that the space above the tracks can potentially be used for an aerial means of transportation. The ground rights are further divided into two sub-categories, one which helps place the footprints for aerial means of transportation and the second being the space next to or in between the two BNSF and one NS track already present, after or before the removal of any obstructions. Further dwelling into the section geography revealed that, when turning southeast to join in the ROW parallel with 49th Street, the section is joined by the CTA Orange Line and CNIC tracks, entering from the southwest.

Section 2: Saint Louis Avenue to Western Avenue

Starting from the end of Section 1, i.e. Saint Louis Avenue, proceeding due east until Western Avenue, Section 2 runs entirely west to east and parallel with 49th Street. There exist four rail tracks on this section, namely, the CTA Orange Line, Canadian National CN/IC, Norfolk Southern, and BNSF. The two BNSF tracks are not accounted for, as they are the shunting tracks, which come to an end at Kedzie Avenue. There also exists the potential for the use of aerial rights and on ground rights. It may also be mentioned that CN/IC, CTA (Orange Line) and NS have aerial rights over their tracks to a certain height so that the space above the tracks can potentially be used for an aerial means of transportation. The ground rights are further divided into two sub-categories, one which helps place the footprints for aerial transportation and the second being the space next to or in between the CN/IC, CTA and NS tracks already present, after or before the removal of any obstructions.

Section 3: Western Avenue (Bridge)

This section is basically a bridge across Western Avenue and the Western Avenue CTA Orange Line Station. The need for the bridge is essential as it is the only means of heading east and proceeding toward the next section. While joining the BNSF and NS tracks from the southwest, the CTA Orange Line is elevated to avoid intersecting with the NS track and stays elevated until it crosses Western Avenue. For this reason aerial rights will be required from the property owners on either side of the bridge as well as from CTA.

Section 4: Over/Past the Trestle

This section needs to be an aerial one due to the presence of an on-ground NS and CNIC trestle. This section is a continuation of the Western Avenue bridge (Section 3) traveling east; avoiding the CTA Orange Line and the trestle by going over/past them.

Section 5: BOCT-NS

This section is proposed on a rail right-of-way currently not in use, under joint ownership of IHB and CNIC. It runs west to east, parallel with 49th Street, starting from the end of Section 4 and ending at the entrance to the 47th/51st Street Yard.

Section 6: NS to 63rd Street

Section-6 connects Norfolk Southern Yards 47th/51st Street with the 63rd Street Yard. The starting point of this section is the end point of Section 5 i.e. the vacant IHB/CNIC right-of-way and it ends at 63rd Street. This section commonly utilizes the right-of-way identified east of the Dan Ryan Expressway and lying east of the Metra track. Here exist three alternative routes to accomplish this task and are labeled as 6A, 6B and 6C.

Each alternative itself is divided into sub-sections due to its length. Following are the proposed three alternatives for Section 6:

- 6A (totally at grade level)
- 6B (requires a bridge/aerial rights when crossing the Dan Ryan Expressway)
- 6C (shortest possible connection requires bridge/aerial rights to be consistent with the right-of-way identified east of the Dan Ryan Expressway.

Section 7: 63rd Street to 64th Street

This short section runs northwest to southeast and connects the right-of-way identified east of the Dan Ryan Expressway ending at 63rd Street i.e. end point of Section 6, with the possible right-of-way identified adjacent to the NS track on 64th Street. An aerial route is also possible due to the short distance but will require aerial and on-ground rights from both property and rail track owners to secure footprints.

Section 8: 64th Street to Calumet River

Utilizing the right-of-way identified at Stateline reveals an existing right-of-way east of the Chicago Skyway; starting from 63rd Street and going on to Stateline, the eastern half of which is currently used by Norfolk Southern. While going southeast along the right-of-way east of the Chicago Skyway, Calumet River is encountered which needs to be crossed to continue on the same rail track that intersects the river when it reaches 97th Street, thereby highlighting the need for an aerial means of transportation or the construction of a bridge.

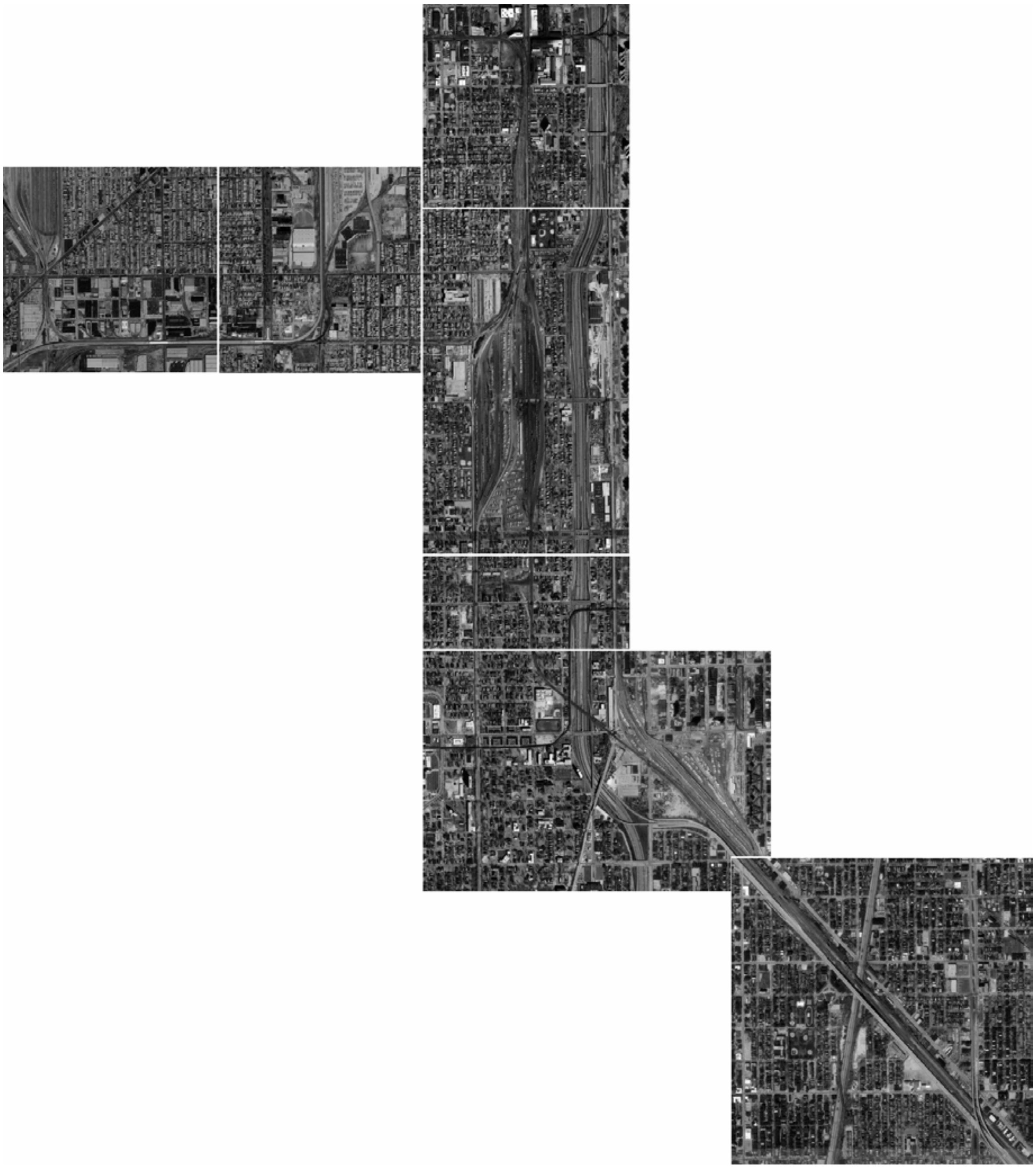
Section 9 Bridge Over Calumet River

As mentioned earlier that there stands the need of a bridge/aerial means of transportation in order to cross the Calumet River. This section starts from the end of Section 8, i.e. at 97th Street, and ends after crossing the river.

