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# Light Rail Transit Surface Operations: Technical Appendix, Trip Reports

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# Light Rail Transit Surface Operations: Technical Appendix, Trip Reports

## **Abstract**

This appendix to the report, Light Rail Transit: Surface Operations, contains unedited trip reports prepared in 1977 covering visits in 1976 to cities in Sweden, Holland, Switzerland and west Germany by Dr. E. s. Diamant; to Holland, Belgium, Italy, Yugoslavia and West Germany by Dr. v. R. Vuchic; and to cities in North America. by Messieurs H. Carve, R. Sauve and G. Fox, to carry out investigations and gain understanding of the fundamental design and operation practices of light rail transportation systems. These trip reports are published at this time to supplement the report Light Rail Transit: Surface Operations.

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# **LIGHT RAIL TRANSIT**

## **Surface Operations**

**Technical Appendix**  
**Trip Reports**

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## PREFACE

Light rail installations in West European cities continue to provide the design and operational data base for new LRT initiatives in the U.S. and elsewhere in North America. LRT projects at Edmonton and Calgary in Canada and at Buffalo in the U.S. are new applications on a limited scale of many techniques pioneered in Western Europe. These cities have adapted European techniques to suit urban characteristics and transit/traffic engineering practices found in this continent. The continuing work on the Toronto system, the Boston MBTA and the San Francisco MUNI, and the incipient activities on the Pittsburgh and Cleveland systems, illustrate the application of modern LRT concepts and practices to extension of upgrading of existing streetcar or LRT installations. It is appropriate that the existing practices and the LRT design concepts being developed at many of these sites provide the basic source material for the detailed review and evaluation of major operational and design factors for new LRT systems reported in a companion volume.\*

The chapters in this volume are the result of trips undertaken by the various individuals who have participated in the continuing Urban Mass Transportation Administration project to assess the applicability of modern light rail technology in North America. A number of cities in Western Europe and North America were visited. While the interests of each visitor varied, common to all investigations was an emphasis on gaining an understanding of the fundamental design and operational practices of the LRT systems in each city. The chapters, therefore, include a general discussion of overall system designs and operational trends. The control of LRT, motor vehicle and pedestrian movements at points of possible contact (intersections, crossings and along the LRT lines), being of particular importance to operations, is reported in considerable detail. Another subject of interest to the investigators was the application of modern traffic engineering techniques to achieve the highest levels of safety for pedestrians, motor vehicles and LRVs. Several of these techniques are discussed. Means for improving the operational efficiency of LRT and its appeal to the riding public via enhanced convenience factors and accessibility to major urban activity centers are also described by the authors.

It is natural that the emphasis and perceptions reported in this volume vary from one author to another. No attempt was made to edit these trip impressions into a common format. Rather, the chapters were permitted to reflect each visitor's own sense of priorities and attention to detail. Taken as a whole, the volume represents a multi-dimensional view of a complex and promising transit alternative as seen and experienced in its actual operating environments. It is hoped that readers will find, in the chapters that follow, concepts and directions for their own assessment and consideration of LRT options.

The trip reports were authored by Dr. E. S. Diamant of De Leuw, Cather & Company, who visited cities in Sweden, Holland, Switzerland and West Germany; Dr. V. R. Vuchic of the University of Pennsylvania, who visited cities in Holland, Belgium, Italy, Yugoslavia, and West Germany; and Messrs. H. Korve, R. Sauve and G. Fox of De Leuw, Cather & Company, who visited cities in Canada and the U.S.

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\**Light Rail Transit: Surface Operations* (Chicago: De Leuw, Cather & Company), prepared for the U.S. Department of Transportation, Urban Mass Transportation Administration, December 1981.





# CHAPTER 1

## LIGHT RAIL TRANSIT OPERATIONS IN SWEDEN, GERMANY, SWITZERLAND AND HOLLAND

A REPORT ON A EUROPEAN TRIP BY  
DR. E. S. DIAMANT

In late October and early November, 1976 a visit to Western Europe enabled the writer to observe and learn about the operations of several outstanding light rail transit systems. The intent of the visit was to add a background of personal observation to the data and conclusions of the 1976 report entitled *Light Rail Transit: A State of the Art Review*.<sup>1</sup> This report indicated that an understanding of light rail operations on at-grade routes, and particularly at street intersections, is important to making decisions on the feasibility of the light rail systems in the United States. Consideration of at-grade operations and a more comprehensive review of the economics of self-service fare collection than that provided in the *State of the Art Review* were also the objects of the second phase of the research which led to the 1976 report. Thus, a visit to Western Europe became essential to the study.

The trip included stops in Sweden, Germany, Switzerland and Holland. In these countries, the cities visited were carefully chosen to provide a solid background on the most advanced applications of light rail technology. Also of interest was a sampling of the various operators' philosophies concerning light rail operations, engineering and standards for future deployment.

In Sweden the visit centered on Gothenburg, one of Europe's best known sites of light rail operations and of imaginative traffic engineering solutions to the difficult automobile traffic conditions found in many older cities.

In Germany, the visit included Dusseldorf, Cologne and Munich, three cities with extensive light rail networks. To the visitor each city represents different attitudes regarding the role of light rail transit in large, German metropolitan areas. In Dusseldorf, the light rail system has just celebrated its first centennial. As a result of successful efforts to control conflicts between private automobiles and transit, the existing systems operate entirely at grade on the city's streets and arterials, and with remarkable efficiency. The current trend toward grade separation is only now becoming apparent in Dusseldorf, where construction of the first underground segment of its transit system is in progress. In Cologne, part of the light rail network is already emplaced underground in the center of the city. At Munich, the third largest city in Western Germany, the extensive light rail network is viewed largely as a vestige of the earlier streetcar system. The pride of Munich is the network of U-Bahn and S-Bahn crisscrossing the city and its suburbs. The Munich system, however, in spite of its extensive coverage of the metropolitan area, does not display the attention to detail and application of innovative traffic engineering practice that is so visible in Dusseldorf and Cologne.

In Switzerland, the visit was continued to Zurich where some of the most rudimentary forms of traffic control can be found adjacent to some of the most modern applications of computer technology to the control of complex movements of private automobile traffic and surface transit.

Finally, in Holland the visit included the neighboring cities of Amsterdam and The Hague. Some of the earliest applications of modern traffic engineering practice to the control of conflicting

automobile and light rail traffic can be found in The Hague. Both in The Hague and in Amsterdam, successful traffic and engineering techniques are being gradually implemented along routes characterized by difficult geometric constraints and major automobile traffic problems.

The light rail systems in the cities visited are examples of different implementation, design and operating philosophies. To some extent these variations are colored by political and institutional differences affecting transit in each of the four countries. An important causal factor explaining these differences is, most likely, the strength of historical trends and traditional practices. Similar approaches used in upgrading streetcar operations to light rail standards within constraining urban infrastructures and in the presence of heavy automobile traffic are, however, more interesting and worthwhile of study than differences in system philosophies.

Since the newer suburban developments are often as dispersed as their U.S. counterparts, planners have, in many cases, stressed the use of bus transit as a less costly and more efficient form of suburban transit. Each of the cities visited supports extensive bus networks concentrated largely, however, on the periphery of the more centrally located rail networks. In the Ruhr region of West Germany, long range plans call for the deployment of an extensive regional network of rail transit. Here too the light rail systems will only provide the backbone of the transport network, while buses will furnish the wide area coverage.

Looking into the future, it is tempting to say that in some cities the responsible planners have reached a plateau position, a point of regrouping and rethinking the approach which will shape the form of urban transportation in years to come. The improvement of light rail operations to render them more compatible with the competing automobile is continuing, but at a slower pace. In some cases, such as in Dusseldorf and Munich, emphasis seems to have shifted to more capital-intensive system modifications and expansions. At the time of the visit, none of the cities contemplated significant expansion of their at-grade light rail networks. Caught in the grips of decreasing funds available for transit because of inflation and changing priorities, these cities, at least for the immediate future, appeared to be limiting any system expansion committed programs for which funding was continuing at previously set rates.

Planners in some cities felt that they were near the limits of improvements to streetcar operations achievable with current engineering practice. Development work now taking place is largely of a spatial nature: expansion of more streetcar routes to LRT-type operations and penetration of new neighborhoods with LRT lines. The high costs and the uncertainties of new traffic control and computer technologies have discouraged their use on a wide scale. While exceptions could be found, future upgrading of LRT operations by use of newer technologies were not generally given a great deal of consideration. Most of the planners and engineers met on this trip did not judge these technologies to promise future cost-effective improvements to streetcar operations.

Each of these cities, regardless of its experience during World War II, is today enmeshed in a conflict of changing lifestyles, resulting from the emergence of the automobile as a major form of transportation and the desire to maintain unchanged their traditional urban structure and quality of life. Some time ago politicians and transit planners in each of these cities decided to retain the municipal streetcar systems and to improve their operations, but to do so with minimal impact on automobile traffic, pedestrian movements and traditional land use. As a result, the variety of traffic engineering solutions and ingenuity displayed in transit operations on many of these cities' light rail lines is almost overwhelming. Undoubtedly, the success of these efforts is due in no small measure to the prevailing pro-transit attitudes found in the countries visited.

While all of the transit systems were experiencing the well known operating deficits of American properties - and eliciting the same expressions of alarm from public officials over mounting losses - there seemed to be little interest in exploiting secondary sources of revenue through value capture and joint development concepts. The few exceptions notwithstanding (such as the

central station at The Hague), transit is seen, at least in the cities covered by this visit, as a unique resource for maintaining the historical character of the cities rather than as a catalyst for change. One does not find transit related West European developments reminiscent of Yonge Street in Toronto because local government appears to place greater emphasis (and controls) on maintaining the cities' lifestyles, rather than on changing them through growth. Where growth and change has occurred - primarily in the newer suburbs - there are some successful examples of rail transit, light or otherwise, being used as a catalyst for development or as an alternative to the automobile. For instance, light rail connections to new suburban residential developments are in evidence in Zurich, the Ostrop suburb at Amsterdam, and at Storås and neighboring developments near Gothenburg. Light rail stations have recently been used as the unifying element of innovative downtown malls and commercial development in Rotterdam, Hannover, and elsewhere. It appears that for these developments the emphasis is on the maintenance or enhancement of the urban lifestyle of the respective cities, rather than on fostering residential or business growth.

In reporting on a trip such as this, the technically inclined visitor is often tempted to concentrate on the system, the equipment and the operations - in short, the inanimate part of the light rail experience. It would be unfair to end the introduction to this trip report, however, without paying tribute to the people who, without exception, made the visit not only an informative learning experience but also a warm and friendly get-together among individuals with common interests. A note of appreciation is due to all the people mentioned in this report and to many others who made even the depressing fall weather of Western Europe seem bearable and the trip memorable.

## **GOTHENBURG**

The visit to Gothenburg started Sunday evening, November 7, 1976, after a transpolar flight from Los Angeles and a change of plane at Copenhagen. The following morning at the City Planning office my hosts were Mr. Max Raberg from the City Traffic Planning Department, who had helped set up the appointments in Gothenburg; Mr. Bjorn Refsnes, head of the City Traffic Planning Department; Mr. Gunnar Lagerqvist, Chief of Advanced Transit Systems, Gothenburg Public Transport Study; and Mr. Jan Olaf Bemdsson, traffic engineer in the traffic signal section of the Traffic Planning Department. Messrs. Lagerqvist and Bemdsson provided an extensive briefing of transit developments in Gothenburg. Later Messrs. Bemdsson and Lagerqvist conducted an extensive tour of the City's light rail system, concentrating on interesting treatments of signalization at various intersections. At noon on Tuesday, November 9, Mr. R. Domstad, traffic engineer with the Gothenburg Spavargar, the City's transit organization, provided extensive briefing on operational details of the transit system and later an inspection trip on several lines of the system.

Discussion with the people at Gothenburg covered a number of topics, which help place in perspective the current state of the transit system as well as its future developments. The impact of Swedish law governing transit investments and of Swedish transit and traffic planning practice are essential for understanding the current state of the system. Equally significant is an understanding of the economic and demographic changes that have taken place in recent years in the City.

The several field trips highlighted the great variety of engineering solutions and design treatments of the Gothenburg light rail system which have helped to establish its well deserved reputation of efficiency and ingenuity.

## NATIONAL TRENDS AND POLICIES

In many respects transportation related trends in Sweden parallel those in the United States. Car ownership is continuously increasing; at present one out of three Swedes owns an automobile. In the urban areas one out of two Swedes is a car owner, while in the suburbs fifty percent of the households own two autos. There is a growing trend of movement to the suburbs, particularly in the middle and upper middle income classes. In the suburbs, the trend is toward single family home ownership.

Environmental protection policies follow closely and sometimes exceed the requirements of policies in the United States. Controls on emissions on automobiles are set at standards similar to those of California. According to one proposed policy, noise levels within homes should be maintained at 45 dBA. Since background noise levels are usually 60-65 dBA the implementation of this policy would be very costly. In addition, the overall environmental clearance process may require 5 to 8 years, causing implementation problems with all major projects, transit included.