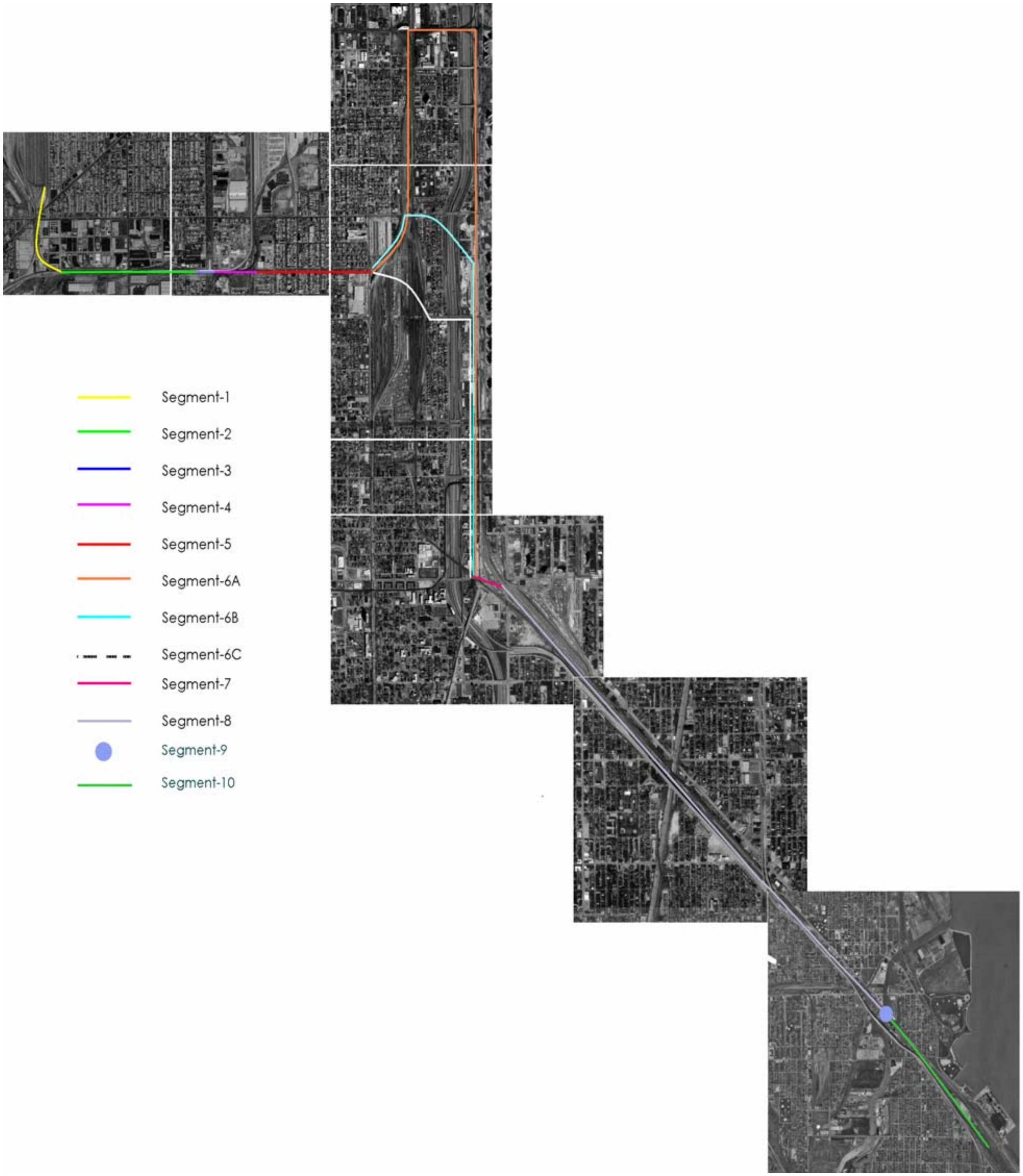
Section-10: Bridge to Stateline

While moving along the right-of-way identified east of the Chicago Skyway, east half of which is in use of Norfolk Southern, the section connects the bridge over the Calumet River to Stateline.

2. Stateline to Corwith Yard: Overhead View of Geographical Location



3. Geographical Depiction of the Sections



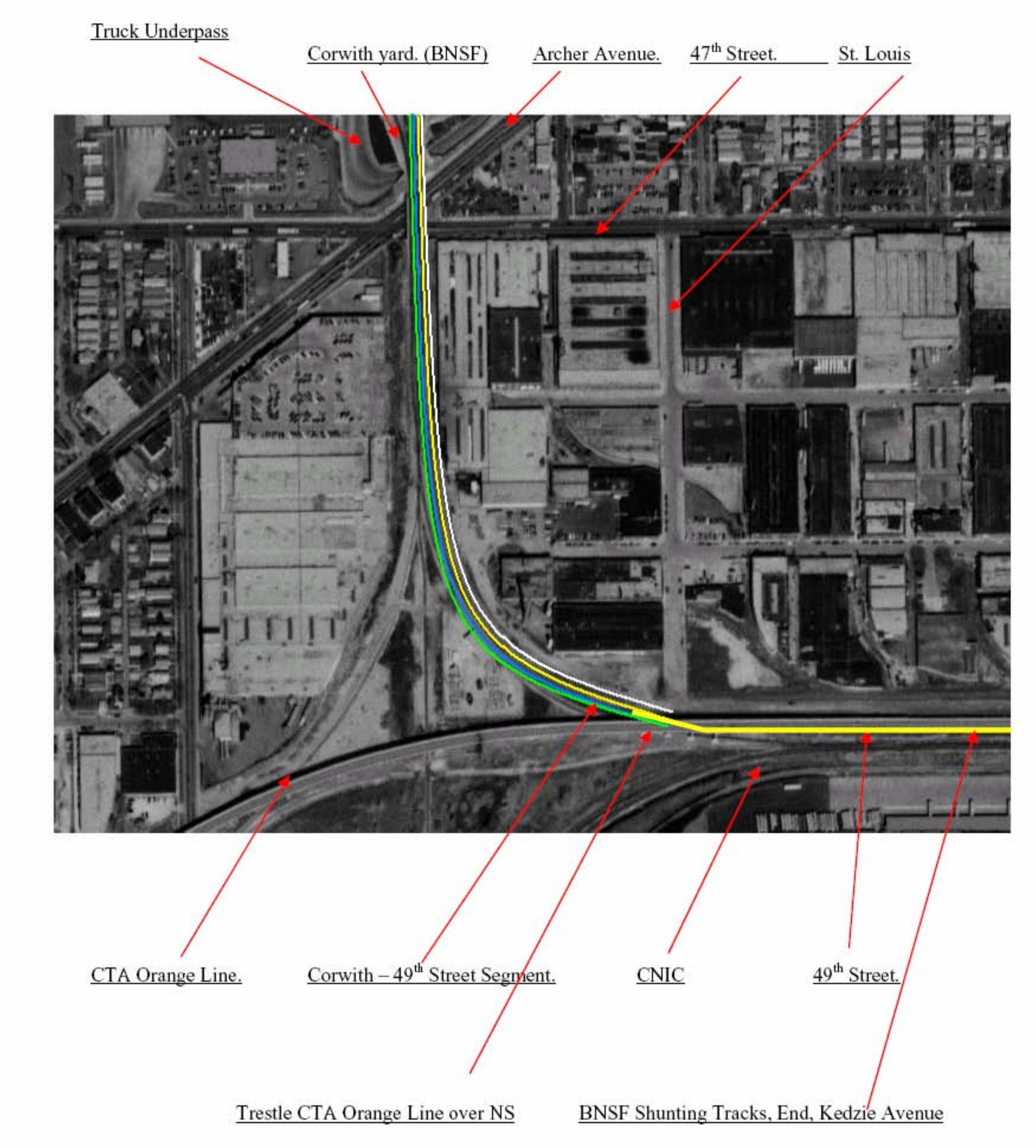
4. Anatomy of Individual Sections

Section-1: Corwith to St. Louis Avenue

Design Options

Rights-of-Way	**Options/Considerations in Section 1**	**ROW Description**
1.	On the Ground-North	Land available for purchase; remove obstructions.
2.	Aerial	Purchase air rights and secure footprints.
3.	BNSF	Not available (X ft), Two Shunting tracks with no aerial limits. Possibility of track sacrifice unknown. Footprint possibility unknown.
4.	NS	Not available (X ft), Has no aerial rights. Footprint possibility unknown.