## TRANSIT AND TRANSPORTATION FINANCING

Construction of new rail transit facilities is financed in part by the National Roads Agency, but is limited to construction carried out to metro standards. National matching funds cover up to 95 percent of the cost of roadbeds. In actual practice exceptions to metro specifications have reduced the funding share for pre-metro construction to as little as 80 percent. Including all costs for new capital improvements the effective share of the national contribution works out to approximately 50 percent. Gothenburg's yearly capital appropriations are made in a comprehensive package which includes budgets for rail transit, streets and highways. The allocation of these funds to transit or to street and highway improvements is usually contested by the affected city departments. Construction and maintenance of intercity roads are generally financed by the national government. In large part, the source of the national funds is a gasoline tax which amounts to 70 percent of the cost at the pump.

Operating deficits, which are continuously growing, are covered by the City. Current transit deficits in Gothenburg are about 50 percent of total operating costs. There is a feeling that in a few years the deficit might amount to 90 percent of the operating costs. The City's contribution is derived from the general budget so that it is not possible to identify specific subsidy sources. The City derives its funds partially from real estate taxes but fundamentally from a city income tax which can be as high as 25 percent of one's income. (The progressive national income tax can be as high as 70 percent of incomes in the range of 100,000 Swedish crowns per year - approximately \$25,000.)

The increasing operating deficits can be explained, in part, by a fare policy which is designed to encourage the purchase of monthly passes at discounted prices, prices that have not kept pace with the inflation. For instance, an individual three-Swedish-crown ticket costs only 1.68 Swedish crowns on a monthly pass. As the ridership on the system has not increased significantly and as more people have switched to the more economical passes, the overall revenue to the transit agency has decreased.

The method used for calculation of operating costs includes an allowance for equipment depreciation, thus adding to the high deficits. Only 50 percent of the O&M costs are attributable to labor; the remaining 50 percent are broken down about equally between the depreciation and the other customary O&M cost elements.

## GENERAL STATISTICS OF THE GOTHENBURG METROPOLITAN AREA

Gothenburg, the biggest port in Scandinavia, covers an area of approximately 360 square kilometers and is located on the river Gotha some 50 kilometers from Stockholm. The river Gotha bisects the city; two bridges and one tunnel (a third bridge is in construction at this time) link the two urban areas. Most of the population live in the southern side of the City. The population in the region surrounding Gothenburg is about 700,000 while in the municipality itself there live 450,000 people, with the heaviest population concentration in the center of the City. Most of the buildings in the City are multiple dwellings, but there is a limitation on building height predicated on historical reasons and maximum building heights are limited to 16 meters - equivalent to a 6-story house.

While there has been a general increase of the population residing in the suburbs, and a corresponding decline of city dwellers, there has also been a general decline of the overall metropolitan population. This decline is attributed to the recent economic recession. In 1967, the City doubled in size after the incorporation of vast areas to the northeast and south. At that time the population in the northeast region was projected to be approximately 100,000 people by the year 2000. Current projections, however, have cut that figure by half. The magnitude of the migration to the suburbs is evident in statistics which show that between 1960 and 1970, the suburbs experienced a 75 percent increase in population.

Most of the employment is located within the municipal boundaries, but only 65,000 jobs are located in the center of the City. Large industries, such as the Volvo factory which employs 15,000 people, and the shipyards, account for a good share of Gothenburg's employment.

Other factors, not related to national economics, may have contributed to the general decline of the suburban population projection, particularly in the northeastern region. The end of the light rail lines Nos. 6, 7 and 8 are located in that general area. The beauty of the area's scenery, accented by hilly wooded terrain, is impressive. Most of the buildings found near the light rail stations are multiple story structures erected during the 1950s and 1960s. The buildings are large, barracks-like apartment complexes, which under the cloudy skies of early November, appeared to be particularly depressing in their isolation and absence of cheerful architectural details. Few people not forced by harsh economic conditions elect to live in these communities. The modern trend is toward construction of single dwellings—a trend that will have to continue for a very long time before the demographic forecasts of the 1960s will materialize.

There appears to be no evidence of current policies which attempt to use transit to influence the evolution of suburban land use. In the late 1960s, following the incorporation of the northeast area of the City, the most recent Gothenburg light rail line was built in that direction towards Storås (Line No. 8). However, little is now being done to expand or improve public transit service in the area. A minor extension of Line No. 8 is being contemplated but the emphasis there, as well as in the other suburbs, is to provide transit service by bus. Currently, there are 10 to 15 private bus companies operating in the suburbs and a plan is in effect to consolidate them in order to provide consistent and interconnected service to the various communities. There is no significant rail commuter service to the suburbs. An existing line operating to the suburban communities to the east is being discontinued because of increasing costs.

## TRAVEL PATTERNS

Travel patterns in Gothenburg are not too dissimilar from those found in many American cities. Gothenburg is often described as a small scale facsimile of Los Angeles: extensive in area, with jobs and residential units distributed fairly evenly throughout. The travel statistics are, however, more typical of European transit oriented cities. In the municipality of Gothenburg, some 25

percent of all work trips take place on public transport, but only 10 to 15 percent of work trips are by transit in the entire Gothenburg region. Some 50 percent of all long distance commuters use public transport. A strong preference for transit is also found in the circumferential trips; close to the central city, 35 percent of these trips are on public transport, while in the suburbs the fraction drops to 20 percent.

The population shifts have not significantly influenced the percentages of trips taken by public transport. This has been helped by the fact that between 15 to 20 percent of the population, including the fairly significant percentage of the population that does not own a private automobile, is dependent on transit.

The average work trip by transit is of approximately the same length as the average work trip by private auto, both peaking at 6 kilometers. However, the average travel time by private automobile is shorter than that by public transit, in spite of the system's coverage and efficiency. Average automobile travel speeds are fairly high in the region, ranging from about 35 to 50 kph on arterials and up to 70 kph on highways.

## STATISTICS OF THE TRANSIT SYSTEM

The light rail system of Gothenburg has 148 kilometers of single line, of which 72 percent is located in exclusive right-of-way (ROW), 7 percent in reserved lanes and 21 percent on streets. The goal is to have 92 percent of the system operating on exclusive or reserved lanes. Operating on these lines are 255 vehicles which are essentially modified PCC cars. The first of these vehicles was acquired in 1955 and the last one in 1972. The most recently acquired vehicles were built by the ASEA Company. It is expected that within the next 5 to 10 years the vehicle fleet will need replacement. A decision will have to be made, in the interim, as to whether the system should be retained or replaced by buses. Contributing to the pro-bus thinking is the perception that the cost of new light rail vehicles will be very high. Should a decision be made to replace the trams - as the light rail vehicles are being referred to in Gothenburg - with buses, it was felt that the current route and signalization schemes would be retained.\* There was little interest in considering electric buses as a replacement for the trams, mainly because of their higher cost compared with that of equivalent diesel-powered equipment. It is also unlikely, on the basis of the information received during the visit, that more advanced system technologies would be considered as a replacement for the light rail system. Up until 1972 advanced systems were under active consideration by Gothenburg planners. However, in that year the City Council decided to defer consideration of these technologies because of their high cost and technological uncertainties. The City Council also decided to defer any further consideration of rapid rail transit installations and to devote all major capital investment to improvements of the existing light rail system.

The transit system also uses 300 buses operating on 40 lines. Included in this number are 40 articulated Volvo buses operating on the mostly heavily traveled lines. The buses were quoted at 600,000 Swedish crowns per vehicle - equivalent to approximately \$150,000.

## SELF-SERVICE FARE COLLECTION

The Gothenburg transit system operates with self-service fare collection (SSFC); that is, boarding passengers are expected to have tickets and their access to the vehicle is not controlled.

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\* Considering the high cost of labor in Sweden and other possible costs associated with conversion, the LRT-to-bus replacement idea was more than speculation. Of course, mitigating factors such as the possible widespread use of high capacity buses could make the conversion more attractive. In any event, a decision to convert, if ever made, would be founded on comprehensive economic evaluations of all cost factors.

Tickets can be purchased onboard from the driver but cheaper multiple trip passes, available at kiosks located near some of the stations, are preferred by the majority of riders. Gothenburg's trams can be accessed only through the front and rear doors and, theoretically, the center door is to be used for exiting. Passengers who wish to buy tickets on the vehicle lose some of their boarding flexibility since they must enter at the front door. This, too, has helped reduce the purchase of tickets onboard. Ticket cancelling machines, for use only with tickets purchased from the driver, are rather simple affairs mounted on poles. The articulated buses can be accessed through all three doors, further accelerating passenger loading and unloading at stations.

The transit system employs some 10 to 20 roving fare control inspectors on all of its light rail and bus lines. The inspectors do not have police authority as employees of the transit agency. Payment of the fine from passengers found to be riding without tickets is essentially voluntary; the inspector has no authority of arrest. When a delinquent passenger refuses to identify himself or to pay the fine the inspector must find a policeman to collect the fine or make an arrest.

The transition from onboard sale of tickets by a conductor to sale by the driver was relatively smooth. The approach used was to retrain the conductors as drivers. Since drivers were in short supply, as their job is monotonous and the pay low, new employment could be easily found for the retrained conductors. Drivers, however, were dissatisfied with the change since their pay did not increase in proportion to their added responsibility of selling tickets.

## SECURITY AND VANDALISM

The trams and buses of Gothenburg are refreshingly free of graffiti. There are very few, if any, security problems on the system and where they exist they can be attributed to youngsters, particularly those residing in the newer suburban areas. On only one line, Line No. 8, did the transit agency find it necessary for a time to assign a police rider to the trailer car to control vandalism. The City, not the transit system, must pay the salaries and other expenses of policemen assigned to the transit system.

## SOCIAL WELFARE

The design and operation of the Gothenburg transit system is an excellent example of Swedish concern for social welfare. For instance, many traffic signal columns located at street corners are equipped with devices producing a ticking noise which changes frequency with the change of the traffic signal (Figure 1). The devices have been located to aid blind pedestrians in crossing intersections along certain preferred routes. On divided arterials this technique is further refined. The devices are installed on both sidewalks and the median; two devices are positioned at each location, to the right and left of the person crossing the arterial. The sound switches from right to left in accordance with the change of the signal cycle. A blind person reaching the median can thus tell whether crossing the second group of lanes would be safe.

Vehicle design also emphasizes concern for people in need of help. In addition to the usual seats reserved for handicapped, each vehicle has a specially reserved space for positioning baby carriages. Because it is difficult to enter the car with the carriage in a simple movement, a button is provided near the entrance of the vehicle to allow the adult to enter first, press the button to keep the door open, and then negotiate the baby carriage up and into the vehicle. Nowhere else on this tour of European LRT systems could so many mothers with children in baby carriages be seen riding transit vehicles.



Figure 1. Pedestrian Crossing for the Blind in Gothenburg

## LINE CONSTRUCTION

Most of Gothenburg's streetcar lines were built in the 1950s and earlier. In the 1960s construction concentrated primarily on the extension of Line No. 2 to the southwest, the construction of Line No. 8 and three other lesser line extensions. All of these lines were built on grade-separated or exclusive ROW. Line No. 8, built largely to pre-metro standards to qualify for national funding (as pointed out before), is the only major system addition made during the last 10 years. At the time of the trip the City was planning only minor line expansions needed to interconnect lines in order to improve the efficiency of operations and to reduce passenger loads on a heavily traveled line by creating a diverting loop. The new construction will be located entirely on city streets, in reserved lanes, with at-grade crossings and preemption signalling. New lines located on city streets require 7.2 meters of lane width to permit installation of dividers used to mark the boundaries of the tram lane. On some of the narrower streets, widths can be reduced to 6.2 meters, but the lane will be marked with striping.

A number of agencies are involved in a cooperative manner in all aspects of transit planning and operation. Decisions regarding planning and implementation of new transit investment are arrived at by a committee. Traffic Department representatives sit together with personnel from the City Planning Department, the police and the political representatives. The City's four major departments, traffic, planning, streets, and real estate are all involved in the planning and implementation of the traffic system. The Traffic Department is responsible for the operation of the system and its construction but not for trackage construction, which falls under the responsibility of the streets department. In addition, the City electrical department is responsible for the design and installation of the electrification and signals.

## DESIGN AND OPERATION OF INTERSECTION SIGNALS

There are 280 signalized intersections in Gothenburg; light rail lines traverse 80 of these intersections. At 70 intersections, traffic controllers have been installed to give trams priority over



private auto traffic. The remaining 10 intersections operate under a standard fixed traffic signal cycle approach because the existing street geometrics and traffic movements are too complex for priority signalization.

The application of traffic signal preemption and intersection control does not originate in Gothenburg; the concepts were first developed in Holland and in Germany and were then adapted for use in Gothenburg.

The first preemption installation dates back to 1972. There are no fixed ground rules for deciding when an intersection controlled by fixed cycle traffic signals is to be converted to a light rail preemption system. In general, these decisions are made on a case-by-case basis and often as a result of a cost-benefit analysis. It has been possible to show that the safety at intersections increases when the preemption system is introduced. Since most preemption installations are found at intersections where light rail routes negotiate turns, it has been observed that the increased red time given to opposing automobile movements has had a tendency to reduce conflicts and has contributed to smoothing of movements through the intersection. It has also been observed that a preemption system will disrupt the routine movements through an intersection and cause drivers to be more alert to changes in traffic signals. It is less likely that the habitual driver will be able to predict with accuracy the timing of the cycles and as a result will drive more carefully.