Geographic Representation

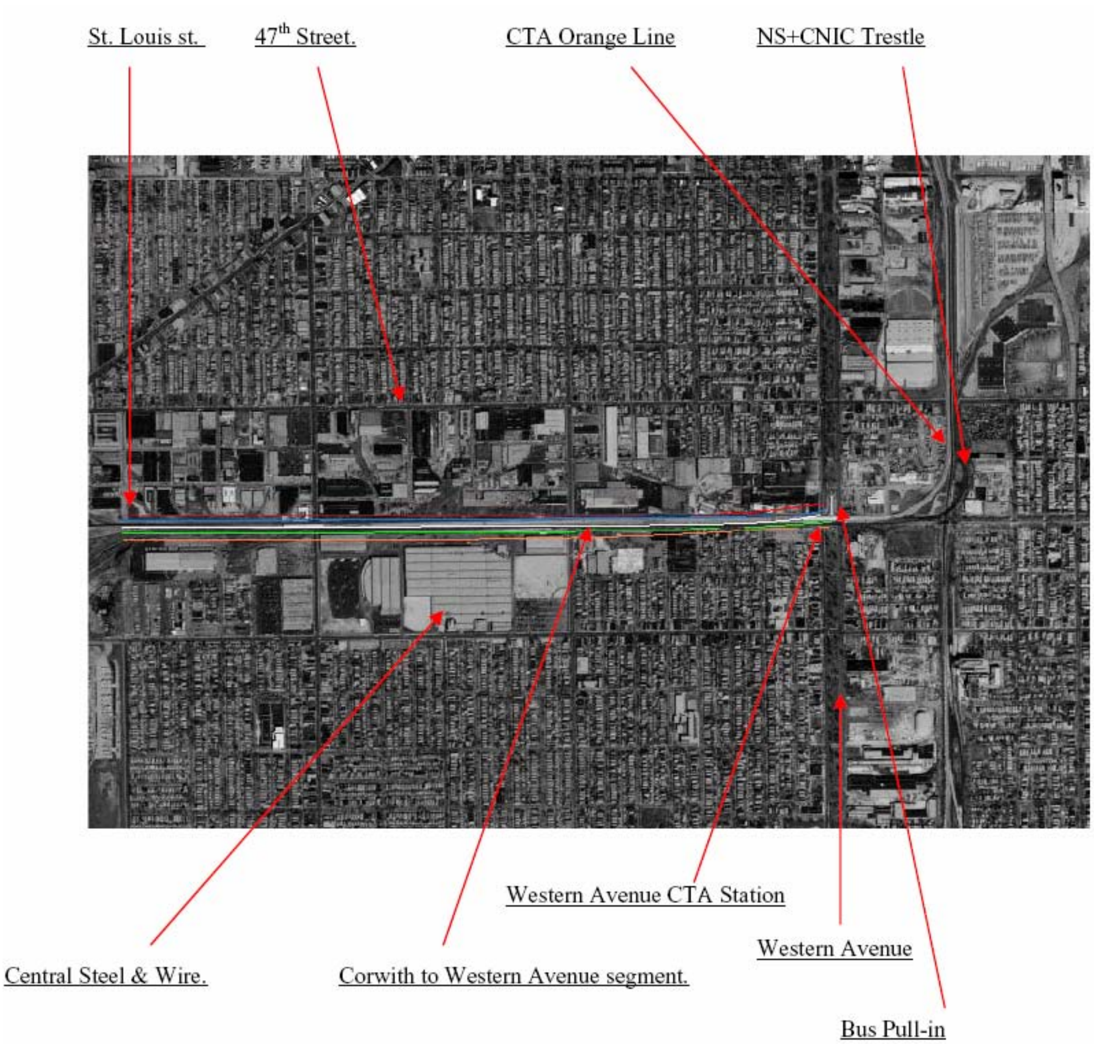


Section 2: St. Louis Avenue to Western Avenue

Design Options

Rights-of-Way	Options/Considerations in Section 2	ROW Description
1.	On the Ground-West to East.	Land available for Purchase, Remove Obstructions.
2.	Aerial	Purchase air rights and secure footprints.
3.	BNSF	Not available (X ft), Two Shunting tracks. Have no aerial limits. Possibility of Track Sacrifice Unknown. Footprint possibility Unknown. Tracks ending Kedzie Avenue.
4.	CTA Orange Line	Not available (X ft), Has no aerial limits. Footprint possibility unknown.
5.	NS	Not available (X ft), Has no aerial rights. Footprint possibility unknown.
6.	Canadian National CN/IC	Not available (X ft), Has no aerial limits. Footprint possibility unknown.

Geographic Representation

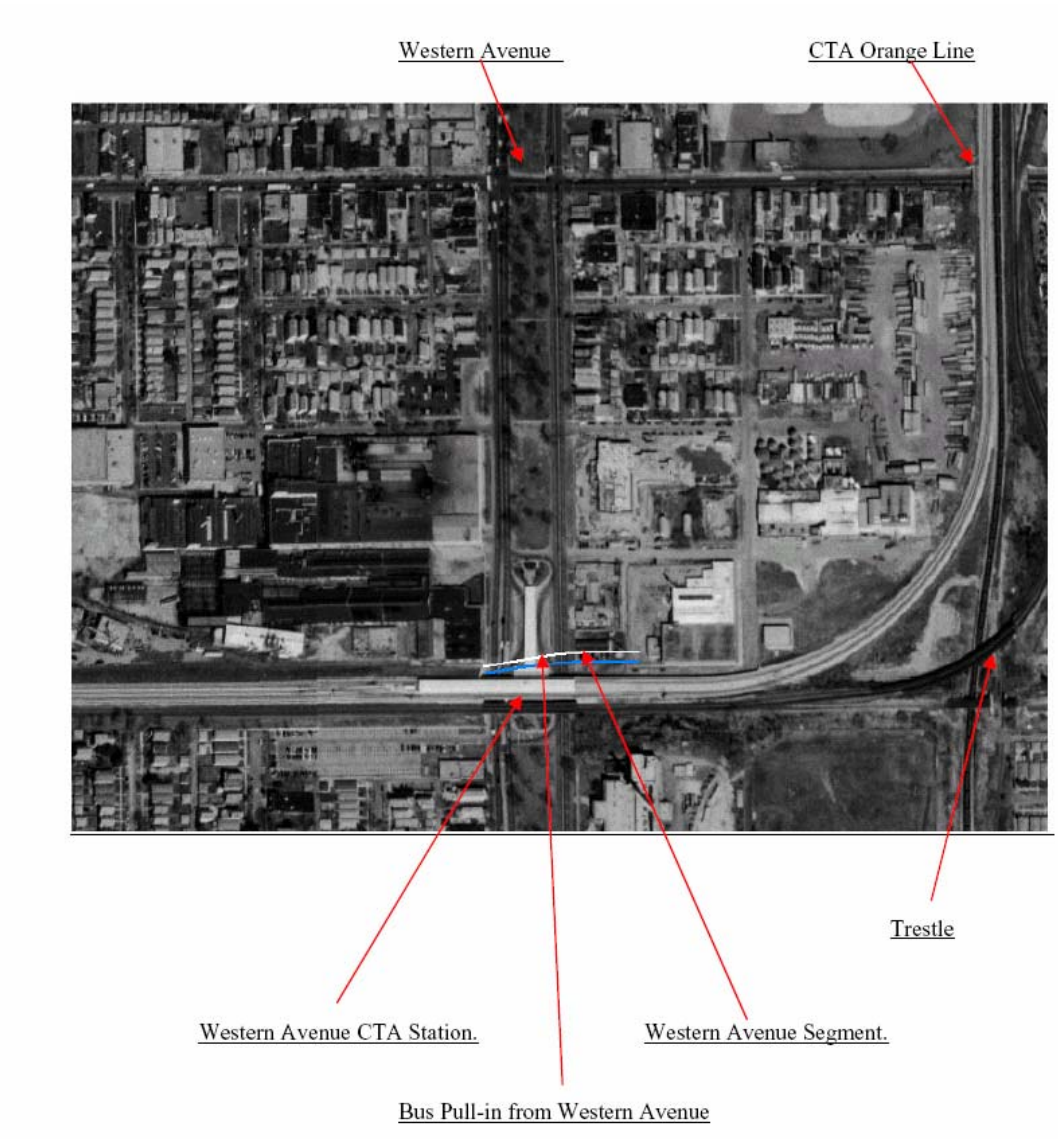


Section 3: Western Avenue (Bridge)

Design Options

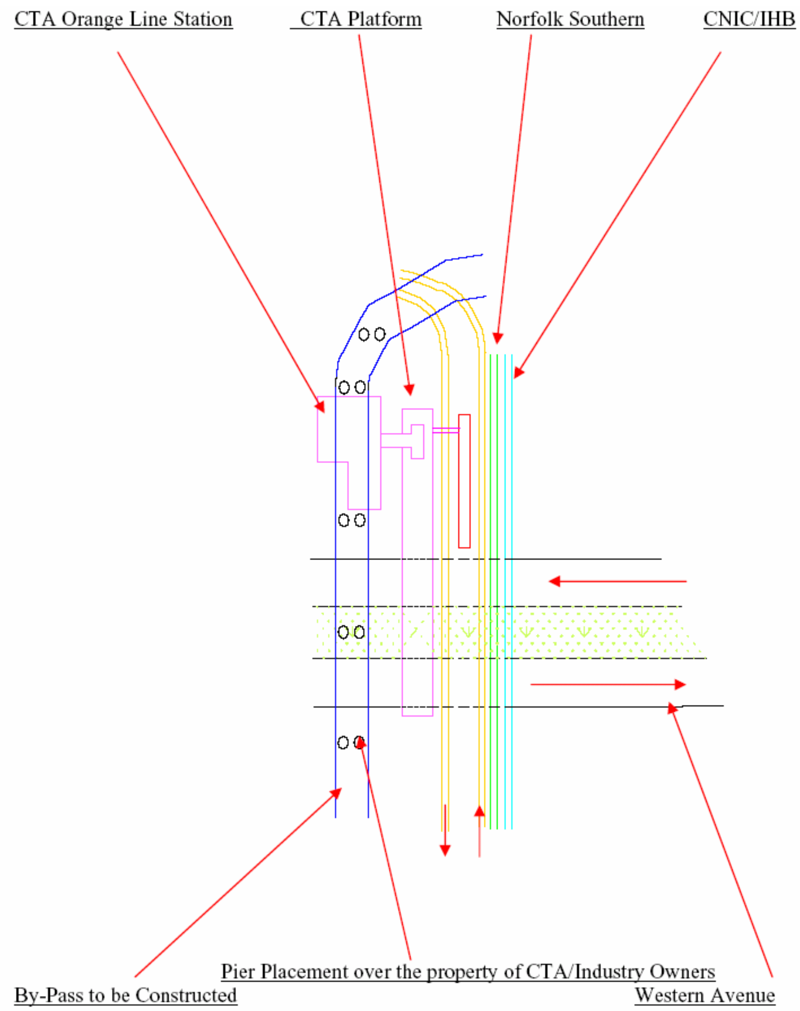
Rights-of-Way	Options/Considerations in Section 3	ROW Description
1.	On the Ground-West to East	No possibility due to the presence of CTA station.
2.	Aerial	Purchase air rights and secure footprints from CTA and either side of bridge property owners.

Geographic Representation



Definition of Section 3

Due to the presence of the CTA Orange Line train station on Western Avenue, which poses an obstruction for the throughway of a Right-Of-Way, the need for a bridge is essential as being the only solution to jump that section and proceed to the next. For this purpose aerial rights will be required from the property owners on either side of the bridge as well as from the CTA.

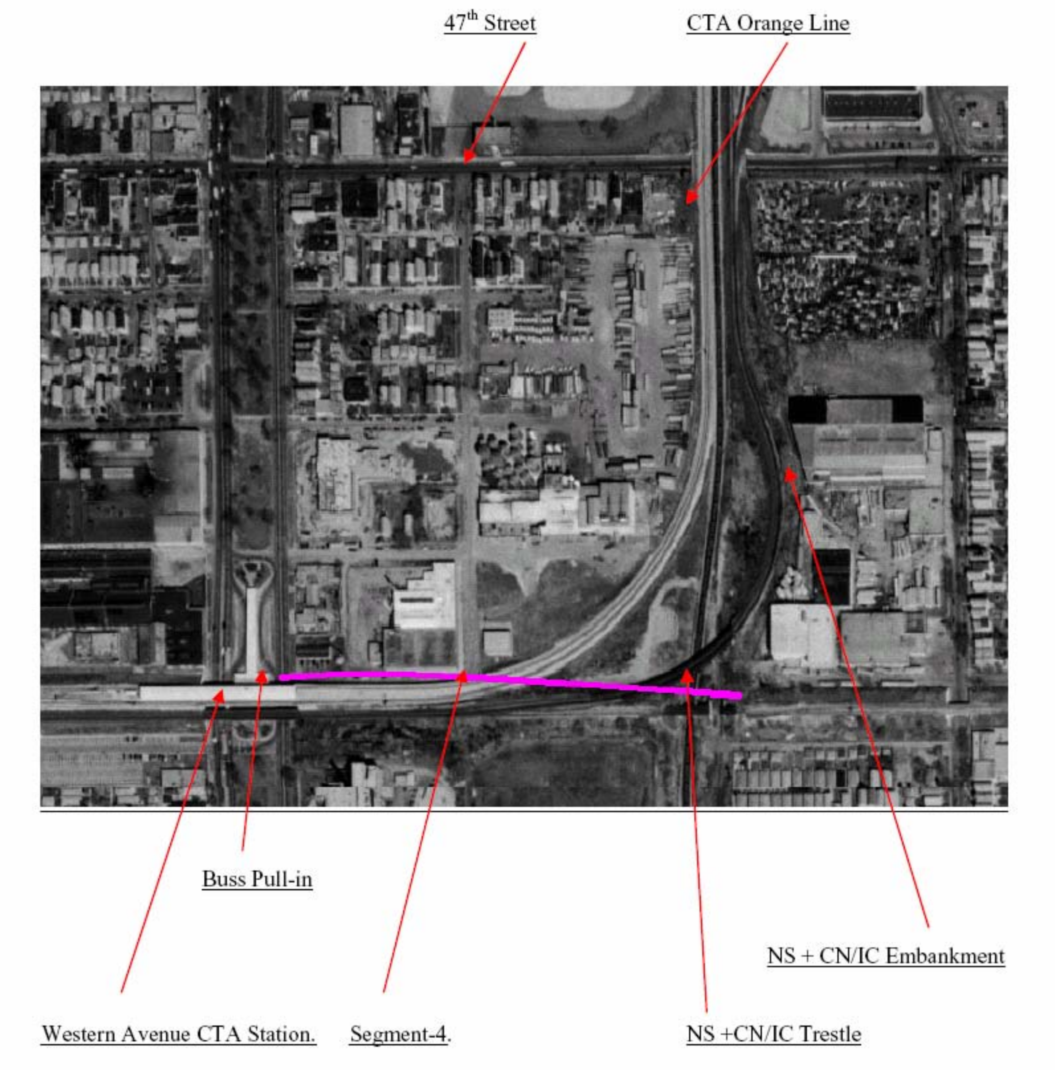


Section-4: Over/Past the Trestle

Design Options

Rights-of-Way	Options/Considerations in Section 4	ROW Description
1.	On the Ground-West to East.	Due to the presence of an on ground trestle the only possibilities are by going overhead or a wide detour.
2.	Aerial	Purchase air rights and secure footprints.