As the number of intersections equipped with preemption signals proliferated, it did not create unusual traffic congestion. This is due in part to the traffic volumes on most of the streets with light rail. Although some of the routes run on streets carrying up to 40,000 vehicles per day most of the lines operate on streets carrying less than 20,000 vehicles per day. In this country a vehicular volume of 10,000 vehicles per day is often cited as the dividing point between a rail surface line and grade separation. The successful operation of the system in Gothenburg presents evidence to the contrary. However, this must be seen from the perspective of Gothenburg's public accustomed to living in an urban environment that has always contained streetcar lines operating in mixed traffic. The drivers' willingness to adapt to the inconvenience created by preemption can be attributed, in part, to this prior conditioning. City officials were not certain that similar success would have been experienced had a brand new system been installed in an area which did not have a prior streetcar system.

The preemption system is designated to have minimum impact on parallel vehicular flows. On a statistical basis it can be shown that 60 percent of the signal cycles during which preemption takes place occur during the normal green, thus minimizing the impact on vehicular flows. This observation would be true mainly in cases where the traffic on the cross streets is light compared to the traffic volumes on the street traversed by light rail. It is estimated that only 10 percent of all travel time is lost at intersections because of red lights; the priority system, therefore, causes only a fraction of the delay. Since at Gothenburg, more than 80 percent of the track mileage is reserved, i.e., automobile traffic is prohibited in the light rail lane or on exclusive ROW, the vehicles operate at near optimum conditions even without preemption signals.

The preemption system is activated through the overhead wire (Figure 2) or by magnetic detectors (Figure 3) installed in the roadway. Detectors are usually located some 170 to 250 meters ahead of the intersection. If detection occurs at a specific point during the cycle of the traffic signal the normal cycle will be modified giving the light rail vehicle, in most cases, priority over conflicting private vehicular traffic.<sup>2</sup>

Few serious accidents have been attributed to light rail vehicles intercepting pedestrians or automobiles in intersections. Figures 4, 5 and 6 show the safety record at three intersections of fairly complex geometric design carrying medium to heavy automobile traffic. Where accidents are recorded they average about one per year. Foreign object detectors are not used as an added

safety feature; reliance is placed on providing an adequate line of sight on the approach to the intersection. Closer to the intersection, special visual signals, usually a simple light mounted on a post close to the track indicate the condition of the signal controlling opposite traffic. As the vehicle enters the intersection another detector is activated, cancelling the preemption and returning the signals to their normal cycle.



Figure 2. Overhead Detector used in Gothenburg

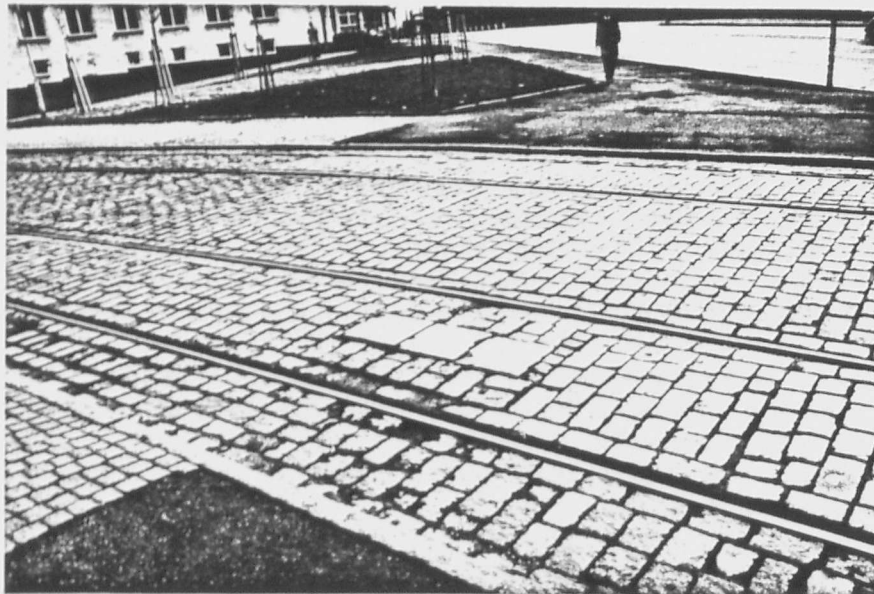


Figure 3. Magnetic Loop Detector used in Gothenburg

**LEGEND:**

- |                   |                    |
|-------------------|--------------------|
| $\frac{250}{210}$ | AM PEAK HR TRAFFIC |
| $\frac{210}{250}$ | PM PEAK HR TRAFFIC |
- 
- LRT Track
  - ▨ LRT Station
  - ▨ Pedestrian Crossing
  - △ 1975 Accidents
  - 1974 Accidents Without Injuries
  - 1974 Accidents With Injuries
  - ◇ 1973 Accidents

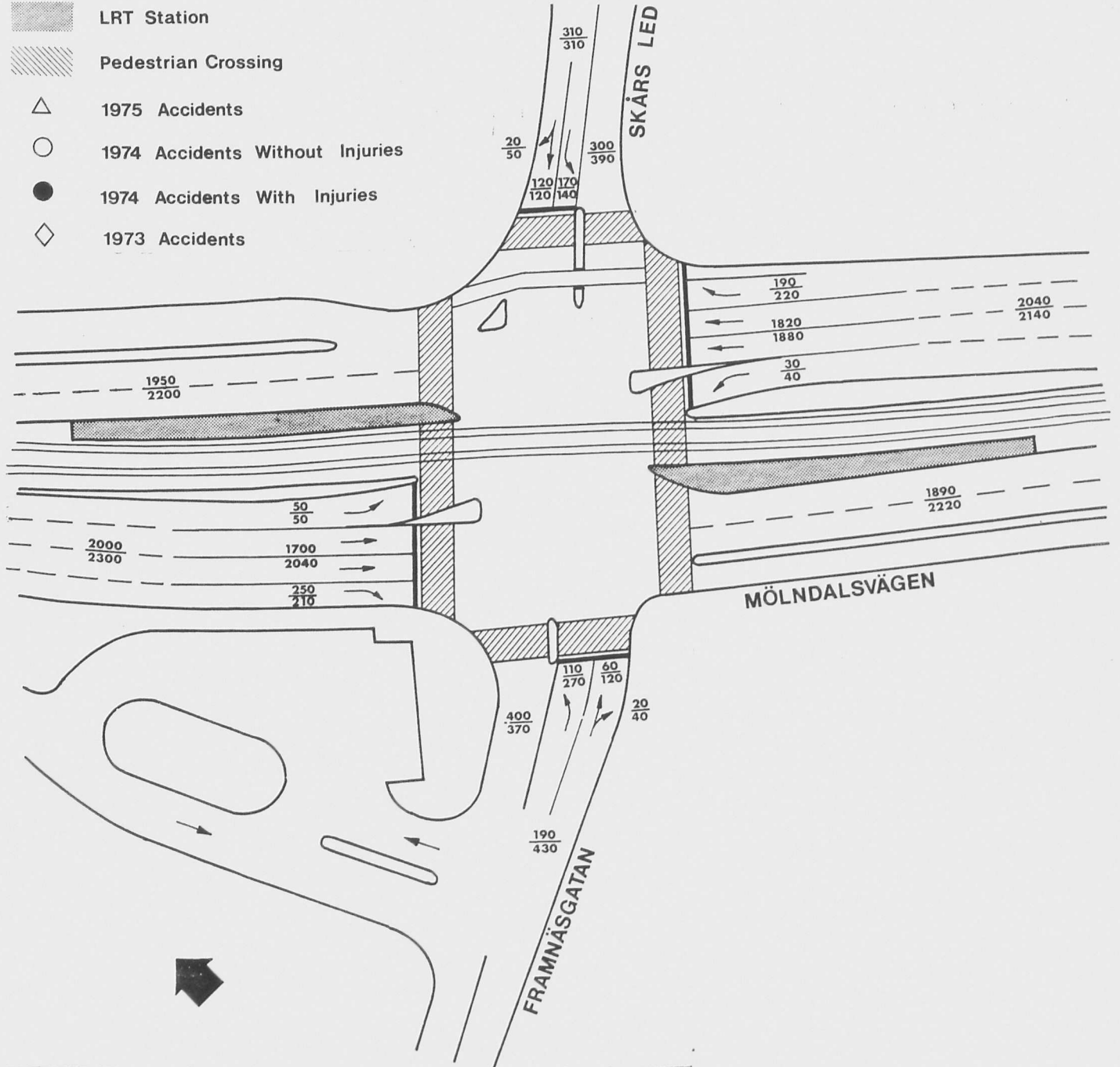


Figure 4. LRT Intersection Geometrics, Traffic and Safety at Mölndalsvägen and Skars Led in Gothenburg (No Accidents 1973-1975)

**LEGEND:**

- |                   |  |
|-------------------|--|
| $\frac{230}{210}$ | AM PEAK HR TRAFFIC<br>PM PEAK HR TRAFFIC |
|                   | LRT Track                                |
|                   | LRT Station                              |
|                   | Pedestrian Crossing                      |
|                   | 1975 Accidents                           |
|                   | 1974 Accidents Without Injuries          |
|                   | 1974 Accidents With Injuries             |
|                   | 1973 Accidents                           |

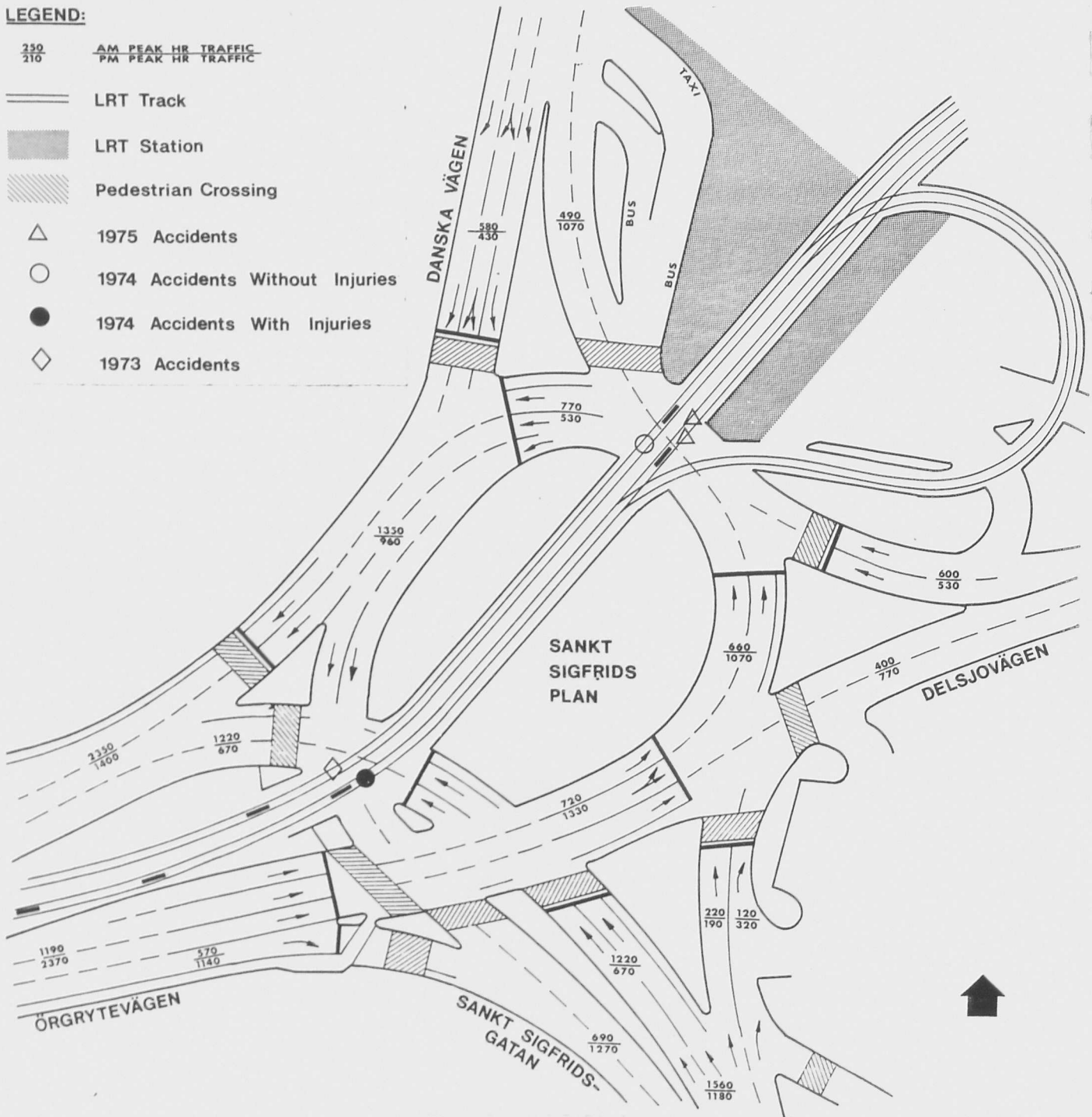


Figure 5. LRT Intersection Geometrics, Traffic and Safety at Sankt Sigfrids Plan in Gothenburg

**LEGEND:**

- |                   |                                 |
|-------------------|---------------------------------|
| $\frac{250}{210}$ | AM PEAK HR TRAFFIC              |
|                   | PM PEAK HR TRAFFIC              |
| —                 | LRT Track                       |
| ■                 | LRT Station                     |
| ▨                 | Pedestrian Crossing             |
| △                 | 1975 Accidents                  |
| ○                 | 1974 Accidents Without Injuries |
| ●                 | 1974 Accidents With Injuries    |
| ◇                 | 1973 Accidents                  |