Geographic Representation

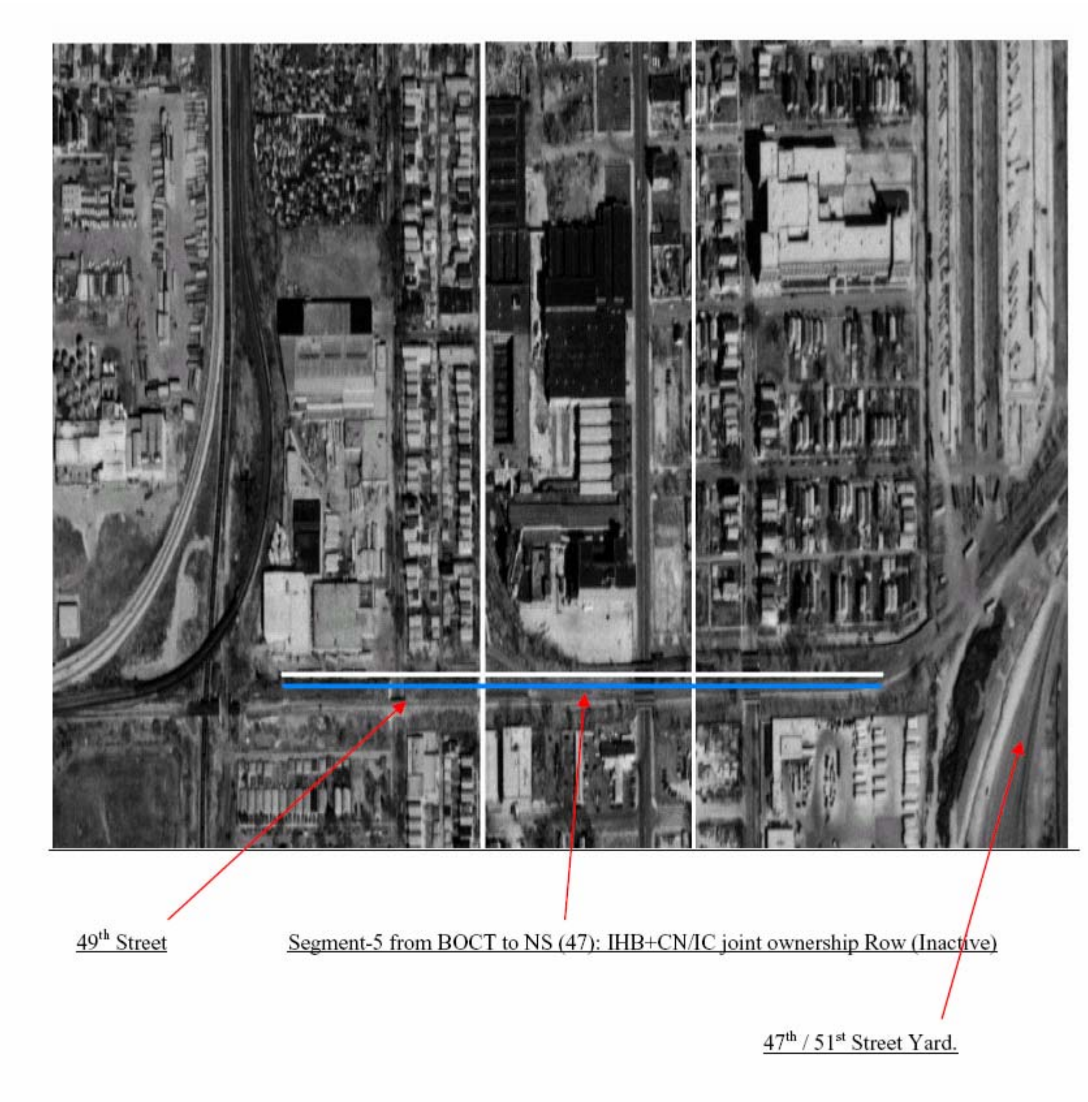


Section-5: BOCT-NS (47)

Design Options

Rights-of-Way	Options/Considerations in Section 5	ROW Description
1.	On the Ground-West to East.	Land available for Purchase, Remove Obstructions. Property rights of IHB/CNIC
2.	Aerial	Purchase air rights and secure footprints.

Geographic Representation



Section 6: NS to 63rd Street

Section 6 is presented in the form of three sub-sections, 6A, 6B & 6C; where A, B & C represent three different alternatives for the connection of NS 47th/51st Street yards with 63rd Street.

Section 6A

Section 6A which connects Norfolk Southern Yards 47th /51st Street to ex-NYC follows a long totally at grade level route. The section itself is divided in sub-sections that include the available ROW next to the Metra track.

Design Options

Rights-of-Way	Options/Considerations in Section 6A	ROW Description
1.	On the Ground-West to East. *	Land available for Purchase, Remove Obstructions. Making use of the ROW detected east of Dan Ryan next to Metra track approx. 50-60ft running from 18th St. to 63rd St. Requires land purchase on west leg; requires accommodation on 47th St. bridge; requires accommodation on Root St. bridge; requires purchase of Row adjacent Metra from 41st St south to 63rd St.
2.	Aerial	Purchase air rights and secure footprints. Aerial not feasible due to the long length of entire section.