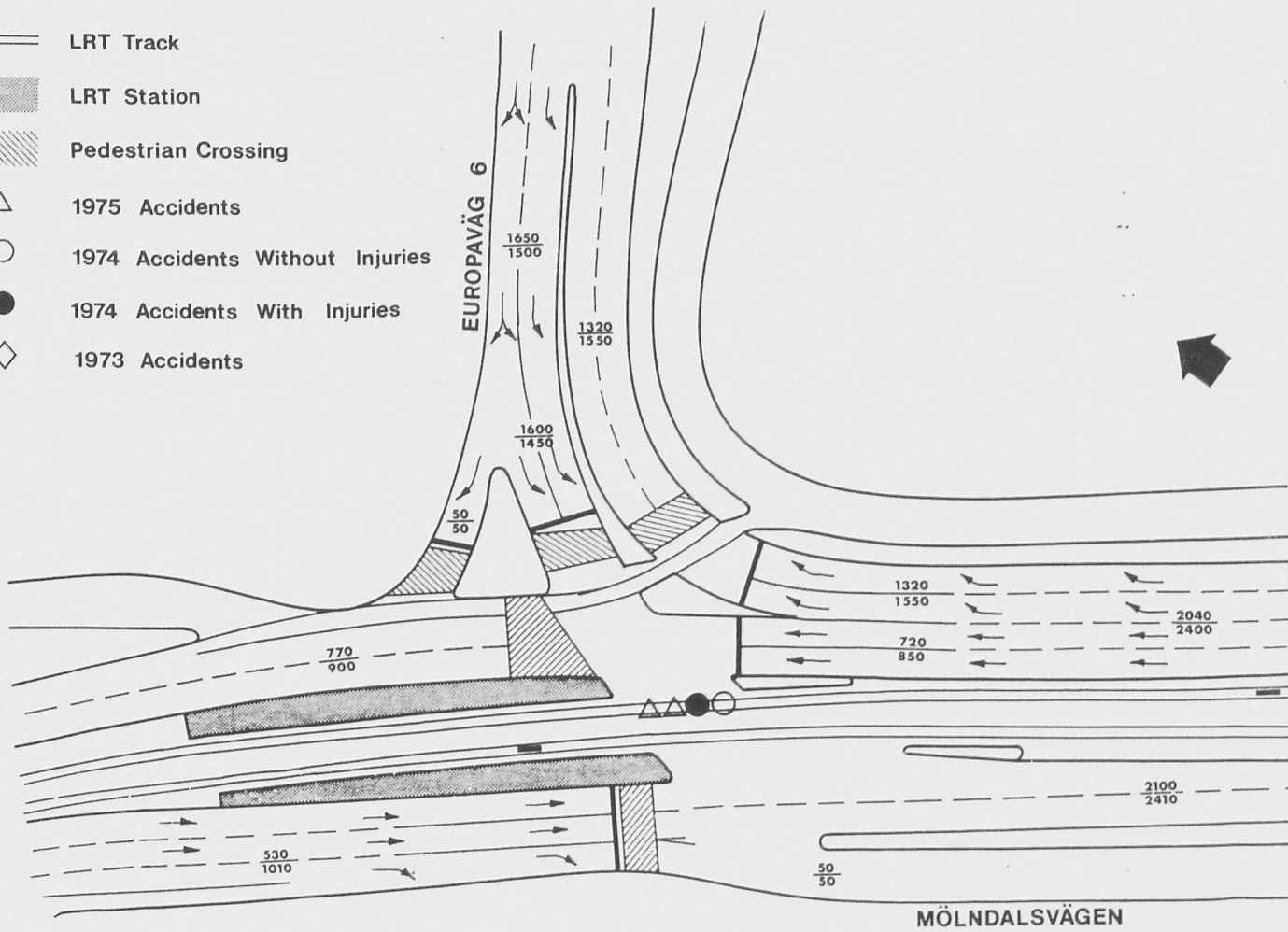


Figure 6. LRT Intersection Geometrics, Traffic and Safety at Molndalsvagen and Europavag 6 in Gothenburg

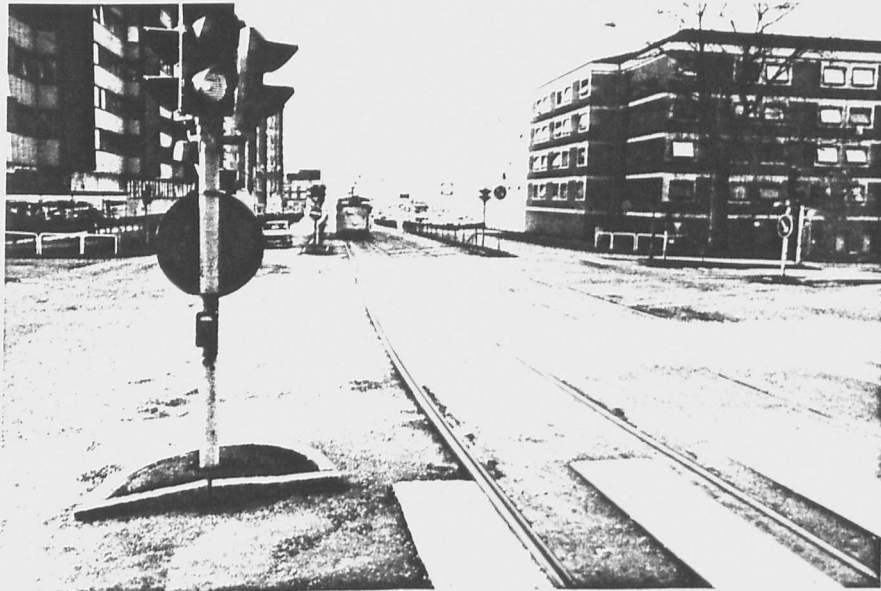
To the visitor, it appears that the system works remarkably well in the very crowded conditions existing on most of Gothenburg's narrow streets. This is due, in great measure, to the careful design of the light rail ROW, sidewalks, parking provisions and pedestrian handling. I did observe one intersection on a fairly busy thoroughfare where conflicts could arise during turning of parallel bus and light rail lines which operate under separate priority systems. While the traffic department recognizes this to be an unusual problem area, there have been no accidents at that intersection in the three to four years since the installation has been in operation.

## STATIONS

As a rule, stations are of simple midstreet platform design. Exceptions are found mainly at the suburban ends of lines where stations are integrated with shopping/residential developments (Figure 7). The stations built on Line No. 8 to pre-metro standards are the most notable exceptions to the low cost station concept (Figure 8). Most travel time delays occur at station stops. Self-service fare collection helps reduce these delays. Beyond that, proper station spacing consistent with traffic conditions on streets will help keep delays to a minimum. It has been estimated that with a station spacing of approximately 400 meters the best speed, approximately 20 kilometers per hour, could be achieved on reserved ROW assuming minimum delays during loading and unloading. This is considered to be near optimum. However, the location of stations can rarely be controlled within the parameters which would lead to the best operation of the system. As in every detail of the Gothenburg transit system, local conditions such as street width, traffic volumes, pedestrian volumes, and the type of activity - commercial or residential - on the street indicate the station design choice. One cannot observe a definite pattern for station locations relative to intersections. Where the local conditions give the planner some latitude, stations are located on the downstream end of the intersection allowing the light rail to take advantage, in most cases, of the priority given to it and traverse the intersection at fairly high speed. However, station platforms are often seen located upstream of intersections or directly opposite each other, suggesting that only one direction is favored by the platform location.



Figure 7. Suburban Station Integrated with Commercial and Residential Development



**Figure 8. Station on Line No. 8 Designed to Meet Pre-Metro Standards**

An example of ingenious station platform design is extension of the sidewalk into the street, beyond the limit of what might normally be a parking or a moving lane and right up to the light rail tracks, to provide a peninsula for passenger loading. This has the effect of physically blocking off automobile traffic behind the stopped streetcar. Automobile traffic can only proceed in the streetcar lane after it has cleared the platform. Obviously this design is only found on streets with fairly light local traffic.

## RELIABILITY AND LIABILITY

Schedule reliability of the system was admittedly not good. The drivers' operating rules are fairly lax. There are no speed restrictions when weather or falling leaves cause the rails to be wet or slippery. There are some restrictions on operating speeds, particularly at switches and around certain curves. Basically, however, the driver is only required to observe a timetable for reaching the end of the line at a prescribed time. He may speed up or slow down at will during the run, often creating bunching of vehicles. Although preemption has been used for the last three to four years, the schedules in use were ones in effect before the system was upgraded.

The entire system is geared to visual control signals only; there are no cab signals provided. All preemption controllers are of the rugged relay type and therefore quite reliable. An electronic version of the same device is available but there appears to be no intention to convert to its use because of concerns about its reliability. Some thinking, devoted to the next possible step in the technology of the preemption controllers, is focused on the use of micro-computers for intelligent control of complex intersections (i.e., intersections carrying several light rail lines, possibly some bus lines and heavy conflicting auto traffic). Again, because of concerns with equipment reliability and with the expense for the large number of detectors required, there appeared to be little enthusiasm for this sophistication in control equipment. At one intersection, however, a micro-computer is being used, but mainly in an experimental way; at the time of this trip it was too early to assess its true potential.

The concept of transit liability in Sweden is also an interesting one, particularly when contrasted with jurisprudence in this country. Stemming from a basic philosophy which is fundamentally pro-transit, it is felt in Sweden that since the railbound vehicle has little latitude in maneuvering it is the obligation of the private driver and pedestrian to stay out of the way. In case of an accident, the initial presumption is that the light rail vehicle is not at fault. To date, the City of Gothenburg has experienced no particular liability problems as a result of the operation of the preemption system. While Gothenburg is reexamining its basic insurance policies and moving toward the adoption of a catastrophe-type policy which would cover it in case of major accident or disaster, no thought appears to be given to protecting the City against special liability problems arising from the normal operation of its light rail system.

## GOTHENBURG TRAFFIC ZONES

As it is well known, remarkable reduction in the downtown traffic congestion has been achieved at Gothenburg by the creation of zones in which automobile through traffic is excluded. Only transit is allowed to penetrate these zones; all other traffic is diverted. The success achieved in the first project and the public acceptance of the traffic restrictions have encouraged the City to continue planning for expansion of the concept to other areas surrounding the CBD. The City Planning Department takes advantage of this opportunity to carefully redesign and improve the trackage, stations and general operation of the light rail system through these areas. In preparing an area for restricted auto use, minor streets are often closed off but care is taken to provide access to each home through at least one entrance. The very detailed plans being carried out for this next expansion of the auto-free zone system represent an excellent example of careful application of traffic engineering practice to very difficult geometric conditions.

## FIELD OBSERVATIONS

The visitor's prevailing impression is the great variety of design configurations that are used, side by side, on narrow streets and on wide arterials to extract the last possible degree of improvement in the operation of the old streetcar system. Driving along the same line one sees it weaving from one side of the street to the other in order to gain the best advantage for vehicle operation. Later the route traverses ROW which is sometimes shared with automobile traffic when conditions make it impossible to keep the private vehicles off the track (Figure 9). Later still, sections of route run between high dividers installed to exclude automobile traffic and lead, eventually, to sections which run in median on ballast in the manner of conventional rail and through intersections which are always paved.

The design of preemption controllers at intersections is equally varied and carefully keyed to the existing local conditions. On one line one will see preemption operating at a simple intersection of a street carrying fairly light traffic with a heavily traveled arterial, where the median contains the light rail line. A few hundred yards away, on the same line, the preemption design may be adapted to an intersection involving heavy vehicular movements turning across the track of the light rail line (Figure 10).

In one location, at Brunnsparken, preemption technology has been coupled to a rather sophisticated system of pedestrian crossing signals. The crossing signals can be activated either by the light rail energizing induction loops located in the ROW or by parallel auto traffic activating a different set of induction loops emplaced on the pavement. This installation is located at a pedestrian crossing carrying approximately 3,000 persons in the peak hour and had been operating, at the time of the trip, for almost one year without an accident. The City conducted a fairly sophisticated study of the pedestrian and vehicular movements in this crossing, using video cameras to record all movements. The success of the installation has convinced them to expand it to other locations with heavy pedestrian traffic.





Figure 9. Line No. 3 Right-of-Way, Gothenburg



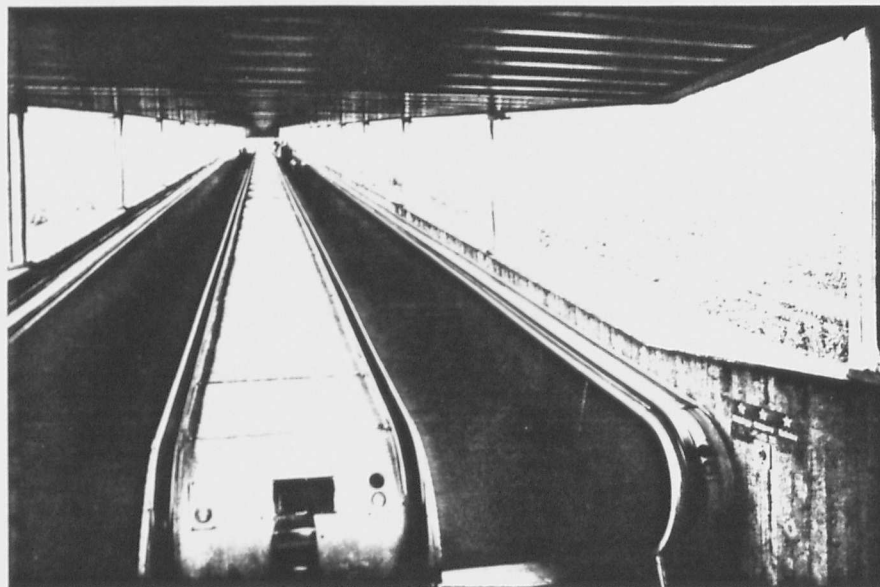
Figure 10. Intersection with Large Automobile Turning Movement Volumes

Line No. 8 is the most recent of the light rail lines built in Gothenburg and it is largely constructed to pre-metro standards. At the moment the line is not interconnected with the rest of the Gothenburg system and may be likened more to a suburban commuter line than to typical light rail service in the City. The line is constructed on an abandoned rail ROW and, because of the wide spacing of the stations, it operates at fairly high speeds. It traverses a tunnel for

approximately one mile and terminates in one of the northeastern suburbs. The end of the line is located in one of the largest apartment complexes found in the area. The station design at that point as well as at least one additional location, is clearly of pre-metro type. Because of the unrealized increase in northeast suburban population, the expected passenger volumes at the stations have obviously never been met. These stations are typical of others in the region such as those on Lines Nos. 6 and 7 (Figure 11) where extensive metro-type construction was also undertaken to provide easy station access from apartment complexes located some distance away and at a different elevation. Inclined walkways, escalators and elevators have been provided to facilitate station access and promote transit travel (Figure 12).



**Figure 11. Station Integrated with Residential Complex**



**Figure 12. LRT Station Escalators**

Line No. 8 proceeds through a tunnel which is carved out of solid rock. The tunnel walls are unlined but are sprayed with concrete and equipped with plastic drain pipes.

A station built in the tunnel features one of the deepest escalators in Sweden and other special facilities such as elevators for handicapped persons and for baby carriages.

As the line approaches Gothenburg it switches from two to single track configuration with bypasses provided for trains moving in the opposite direction. The trains negotiate the bypass at high speed and the line eventually terminates at the railroad station in Gothenburg.

## SUMMARY OBSERVATIONS

Undoubtedly an important factor in explaining the successful upgrading of the Gothenburg streetcars into the current light rail system is found in the prevailing pro-transit attitudes of the Swedish government and Swedish law. The support of the public at large and its willingness to accommodate to changes brought about by proliferating preemption treatments are also important factors.

The funding split, between the National Roads Agency for capital investments and the City for operating deficits, explains not only the recent developmental history of the system but also current attitudes. The criterion applied by the National Agency for determining the acceptability of plans for capital funding, provided they meet metro standards, is an important factor in the current debate concerning the future of the light rail system.

Demographic forces, economic changes brought about by the international recession and the growing trend toward suburban living may bring about, in the long run, the same transit system survival problems that are common in this country. However, the success of the traffic zone system will prove an impetus to their expansion beyond the CBD, and will call for continued intensive use of public transit.

The Gothenburg light rail system is an efficient and safe form of transit the effectiveness of which is based on the solution of the complex problems it must circumvent on the City's streets. It is difficult to imagine how the system might have evolved toward its current state of operational effectiveness without the acquiescence, if not the active support, of the Gothenburg people. This element of popular support, given the urban characteristics and lifestyles of Gothenburg, appears to be the essential ingredient for the successful conversion of streetcar systems to light rail standards.

## DUSSELDORF

The Dusseldorf visit began about mid-morning on Wednesday, November 10, 1976. The trip from the airport to the city central railroad station can be made by a shuttle rail connection operated by the Bundesbahn, providing frequent connections from the heart of Dusseldorf right into the airline terminals at the airport. The principal contact was Mr. W. Jahnichen, who directs the Gesellschaft für Verkehrs- u. Betriebsplanungen von Stadschellbahnen u. anderen Personen-Verkehrsanlagen mbH, a business branch of the Rheinische Bahngesellschaft A.G., Dusseldorf's transit agency. Mr. Joachim von Rohr, head of the Rheinische Bahngesellschaft shops and Mr. Leveringhaus, an aid to Mr. Jahnichen, were also present at the initial meetings. Mr. Jahnichen's firm is empowered to deal with foreign visitors and business. The firm's staff was most

accommodating in devoting their time and effort to answer questions and conduct visits on various lines of the Dusseldorf system.

During the afternoon of November 10th and the following days, November 11th and 12th, a number of people participated in our discussions and provided valuable data and observations on the makeup and operation of the Dusseldorf light rail transit system. Many thanks go to Mr. von Rohr, who conducted a field inspection and an extensive meeting at his offices; to Mr. Leveringhaus, who provided considerable background on the Dusseldorf system; and to Mr. Martin Bahr, a traffic engineer on Mr. Jahnichen's staff. In addition, Mr. Helmut Viergutz and Mr. Herbert Rodgers of the Dusseldorf transit system conducted a field trip during a wet afternoon, patiently describing the operations of their signal systems.

While the discussions in Dusseldorf were as extensive as those in Gothenburg, they tended to concentrate more on the practical aspects of designing and operating the system and less on the general planning details of the Dusseldorf metropolitan area. In the extensive system of trams at Dusseldorf, only two lines qualify for the designation of light rail. Both lines are suburban, one extending to the west to the City of Krefeld, the other to the north, to the City of Duisburg. A massive effort is under way now, in the center of Dusseldorf, to place a number of streetcar routes underground, including the extension of the Krefeld and Duisburg lines into the City. When this project is completed, some years from now, a larger fraction of the Dusseldorf system will be categorized as light rail. In the meantime, there is some confusion of nomenclature as the entire streetcar and light rail system are operated by the Rheinbahn, making it difficult to distinguish between streetcar and the operations more appropriately described as light rail. The project for underground placement of certain lines is referred to as U-Bahn, thus giving the impression that it is a transition from a surface, streetcar type operation, to an underground conventional rail rapid operation. This is deceptive, as the intent is to upgrade the transit system, but the large capital expenditures of the project are quite comparable with investments made in rail rapid transit.

The Dusseldorf system is one of the oldest and most extensive installations in West Germany. It has recently celebrated its centennial but for all practical purposes, it is a system which dates back to 1945. In March of 1945 the destruction of the system caused by Allied bombings was so extensive that service was suspended. Following the end of hostilities extensive reconstruction began almost immediately, proceeding at a rapid pace which allowed streetcar service to be resumed as early as October 1945. Since then there have been continuous improvements made to the system, particularly line extensions and enhancement of operations through the installation of preemption traffic signal controls at many intersections. The most dramatic change to the system, however, is now in the offing with the construction of its first underground segment. In that aspect, Dusseldorf is merely adopting the practice of several of the larger West German cities (Cologne, Hannover, etc.) which have already placed portions of their streetcar operations underground.

## DUSSELDORF SYSTEM

The system of light rail and buses operated by the Rheinbahn is quite extensive. The agency operates 20 rail lines; two are suburban, high-speed light rail; the other 18 are conventional streetcar operations. There are also 24 local bus lines and 30 suburban bus lines. Table 1 shows other statistics that are helpful to gaining a picture of the system's extent.

The light rail service operates at fairly low frequency, not less than seven minutes between trains. Generally not more than two lines share the same route although exceptions can be found. As a result, minimum headways are fairly large. Because of the extensive networking of lines in the central part of the City, it is possible to keep the frequency of trains fairly low and still provide a

**Table 1. System Characteristics**

	Total Line Length		Average Speed		Average Station Spacing	
	Miles	(km)	MPH	(km)	Feet	(m)
Local Streetcars	67	(108)	11.7	(18.8)	1581	(482)
Suburban LRT	29	(47)	18.2	(29.3)	3996	(1218)
Local Buses	115	(185)	14.3	(23.0)	1542	(470)
Suburban Buses	278	(448)	17.2	(27.7)	2329	(710)

Source: Informationsbuch der Rheinischen Bahngesellschaft AG Dusseldorf, 12/31/75

**Table 2. Operational Statistics**

	Passengers (Millions)			Vehicle km (Millions)			Passengers per Vehicle km		
	1973	1974	1975	1973	1974	1975	1973	1974	1975
Local Stations	116.9	113.8	115.6	18.8	18.3	18.0	6.22	6.22	6.47
Suburban LRT	5.98	5.84	7.05	2.1	2.0	1.9	2.83	2.9	3.69
Local Buses	34.4	40.2	49.8	9.7	10.4	13.0	3.53	3.85	3.81
Suburban Buses	36.86	36.95	42.66	13.9	14.1	12.7	2.65	2.62	3.34

high overall level of service. With certain exceptions - in the center of the City, at the Jan Wellem Platz, on the Berliner Allee and its extension Cornelius Strasse, on Graf Adolf Allee and the area around the central railroad station - traffic on the streets traversed by the light rail system is fairly low, thereby facilitating automobile traffic preemption and enhancing the operation of the trams. Maximum speeds on the various streetcar lines, as stated in the driver's operating manual, are fairly high ranging for the most part from 40 to 60 kilometers per hour (Figure 13) but averaging in the City from 25 to 30 kilometers per hour when stops are included. Because much of the streetcar is on reserved ROW, with the exception of those routes traversing the busiest portions of the CBD, the transit system enjoys an advantage over private automobile traffic. The latter has been clocked at as low as 5 to 10 kmph at the peak period on the most heavily traveled streets. The suburban lines, lines K and D, operate over most of the route at speeds of 50 kilometers per hour and higher. Their average speeds are considerably higher than the trams since stations are spaced farther apart and all intersections are signalized with preemption systems (outside the immediate center of town).

At the moment, there is little expansion work on the system except on new streets wide enough to permit the inclusion of a reserved ROW. Most of the construction emphasis is placed on the current U-Bahn project for interconnecting the suburban lines with the surface distribution system. The construction of the U-Bahn type tunnel is described as an element of the City's future rapid transit network. This project does not have the unqualified support of the local transit operators and planners as it is based, in part, on political decisions.

The U-Bahn project is structured in three phases. In the first phase, the interurban D lines will be taken underground for a portion of the distance toward the central railroad station. In the second phase, the connection with the central railroad station will be made as well as other extensions including one with the K line. The cost of the first and second phases has been estimated at approximately 1.5 billion D.M. (approximately \$.63B). Included in this budget are funds for 105

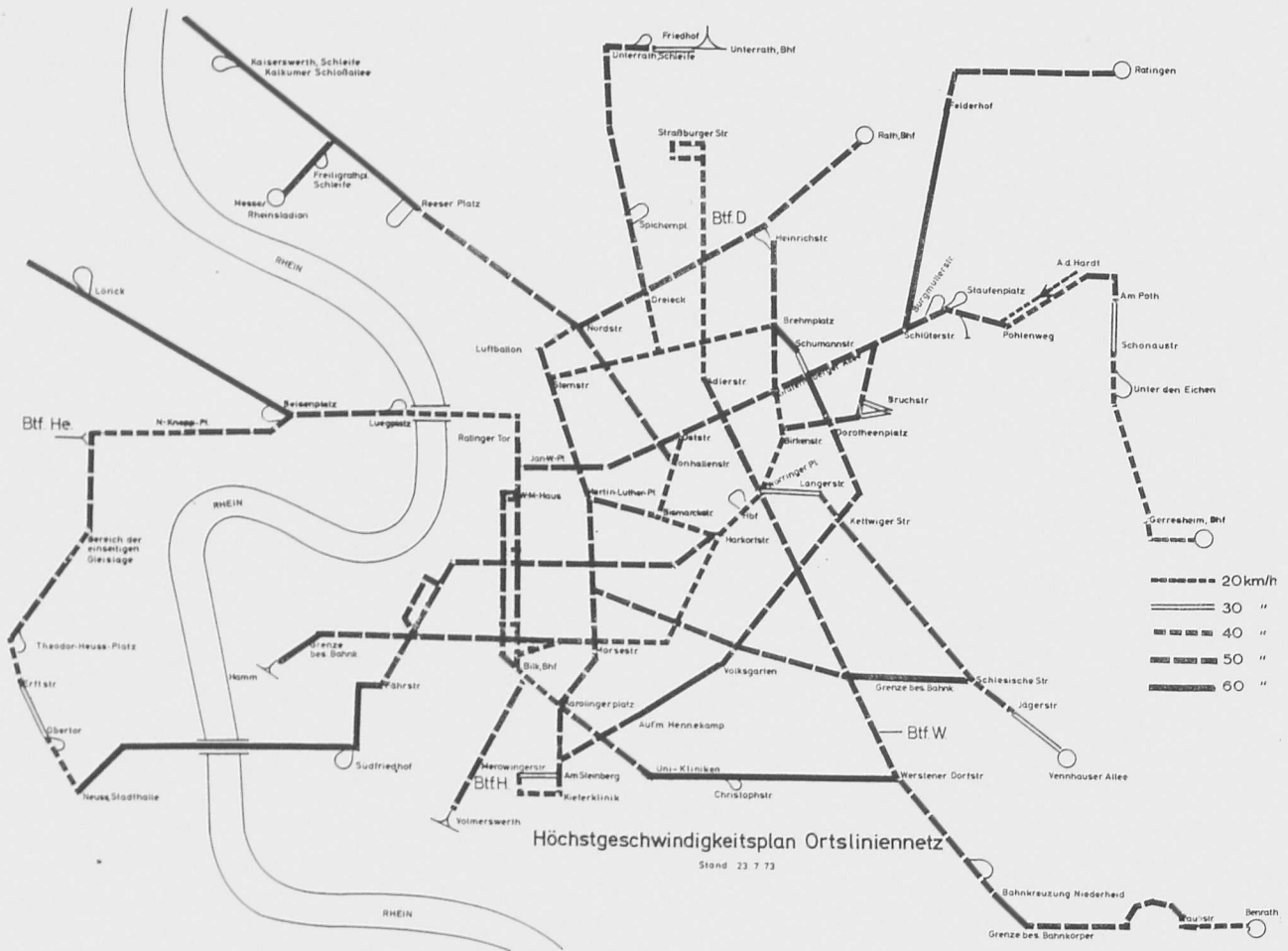


Figure 13. Dusseldorf Transit Line Maximum Operating Speed

vehicles of the Cologne B-type, estimated now to cost 1.5 to 1.6 million D.M. (approximately \$.65M) per vehicle. The kind of transit service to be provided on the new underground lines falls in the pre-metro category. Some very expensive stations are contemplated, such as the stop at the Heinrich Heine Allee which is forecasted to cost in excess of 100 million D.M. (approximately \$.42M).