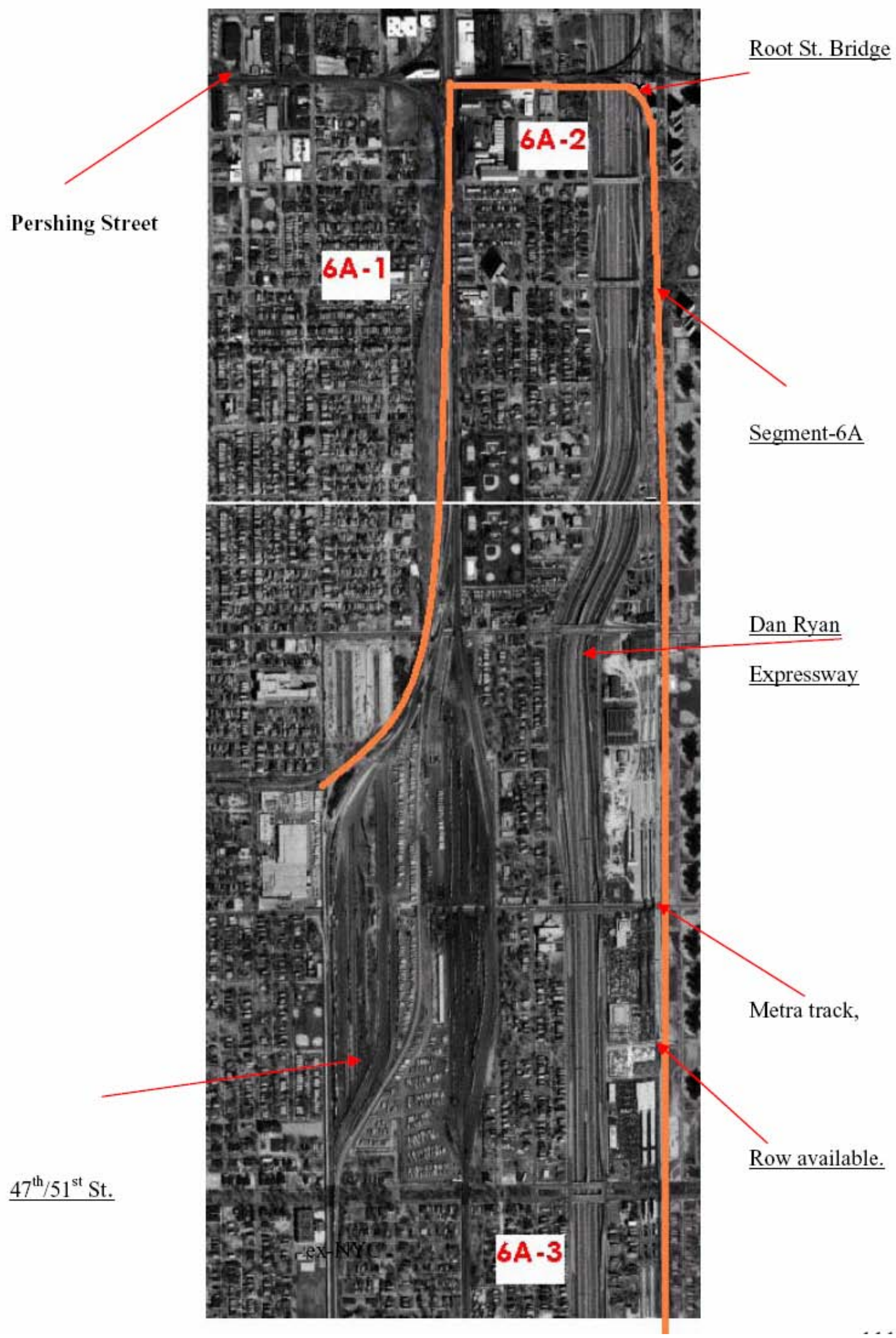
Section 6A Breakage

- 6A-1 (starting from the end point of Section 5 i.e. inactive IHB +CN/IC joint ownership land and moving north along the former C & W I Rail Road running parallel with the Dan Ryan Expressway.) There is an at grade level issue crossing CWI at Root & 41st Street.

- 6A-2 (starting from the end point of 6A-1 i.e. former C & W I Railroad going east on a (presently believed to be Chicago Rail Link) RR parallel with 40th Street going across the Dan Ryan Expressway on the Root St. bridge to the N-S ROW, owned by Metra on the west side and vacant ROW approximately 50-60 feet on the east)

- 6A-3 (Starting from the end point of 6A-2 moving south on vacant ROW parallel to the Dan Ryan Expressway, south to 63rd Street)

Geographic Representation



Section-6B

Design Options

Rights-of-Way	Options/Considerations in Section 6B	ROW Description
1.	On the Ground-West to East. *	Requires land purchase on west leg; requires a structure to clear the NS Yard, to Dan Ryan, the Metra Shops & the Metra ROW, but not necessarily all them, depending on where the structure is placed.
2.	Aerial	Purchase air rights and secure footprints. Aerial route required to cross Dan Ryan; aerial/bridge starting RR // Princeton Avenue, leading us to the ROW available east of Dan Ryan

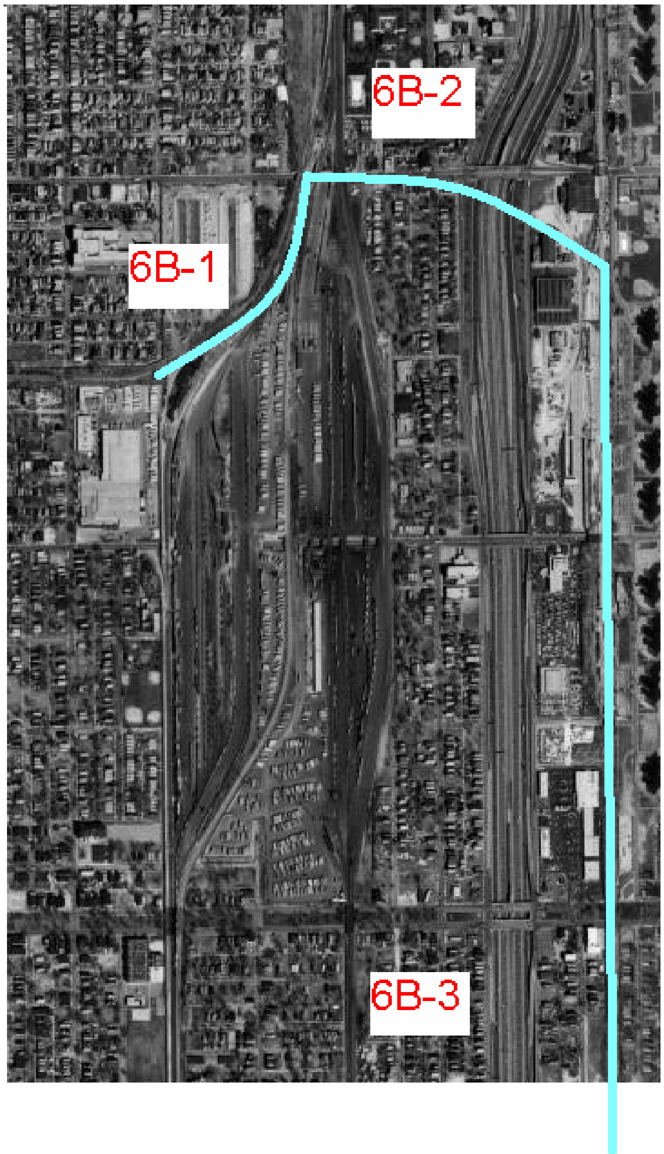
Section 6B Breakage

- 6B-1 (starting from the end point of Section 5, i.e. inactive IHB +CN/IC joint ownership land and moving north towards 47th Street.)

- 6B-2 (starting from the end point of 6B-1 going eastward, parallel to 47th Street until South Princeton Avenue RR, then there is a need of a bridge/aerial route in order to cross the Dan Ryan Expressway; bridge starting Princeton Avenue, leading us to the ROW available east of Dan Ryan, east of the Metra track.)

- 6B-3 (Starting from the end point of 6B-2 moving south on a vacant Railroad parallel to Dan Ryan, south to the 63rd street)

Geographic Representation



Section 6C

Design Options

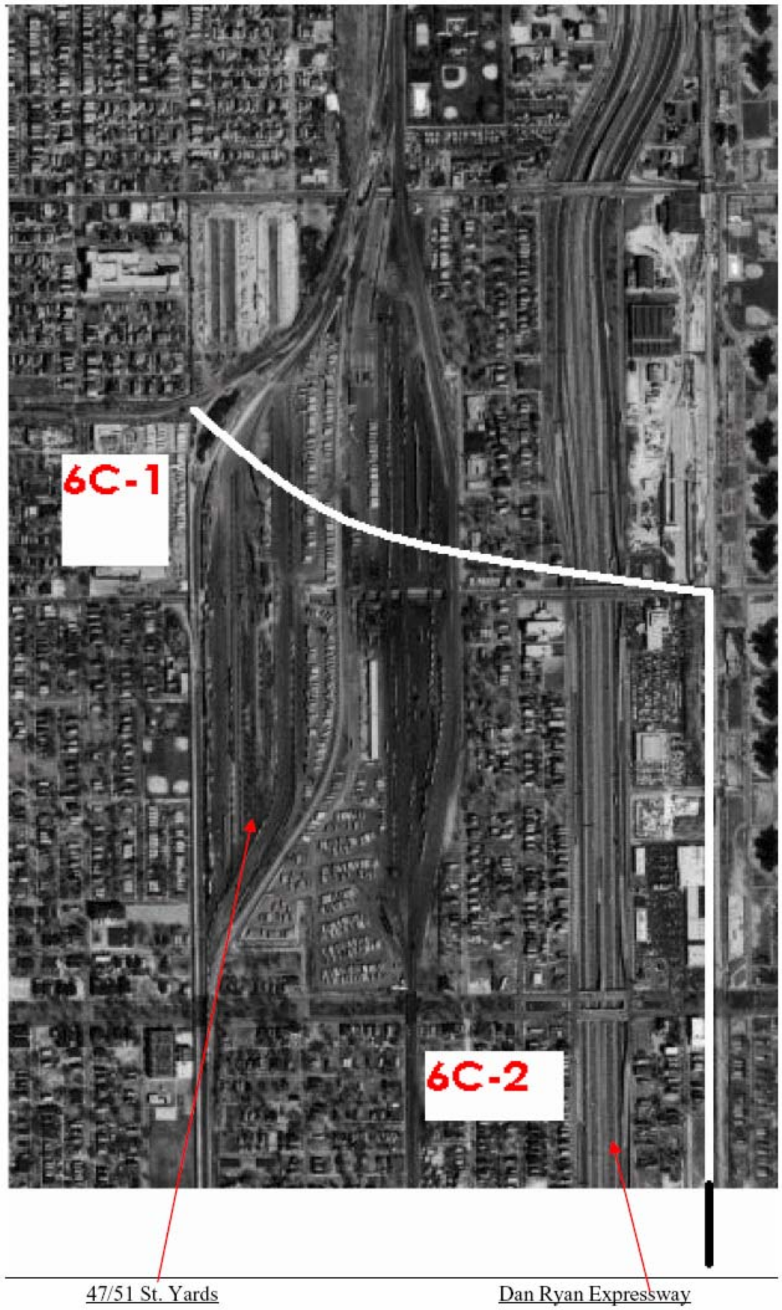
Rights-of-Way	Options/Considerations in Section 6C	ROW Description
1.	On the Ground-West to East. *	Land available for purchase, removal of obstructions. Making use of the ROW detected east of Dan Ryan next to Metra track approx. 50-60ft running from 18th St. to 63rd St.
2.	Aerial	Purchase air rights and secure footprints. Aerial required from the end of Section 5 to the ROW identified next to Dan Ryan.