The decision to select the Type B vehicle\* for the new installation is, in part, manifestation of a design trend to replace the current narrow vehicles with cars that are more comparable in width with those used in metro installations. Of course, the wider cars will only be able to operate on those routes with sufficiently wide ROW.

\*The B-type vehicle is different from the LRT vehicles now used on Dusseldorf's suburban lines in the following way:

	Width (m)	Length (m)	Empty Weight (kg)	Max. Speed (kph)	Passenger Capacity
Current Vehicle (8 axles, 4 elements)	2.4	26.14	35,000	70	515 + 174 stdg.
Type B Vehicle (6 axles, 2 elements)	2.65	28	39,000	100	725 + 111 stdg.

The newest LRT cars in operation at Dusseldorf are the red and white vehicles running on the suburban lines and also on some of the city lines. They are 8-axle, double-ended, articulated units manufactured by DuWag which are similar to the P-8 vehicle operating in Frankfurt except for some minor cosmetic modifications. On the suburban lines, these vehicles operate in trains of two providing a capacity of 225 passengers per car or 450 passengers per train. The vehicles look very modern and their interiors are quite different from traditional streetcars. The seats are upholstered, there are little window trays on which purses or packages can be placed; and on the D line cars are equipped with small canteens and a few tables where snacks can be consumed during the fairly long ride from Duisburg to Dusseldorf. These vehicles not only look good but they provide an exceedingly smooth ride, particularly on the welded rail used on the suburban lines. The traction control, which is supplied by Siemens, contributes to the smooth ride. This device is a contractor type control assisted by a solid state logic circuitry box stored under one of the seats for easy maintenance access. Braking is extremely smooth and is provided by the usual dynamic brakes supplemented by two motor-actuated, spring applied brakes, 8 electromagnetic track brakes and one solenoid brake.

Maintenance people are somewhat disenchanted with the vehicles. It appears their beauty is only skin deep; maintenance crews object to the increased maintenance required, compared to the older yellow cars which comprise the bulk of the Dusseldorf system, by their many sophisticated braking, heating and control subsystems.

## AT-GRADE INTERSECTIONS AND DESIGN PROCESS

The design of at-grade intersections for light rail transit is governed, in Germany, by a complex of regulations, standards and ad hoc decisions. For instance, the design of railroad crossings is governed by certain guidelines, originating with the Bundesbahn, which can be used to decide on the need for grade separations based on the speed and frequency of the rail service and the volume of private traffic on the conflicting surface streets. Of all the existing guidelines concerned with grade crossings, the Bundesbahns are considered to be the stiffest. For light rail crossings on suburban lines, guidelines derived from private railroad practice, *Vorschrift fur die Sicherung der Bahnübergänge bei nichtbundeseigenen Eisenbahnen (BUV NE), 1974*,\* can be used. These guidelines dictate the type of signals to be used, the positioning and type of barrier to be used, the required lines of sight, etc. While the Rheinbahn has applied these guidelines to some of the intersections on the K line, most of the crossings on this line reflect ad hoc design decisions. The line is located in abandoned railway ROW which pre-existed the adoption of the guidelines; use of the guidelines was, therefore, not mandatory.

For intersections which are governed by neither Bundesbahn or BUV NE guidelines, decisions for grade separation are arrived at on an ad hoc basis made usually by joint working groups including the representatives of the Transit Agency, the City Traffic and City Construction Departments. Local police representatives have an overview of the decision process but are not generally involved. The overall design of the intersection and general operational details of the light rail system must meet the national guidelines, BOStrab, developed by the VOV: *Verordnung über den Bau und Betrieb der Strassenbahnen, 1965*.\*\* This document spells out dimensional requirements for clearances as well as operating and maintenance factors. In addition, the design of LRT ROW, trackage, electrification, and other system elements is governed by an extensive set of published standards which are updated continuously as frequent changes are made. For example, signalization on light rail lines is governed by *Rechtlinien für den Bau und Betrieb von Lichtsignalanlagen im Strassenverkehr*.\*\*\*

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\*Specifications for the Safety of Crossings of Non-Federal Railroads.

\*\*Regulations for the Construction and Operation of Streetcars.

\*\*\*Guidelines for the Construction and Operation of Traffic Signals in Street Traffic.

Overseeing the entire process of design is the Technische Aufsichts Behörde, (TAB), an institution comparable to the Public Utilities Commissions in this country. The TAB checks all plans and must approve them for conformance with prevailing standards. The TABs circulate the plans and seek comments from municipal and other agencies. At times, exemptions are granted from the prevailing standards.

Some of the LRT operators believe that the existing guidelines are not sufficiently explicit regarding the safety of at-grade intersections. Unofficial opinions are that new light rail systems using high speed and frequent service should be grade separated at intersections that carry 2,000 cars per hour or more. Even at a volume of 1,000 cars per hour, the attendant safety problems inherent with high-speed light rail operations should be considered in making the decision to grade separate.

## SIGNALS AND PREEMPTION

In Dusseldorf, a number of intersections traversed by LRT lines are equipped with traffic signal controllers which extend the green phase or shorten the red phase in order to give priority to approaching transit vehicles. An extensive study carried out by the City Traffic Department in the late 1960s developed detailed designs for most intersections providing for the activation of traffic signals in favor of light rail, thus improving transit operations. It is believed that overall traffic safety is improved as well. In addition to the customary signalization schemes which block oncoming or conflicting light rail and automobile traffic at various turnouts, most intersections are equipped with detectors located in the power distribution wire which, under certain conditions, may cause the normal signal cycle to be changed to give the light rail vehicle several seconds advantage over private automobiles. The signals operate on a fixed cycle which contains a reserve phase that is available for preemption when activated by a streetcar approaching the intersection. If successive light rail vehicles approach the intersection at the right time in the cycle, preemption will continue to be given to transit no matter how many cycles would be so affected. However, there exists no absolute preemption (i.e. stopping conflicting traffic whenever a tram approaches an intersection) in the system as it currently operates. An exception will be made when the first segment of the underground network is opened. At one location, light rail vehicles will be required to traverse several lanes of automobile traffic upon leaving a tunnel. High volumes of passengers are expected on the line as it will serve a sports arena. For this unique installation absolute priority will be provided even at times of peak service when trains are expected to run at 90 second headways.

With one exception, buses do not enjoy the advantages of a preemption system. At the Jan Wellem Platz, where buses share the streetcar ROW, a photocell which is activated by the bus is used to preempt private automobile traffic.

In the future, as the wire detectors are replaced with magnetic detectors embedded in the pavement, the possibility exists that preemption procedures will be extended to buses in general. The traffic signals in the City are interconnected into two major networks operated by computers, but there exists no transfer of intelligence to adjust signals in response to traffic disturbances which might be created by preemption.

Dusseldorf's most sophisticated application of traffic engineering techniques to speed up the operations of streetcars is found in the so-called *green wave or progression approach*. In this technique, light rail stations are located relative to intersections to take maximum advantage of the progression of "greens," enabling the transit vehicle to attain speeds comparable to those of the parallel automobile traffic. Normally, because of station stops and intersection delays, light rail speeds are much lower than average speeds of automobiles in parallel lanes. To overcome this effect, stations are located in patterns of three. In such a pattern the first station is located



upstream of an intersection allowing the train to traverse it at a suitable green signal. The second station is typically located downstream of the next intersection which would be traversed by the vehicle moving along with the green progression. There would be no station at the third intersection, and finally at the fourth intersection the third station would again be located upstream of the traffic light. Here, the vehicle might be delayed until the next green phase, but it would have had a reasonable chance of traversing the intervening intersections in step with parallel automobile traffic.

Matching the progress of the light rail vehicle to the advance of the green wave obviously depends on careful control of station stop delays. The stops are programmed from a minimum of 10 to 20 seconds up to a maximum of 20 to 25 seconds. Included in these delays are allowances of three to four seconds for door opening and three to four seconds for door closing which insures that no passengers are trapped in the door prior to departure. This range of station dwell times is maintained at almost all stops except at the busiest stations in the center of the City, such as at the Jan Wellem Platz where significantly longer passenger loading time must be accommodated.

A good example of a route operating under a green wave procedure is found on Cornelius Strasse. There, the green wave technique is used over a distance (2-3 km) covering 8 intersections. Preparation of the route for the high speed light rail operations necessitated some improvements in geometrics; the ROW is partially reserved and is striped to prevent access by unauthorized vehicles. The street carries fairly heavy traffic even on Saturdays (when the visit was made). At one end of this portion of route, at the intersection with the Oberbilker Allee, significant conflicts may arise with automobile traffic (Figure 14). Several light rail lines traverse the intersection making both right and left turns. A fairly complex traffic control system is in effect interconnecting light rail and automobile traffic signals to insure safe operation of turning vehicles. During peak hour, up to 17 trains traverse the intersection in various directions, thus creating one of the operationally most difficult points in the Dusseldorf system. Even more complex traffic control conditions arise at the Jan Wellem Platz, but there part of the automobile traffic was grade separated by construction of a vehicular overpass.

It was felt that additional improvements to the operation of the green wave concept could be accomplished only by eliminating the onboard sale of tickets by the driver. This change would increase the likelihood that desirable station dwell times would not be exceeded even in crowded conditions, but implementation of the scheme is still in the future. Tests were carried out some time ago with onboard automated fare vending machines but the results were disappointing because of equipment problems. The manufacturer is working now on improving the equipment. Transit officials are, however, more interested in a more sophisticated piece of equipment which would be able to handle all kinds of coins and issue change at the same time. Since not all transit operations in Germany desire the same fare dispensing equipment, some of them preferring the exact change approach, the near term availability of automated ticketing machines which are compact (to fit on board light rail vehicles) and rugged (to withstand continuous vibration) is somewhat doubtful.

Transit planners and operators in Dusseldorf also perceive the utilization of the green wave approach as a technique for improving the energy efficiency of the transit system. Vehicles operating in synchronization with the green wave progression have to execute, on the average, fewer accelerations and decelerations. Peaks and valleys in the power utilization of the car are therefore evened out, with attendant energy savings.

At the time of the visit to Dusseldorf, the green wave approach was viewed as the only practical application of the principles of coordination of traffic and transit operations. Further improvement of operations through coordinated signalization was seen as a subject of research at universities. The need for extensive coordination, to interconnect several signalized intersections with the object of smoothing flows and preventing congestion, arises principally at

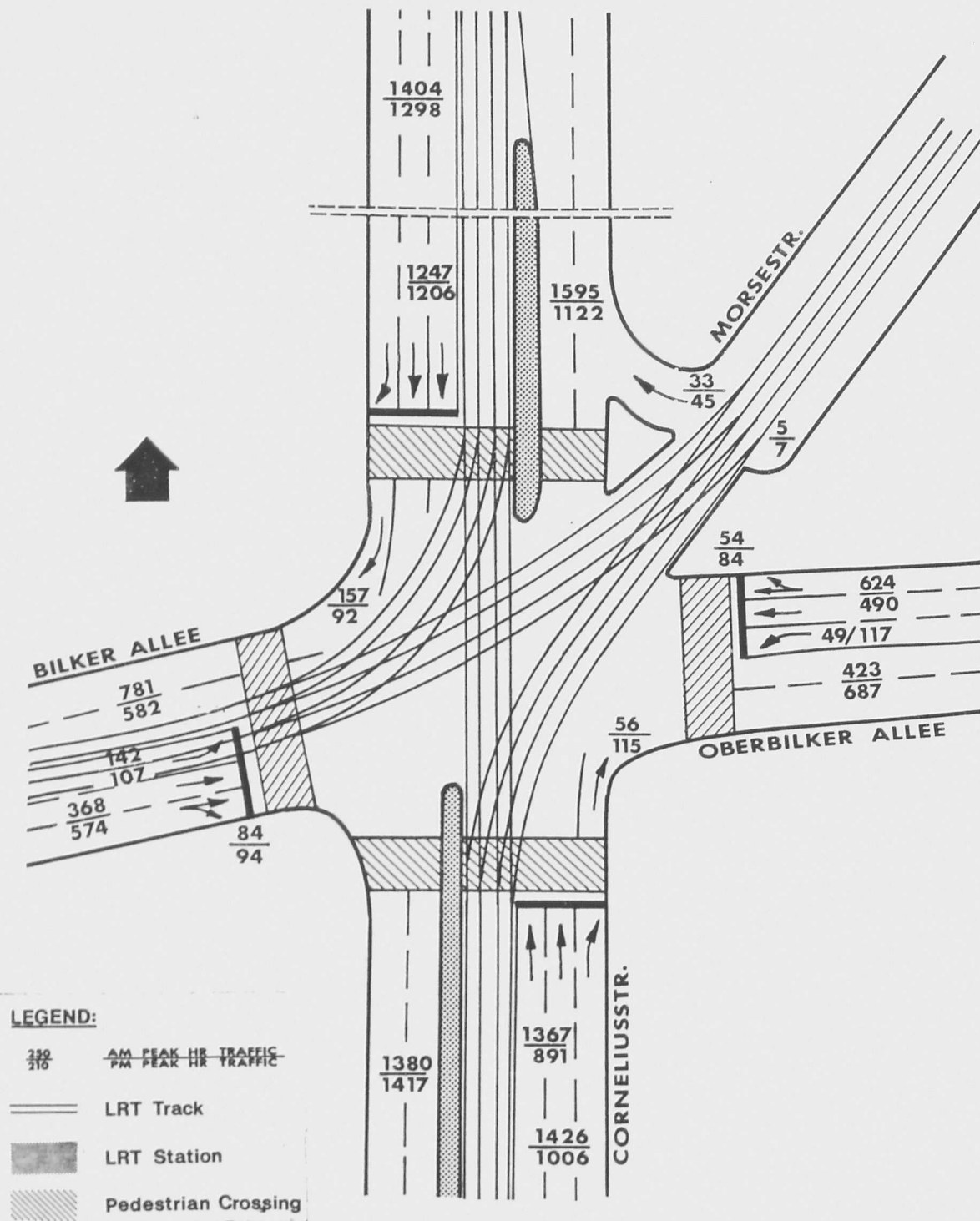


Figure 14. Oberbilker Allee Crossing Vehicular Traffic Volumes

locations of heavy automobile traffic and frequent light rail service. Most of the officials contacted and, in particular, Mr. Barr, doubted the cost benefits of the more sophisticated installations required to achieve areawide coordination. Some earlier studies, carried out at Hamburg for similar connected installations, determined that the instrumentation costs per intersection would be very large, in the range of 150,000 D.M. (roughly \$70,000).

In addition, there are practical operating problems which tend to make automation somewhat difficult. For instance, there are priority problems where two or more light rail lines converge. Theoretically, it would be possible to electrically identify each vehicle with its route and priority, but the economics of this technological application are not perceived as being positive.

While no systemwide studies have been made (of the type currently being planned by FHWA, for instance, in connection with bus priority application), transit officials felt that complications in hardware and degraded reliability associated with an interconnective and/or adaptive traffic control scheme were excessive. In part, this attitude reflects skepticism of automation derived benefits stemming from the unhappy experiences of automated systems both in Germany and in the U.S.; e.g., BART, Krass-Maffei's Transurban, etc. The attitude toward automation in railroad and U-Bahn operations was found to be more positive. Perhaps this is due to the recognition that the exclusive ROW enjoyed by high speed systems makes automation a more acceptable adjunct to safe and effective operations. The BOStrab and other regulations which cover the design of light rail installations do not speak about control of operation below 70 kph but specific requirements for block signalization are called for at the higher speeds more commonly found on U-Bahn and on conventional rail.

## STATIONS

While there are exceptions, as described in the context of the green wave approach, the location of stations with respect to intersections is largely a matter of decision based on traffic volumes, street geometrics, parking requirements and adjacent land use. On suburban lines an effort is being made to place stations on the far side of the intersection in order to avoid confusing motorists when both local and express service share the same track. Should the stations be located upstream of the intersection, drivers crossing streets would be uncertain as to whether the vehicle would slow down to a stop or continue at full speed across the intersection. The downstream location of the platform guarantees that all vehicles will traverse the intersection before coming to a stop. Elsewhere, stations might be placed just as likely on a diagonal across an intersection as they would on a parallel arrangement.

With few exceptions, all stations are extremely frugal in appearance. In most cases, platforms are provided in midstreet and in some cases, where there is adequate ROW, passenger shelters are included. There are locations where, because of inadequate street width, the station stop is identified merely by pavement striping. In a few instances traffic signals are coordinated through activation of a wire detector, stopping automobile traffic a respectable distance downstream of the LRT stop (Figure 15). At the opposite end of the spectrum, there are stations constructed on the suburban D line embodying the high cost features of pre-metro design. The D line's Wittlaer station located a short distance beyond the City boundary, has a costly platform located virtually in an open field with little, if any, provision for commuter parking, indicating that most traffic is served by feeder bus (Figure 16).

## SELF-SERVICE FARE COLLECTION

Self-service fare collection is well established in Dusseldorf. For a variety of reasons, but mainly because of the lower cost of multi-fare tickets, the purchase of onboard tickets has decreased to the point where only 10 percent of passengers buy their tickets from the driver; a good share of

those still doing that are tourists. Originally, the self-service fare approach was adopted in the 1960s because of a shortage of conductors. At that time a serious labor shortage existed in Germany. Millions of foreign workers were brought to Germany to fill the ranks of the work force. As opportunities were being created for better paying and more interesting jobs in the German labor market, more foreign workers began to take the place of drivers and others who were leaving the transit system for other work.

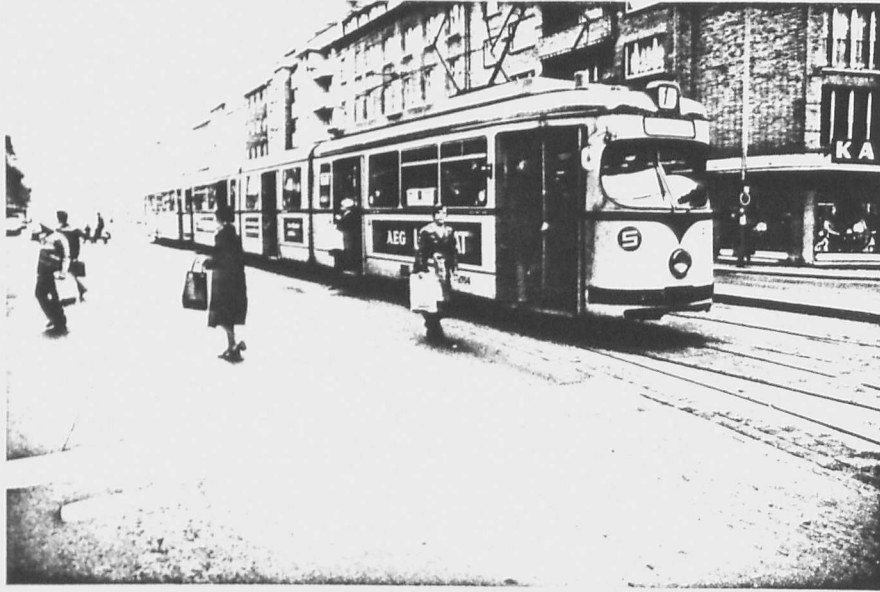
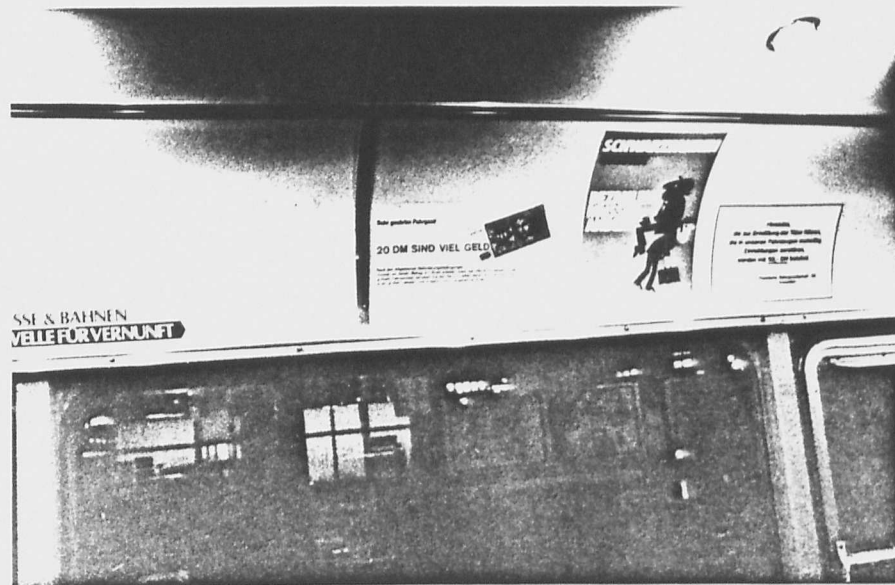


Figure 15. Oberbilker Allee Crossing in Dusseldorf



Figure 16. Wittlaer Station, Dusseldorf

The immediate impact of the conversion to the self-service fare approach was not one of speeding up service, as it is generally assumed. Rather, travel slowed down because drivers, who until then could concentrate on operating their vehicles, now had to spend a considerable share of their time making change and issuing tickets. Obviously, as the public became more accustomed to buying tickets off the vehicle in various forms of multi-ride passes, the burden on the driver decreased and the effects of faster passenger loading began to take hold. Enforcement of the self-service fare is accomplished by inspectors who randomly check 10 percent of the riders. The unfairness of riding without a ticket and the penalties (20 D.M. or about \$85) attendant to being caught are given much publicity in posters found on all vehicles (Figure 17).



**Figure 17. Posters Used to Reinforce Proper Use of Self-Service Fare Collection**

## SCHEDULE RELIABILITY

Transit agency personnel describe the schedule reliability of the system as good. The interpretation given to schedule reliability differs somewhat from that used in this country. The reliability of the system can be attributed not only to the good mechanical condition of the vehicles - in the five days spent at Dusseldorf I never saw a disabled vehicle - but also to generally low frequencies of service which contribute to smooth, uncongested flow. In addition, on the vehicle and at critical points on the line, provisions have been made to allow the driver to take over the function of the signal system in case of failure. For example, on the D line, local streetcar lines share the track and must turn across oncoming high speed inbound traffic. Normally the outbound streetcar activates a detector to set a red signal for the inbound D train at the first upstream station. In case of signal failure specific instructions for normal operation are provided which eventually permit the turn to be made. Similar detailed procedures are available at other points where component failure could create not only a safety hazard but also cause considerable line blockage and delay.

## SAFETY

While there is some concern with safety, the issue is not viewed with alarm. The number of accidents involving transit vehicles is increasing but not at a rate commensurate with the increase

in the number of automobiles and transit vehicles. Traffic signal preemption has had a generally beneficial effect because of the better regulation of left turns and the better separation of vehicular movements. Intersections equipped with half gates are found only on the suburban K and D lines. As part of the U-Bahn project additional intersections on the D line will be equipped with gates, but the great majority of intersections in the system will continue to remain signalized and ungated.

Pedestrian crossings are handled in a very simple manner. The principal technique used to insure pedestrian safety is the routing of pedestrian pathways in a "Z" pattern, forcing them to face the oncoming traffic at all times. I saw no pedestrian crossing signals interconnected with the streetcar signals in the style of the installation observed at Gothenburg. Of course, there are exceptions, the most noteworthy one being at the Jan Wellem Platz where flashing lights are used to assist pedestrians crossing a four-track ROW. German law favors the transit system, and in accident cases the burden of proof is on the pedestrian, not the transit driver. Pedestrian accidents are usually, but not always, ascribed to bad luck.

There are, however, some serious safety hazards. A few days before my visit a major accident involving a truck-trailer which had run a red light and an outbound train occurred at an intersection on the high-speed K line. The light rail vehicle suffered serious damage and the trailer, and perhaps the truck, were demolished. Seven or eight people were injured in the accident. At this location, the light rail ROW runs on the side of a main highway and a right turn lane is provided for traffic crossing over the tracks. The signals are quite elaborate even though most crossings consist of minor two-lane streets. The arrival of a train is detected several hundred meters before the intersection and conflicting traffic is preempted. At the site of the accident, the right turning traffic (except for the ill-fated vehicle) was stopped but because of the poor line of sight created by the curvature of the ROW the driver of the oncoming train did not see the blockage in time to bring the train to a safe stop. I inspected the site of the accident late in the afternoon during the peak hour. At the intersection, 4 or 5 vehicles queued in the right turn lane; very light traffic was visible on the parallel and crossing streets. It is felt that for real safety, even this minor intersection should be grade separated.

## COLOGNE

Cologne is located a short distance away from Dusseldorf. Its surface transit system has been significantly improved, particularly in the central part of the city, by relocating segments of the old streetcar lines underground and converting to LRT-type operations. The Cologne transit agency, Kolner Verkehrs-Betriebe AG, has also pioneered the use of computer controlled traffic signals for coordination of transit and automobile traffic. On a portion of the LRT line between Deutz and Mulheim, traffic signals which control both automobile and transit movements have been interconnected and coordinated by computer. This section runs on a street with heavy automobile traffic traversing several intersections. As the result of the installation, running time on this section was cut by 3 minutes. It is likely that the system will be extended in the future to other portions of the Cologne transit lines.