Section 6C Breakage

- 6C-1 (starting from the end of section-5 is the need of an aerial route/bridge leading us to the ROW available east of Dan Ryan, east of the Metra track.)
- 6C-2 (Starting from the end point of 6C-1 moving south on vacant ROW parallel to Dan Ryan, south of 63rd street)

[This is 6B but avoiding the Metra Shops and without West & North legs]

Geographic Representation

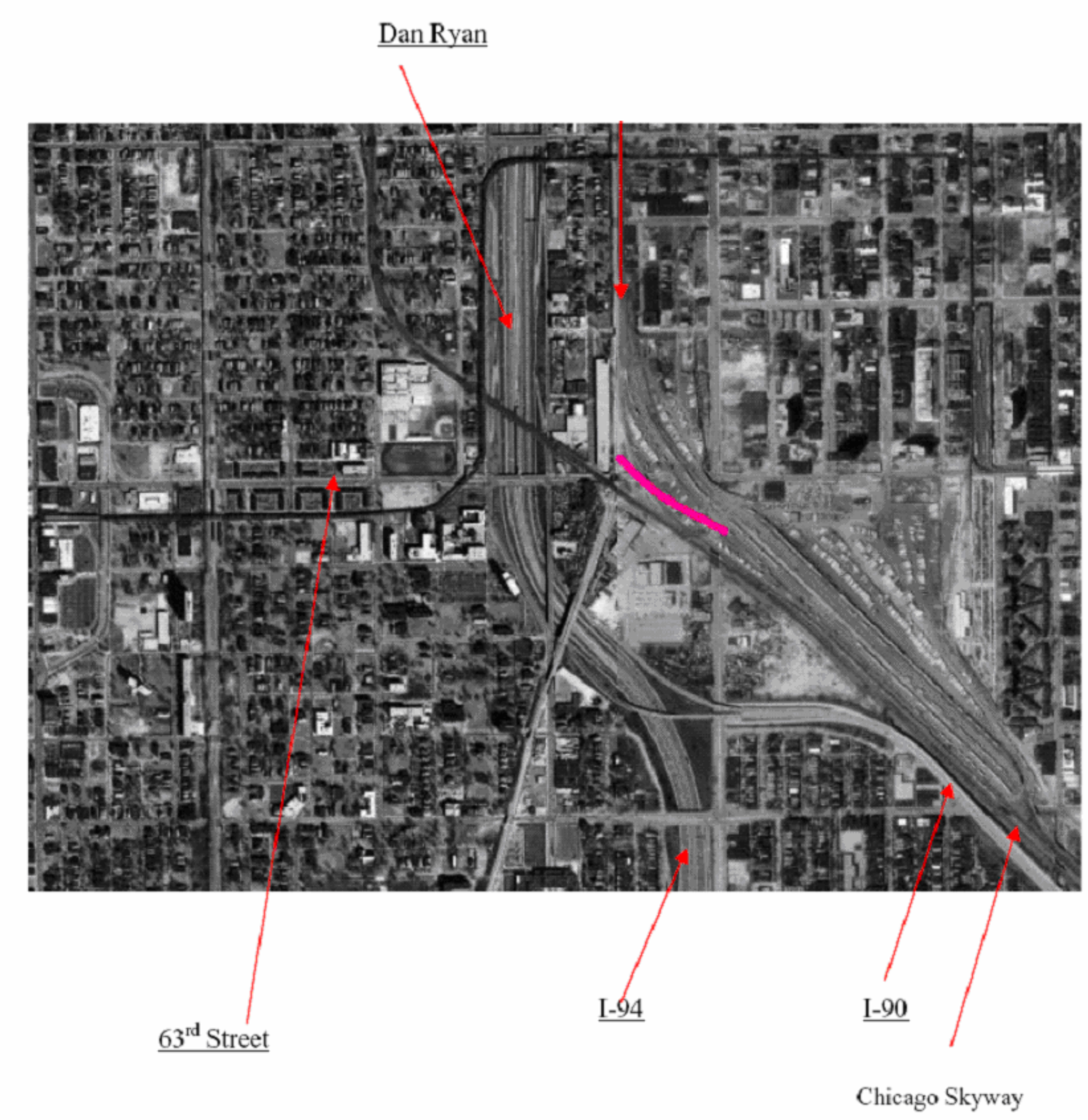


Section-7: 63rd Street to 64th Street

Design Options

Rights-of-Way	Options/Considerations in Section 7	ROW Description
1.	On the Ground-West to East. *	Land available for purchase and removal of obstructions. Continuing from South limit of Section-6 (63^{rd} St.) to NS (64^{th} St.)
2.	Aerial	Purchase air rights and secure footprints. Aerial possible; but requires rights from the railroad owners. Section starting from the end of Section-6 to 64^{th} St.

Geographic Representation



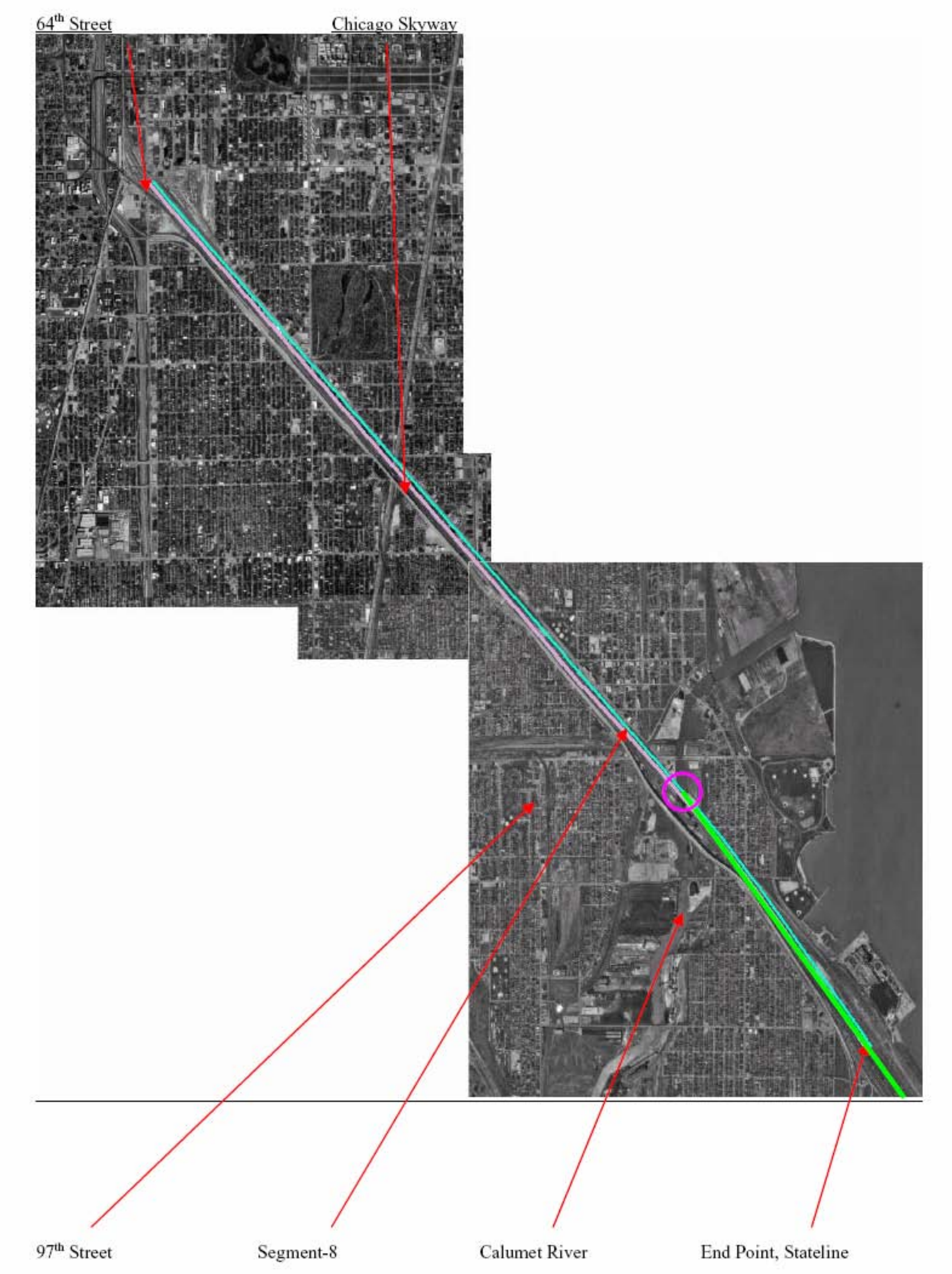
Section-8: 64th Street to Calumet River

Design Options

Rights-of-way were identified east of the Chicago Skyway starting from 63rd Street to the Calumet River, Norfolk Southern is using eastern half of the ROW.

Rights-of-Way	Options/Considerations in Section-8	ROW Description
1.	On the Ground-Northwest* to Southeast.	Land available for purchase and removal of obstructions. ROW available from 63rd St. to River, lying east of Chicago Skyway.
2.	Aerial	Purchase air rights and secure footprints. Not feasible due to the length of the section.
3.	Norfolk Southern (NS)	Not available (X ft), Has no aerial rights. Track lying east of identified right-of-way. Footprint possibility unknown.

Geographic Representation

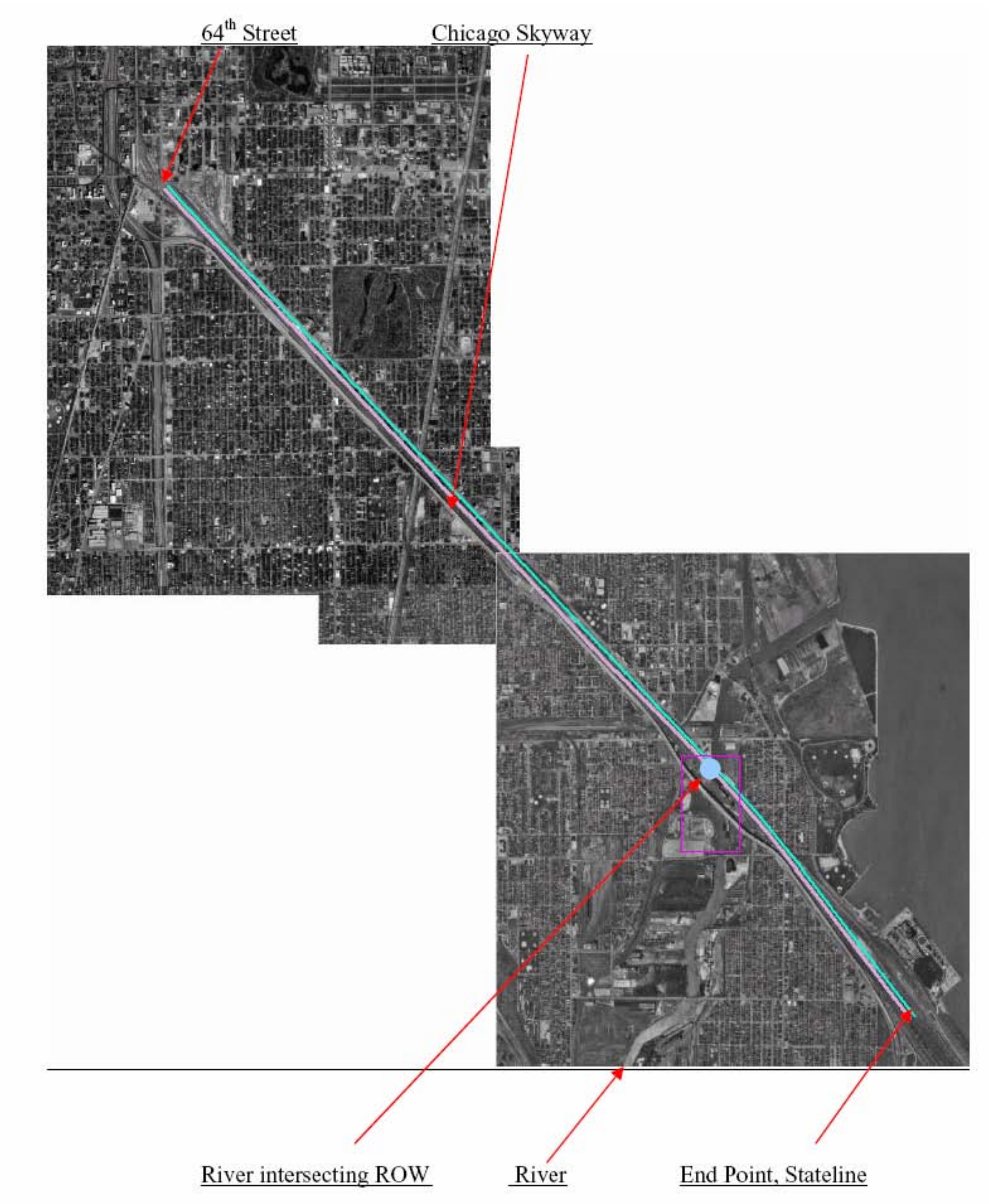


Section-9: Bridge Over Calumet River

Design Options

Rights-of-Way	Options/Considerations in Section-9	ROW Description
1.	On the Ground-Northwest* to Southeast.	No possibility due to the presence of Calumet River.
2.	Aerial	Purchase air rights and secure footprints for a bridge across Calumet River. Going aerial feasible due to the short length of the section.
3.	Norfolk Southern (NS)	Not available (X ft), Has no aerial rights. Track lying east of identified right-of-way. Footprint possibility unknown.

Geographic Representation



Section-10: Bridge to Stateline

Design Options

Rights-of-Way	Options/Considerations in Section-10	ROW Description
1.	On the Ground-Northwest* to Southeast.	Land available for purchase and removal of obstructions. ROW available from 94th St. to Stateline, lying east of Chicago Skyway, along NS track.
2.	Aerial	Purchase air rights and secure footprints for an aerial route. Not feasible due to the length of the section.
3.	Norfolk Southern (NS)	Not available (X ft), Has no aerial rights. Track lying east of identified right-of-way. Footprint possibility unknown.

Geographic Representation