On Friday, November 14th, a ride was taken on Line No. 3 which operates partially on the above route. As the installation is fairly new, few people are aware of its existence, including some of the transit drivers. Line No. 3 goes out into the suburbs traversing a full spectrum of ROW both in the City as well as beyond. After leaving the City the line runs on ballasted ROW traversing numerous gated intersections. All of the crossings are narrow two-lane streets carrying low traffic volumes. Small queues of two or three automobiles were waiting at several of the intersections. In the morning peak hours the queues at these intersections are considerably longer. Since the streets are short it appears that even at peak hour only small volumes of traffic would be affected by the light rail operations.

LRT preemption is operational on Line No. 3. Bright flashing lights are used to indicate to the driver that gates have closed ahead of the train. The operating rules require that the train come to a complete stop at the intersection when the lights are inoperative. At some intersections the stations are located just downstream of the crossings and the gates remain open while the train is stopped at the station. As the vehicle begins to move out from the station it activates a detector which closes the gate. At that point the train is still moving at slow speed so that conflicts with automobiles are very unlikely.

On the return trip, close to the 5:00 p.m. peak hour, considerable delays were experienced. Preemption of vehicular traffic was not particularly enforced within the City boundaries. At more than one intersection, stops were quite long and, at one point, the driver had to activate the signal manually before proceeding through the intersection. Closer to the center of the City traffic began to bunch up very much in the style of rush hour rapid rail transit traffic. The congestion continued into the underground portion of the line which at peak capacity carries 46 trains per hour. This operation is noteworthy because of the high volume of LRT traffic which traverses an at-grade crossing of two underground high speed lines. This crossing, signalized by Siemens, appears to work well and without accidents even under the difficult conditions created by heavy traffic.

An interesting feature of the Cologne LRVs is that they are all equipped with two-way radios, used for communication between a central dispatch station and the individual vehicles. The radios are used extensively with frequent chatter between central control and the drivers.

## SUMMARY OBSERVATIONS

The visit to Dusseldorf leaves one with the impression that he has witnessed a complex but finely tuned LRT system. Both the engineering and the operations of the system suggest a high degree of expertise and command of the myriads of details which make a transit system a truly functional complement to urban life. The approach to signalization is practical and highly pragmatic. As in the other cities visited on the trip, the emphasis is placed on extracting the best possible use of the LRT system with least reliance on technological sophistication. Here, as in Gothenburg, the visitor marveling at the public's cooperative attitudes vis-a-vis transit must recall that streetcars have been a way of life for generations.

Dusseldorf is no exception from the other large German cities in its approach to rail transit. Having established a high level of service, primarily in its central city area, it now devotes its energies to grade separation in the central area and the attendant improvement in operating efficiency. Unlike the developments at Hamburg, Munich and elsewhere, the emphasis is still placed on LRT technology - but the result is the same: improvement of operating efficiencies both on the transit lines as well as for the private automobile traffic. Little, if any, activity is devoted toward expansion of the system to new residential areas to render the central city and its job opportunities more accessible to the suburbanite. The latter's attachment to the private automobile is thus likely to continue to be as dominant, in the long run, as it is in the United States.

## MUNICH

The visit to Munich began on November 14, 1975. On November 15th a meeting was held with Mr. H. Gawron at the office of the Munich Transit Agency, better known as the MVV (Munchner Verkehrs-Und Tarifverband, GmbH). Mr. Gawron, designated by Mr. Engelbrecht to act as host during the trip to Munich was most hospitable; he spent the better part of the day discussing the Munich system, serving as escort on a trip to the U-Bahn maintenance shops and providing sufficient directions for a visit the following day to interesting portions of Munich's light rail network.

## SOME SIGNIFICANT STATISTICS<sup>3</sup>

The region served by the MVV covers approximately 5,000 square kilometers; the City itself only covers 310 square kilometers. In this region there are 276 separate jurisdictions and nearly 2.2 million inhabitants. Some 1.3 million people live in the City of Munich proper and they operate some 377,000 private automobiles. In the entire region served by the MVV there are approximately 845,000 automobiles.

The transit system at Munich consists of the regional rail network, designated as the S-Bahn, the rail rapid system serving the city proper designated as the U-Bahn, a network of light rail, and finally an extensive network of local and regional buses. The S-Bahn operates 410 kilometers of track, the U-Bahn 16 kilometers, the LRT 110 kilometers and the bus network 329 kilometers of line. At the end of 1975 the length of the light rail network declined slightly and the length of the U-Bahn network increased slightly compared with the statistics for the previous years, 1973 and 1974.

In 1975, there were 10 S-Bahn lines, 2 U-Bahn lines, 18 LRT lines and 76 city bus lines operating on this transit network. During that same year, the S-Bahn operated 140 3-car trains and the U-Bahn 72 2-car trains, and there were 286 powered streetcars and 278 trailer streetcar vehicles. The city bus fleet consisted of 60 articulated buses and 280 standard buses. The S-Bahn could operate in trains consisting of 3, 6 or 9 vehicles, the U-Bahn, in trains of 2, 4 or 6 vehicles, and the LRT in trains of 2 vehicles. Some 70 percent of the LRT right-of-way is reserved in one form or another. The Munich LRT network is the fourth largest in West Germany, but light rail transit in no other German city enjoys such a high proportion of reserved ROW.<sup>4</sup>

The operating statistics of the transit system indicate continued growth in usage matched by a slight decrease in overall patronage. From 1973 to 1975 usage of the S-Bahn increased 18 percent from 1.6 to 1.9 million person-kilometers. In the same period, usage increased 20 percent on the U-Bahn from 207,000 to 249,000 person-kilometers. On the LRT network the increase was 14 percent from 550,000 to 623,000 person-kilometers and finally, on the city bus network the increase was 10 percent from 338,000 to 370,000 person-kilometers. The increase in the utilization of the light rail system, as expressed in person-kilometers, was accompanied by a decrease in patronage of 3.56 percent in the same time period, indicating a shift toward longer commuter trips to and from the suburbs.

## SIGNALS AND PREEMPTION

Mr. Gawron reviewed the criteria applied in Germany to reach decisions on grade separation of intersections traversed by light rail. He indicated that according to prevailing traffic law, light rail vehicles have priority over left turning parallel traffic. The priority is provided by giving the LRV an advance of a few seconds green time before private automobile traffic is permitted to turn. There is no additional guideline for priorities in the traffic codes. Site-specific decisions must be made at each intersection to cover prioritization of through and turn movements of the transit vehicles. The usual factors are taken into account in reaching these decisions: traffic volumes, transit speeds and frequencies, etc. Where the LRV operates at headways greater than 3 minutes, prioritization is provided by setting aside a phase in the normal cycle of the traffic signal. For headways of less than 3 minutes between arriving trains, the BOStrab recommends the use of detectors which activate the signal and permit the LRV to turn or to traverse the intersection. The favorite technique for increasing the overall speed of LRT is the green wave approach used in Dusseldorf.

In Munich, all LRVs, except in a few special cases, are controlled by standard traffic signals which do not differentiate between private automobiles and transit. There are some exceptions where



signals are used to allow the transit vehicle to turn safely from minor streets onto major arteries. Usually these devices are activated by the vehicle a short distance before making the turn. A few of the LRT lines travel a significant distance into the suburbs on essentially separated ROW. Because of the fairly long distances separating the intersections these lines attain fairly high average speeds - in the range of 20 kph - without the use of priority signalization at intersections. The good frequency and high speed operation of Lines 12 and 13 at the northern extremity of the Munich network and Line 24 going to the south were impressive. Although the LRT speeds are lower than automobile speeds on parallel streets the transit time differentials, at least on the suburban runs, did not appear to be excessive because trip distances are shorter in Munich than they are in the United States.

In the City, there are several unique installations which have contributed to an appreciable increase in the operating speed of LRT lines. One such installation is located on the Ohlmüllerstrasse (Figure 18) over a stretch of 180 meters. This street is narrow and allows for only one lane of vehicular traffic on each side of the LRT lines which are located in the center of the street. The technique for accelerating the flow of transit vehicles calls for restricting automobile traffic from the LRT ROW between 6:30 and 8:30 a.m. and from 4:00 p.m. to 7:00 p.m. (Figure 19). During this time special signals located over the traffic lanes and over the tracks are turned on showing a green arrow to the oncoming automobile traffic and a red "X" over the streetcar tracks. Striping has also been used to better delineate the streetcar track from the remaining automobile lanes. Prior to this installation the average speed on this street was 8 to 10 kph. Since the installation has been operational, the speed has increased from 22 to 27 kph at the peak hour when up to 32 trains per hour traverse the line in each direction. In 1973, one year after this installation became operational, a similar installation was constructed on Boschetsriederstrasse covering a stretch of 650 meters. In 1976 dollars, this second installation cost some \$45,000, not including \$70,000 spent for modification of the street. Mr. Ampenberger<sup>5</sup> points out in his article that while this technique has proved to be very effective in improving LRT running times, further improvements, short of grade separation, can be obtained only by reducing the delays experienced by streetcars at traffic signals. He estimates that up to 28 percent of overall delays are experienced at intersections due to red lights.

Additional improvements in street running speeds must essentially be the result of regulating transit and automobile flows at each intersection. Mr. Gawron was quite skeptical that a practical way would be found to further optimize running speeds by coordinating signals among several intersections so that systemwide improvements in flow could be achieved. He felt that geometric and traffic conditions were sufficiently different and random at adjoining intersections to make the attempt at systemwide optimization unproductive. Coloring this view somewhat, is the feeling that there are limits to improvements of LRT operations by creating reserved ROW and controlling traffic signals. A more serious problem of LRT operations is seen in the loss of schedule reliability and the impact on automobile traffic which results from random and unpredictable accidents with automobiles.

## TRANSFER POINT DESIGN CONCEPT

Frequent traffic jams occurring mainly during peak hours as a result of LRT/automobile incidents have led to the development of an important design philosophy at Munich. According to this thinking it is important to physically separate LRT lines operating in the City from those operating in the suburbs. Physical separation will prevent the propagation of disturbances, arising mainly in the City due to accidents and general traffic congestion, to the outlying portions of the LRT network. To implement this policy, special transfer points have been built where LRT, bus lines, U-Bahn and S-Bahn lines come together. Major transfer points of this type are found at the Scheidplatz, the Ostbahnhof and several other locations. At these points most passengers transfer between modes; very low transfer traffic is noticed from one LRT line to another. As a



Figure 18. Intersection at Ohlmüllerstrasse, Munich



Figure 19. Sign at Ohlmüllerstrasse Intersection

supplementary measure to relieve the congestion created by disturbances caused by downtown traffic congestion, the MVV frequently uses reserve buses which are put in operation when LRT lines are blocked. Since it is necessary that these buses traverse the same routes as the LRT, a requirement has been established to pave all new light rail trackage in order to make bus operation possible on identical routes.

## SAFETY

As a matter of general statistics, the overall safety of the Munich transit system has steadily been increasing. Between 1971 and 1973, the number of accidents involving transit vehicles on surface streets decreased by 25 percent while the number of vehicles in the City of Munich increased from 368,000 to 382,000.

Accidents involving fatalities and injuries to pedestrians occur largely on the reserved ROW. Although nearly 76 percent of the LRT network is on reserved ROW (this is an increase of 51 percent in the last 15 years) little, if any, of this ROW is fenced in. Generally, low hedges, perhaps 2 to 3 feet in height, are used, but pedestrians of all ages still cross the ROW and are sometimes involved in accidents. Accidents resulting in injuries and fatalities are also common at stations where pedestrians attempt to cross the tracks in front of the arriving LRVs.

With several modes of transit operating at Munich, it has been possible to establish a hierarchy of safety. At the top of the list is the U-Bahn which has been operating since 1971 without accidents. Whatever fatalities have been experienced on the U-Bahn network have been due to suicides. Next in line are buses which are considered to have a better safety record because of their ability to stop short and their capability to take evasive action, often preventing accidents from occurring. Buses, however, have more accidents than the U-Bahn. Some of these involve pedestrians but most of them involve people hurt on board during high acceleration or braking. The LRVs experience fewer on board accidents, more minor accidents with automobiles - primarily fender benders - and the largest number of pedestrian accidents of the entire system. Of course the number of accidents involving pedestrians could be decreased by fencing in the ROW but that is not always possible because of minimum width requirements, as stated in the BOStrab, which cannot be met on most of the streets. Where the ROW is too narrow to meet the BOStrab requirements, fences can be installed only if frequent breaks are provided to allow the escape of people who could conceivably become entrapped in the ROW. Consequently, fences are deemed to be less of a deterrent to incidental crossing by careless pedestrians, and are not used extensively.

## OPERATING COSTS AND SELF-SERVICE FARE COLLECTION

As with transit everywhere else, the costs and operating deficits of the Munich transit system have been increasing. In 1976, the revenues covered only 56 percent of the costs. Forty-five percent of the deficits are covered by the parent agency, the City's Public Works Department, which also operates the profit producing natural gas and electricity services of the City. The remaining 55 percent of the deficits are covered by the City Council. The S-Bahn, which is operated by the German National Railroads (Bundesbahn), uses more personnel per unit than the U-Bahn and only covers 38 percent of its costs from revenues - this is in spite of the fact that S-Bahn ridership is running at 130 percent over projected ridership compared to only 75 percent over projected ridership for the U-Bahn network.

The sale of tickets, both for single as well as multiple fares, is gradually shifting away from on board purchase to purchases from vending machines and through other outlets. From 1973 to 1975 the percentage of fares sold on board vehicles decreased from 42 to 29 percent, while the volume of tickets sold through automated ticket dispensers increased from 46 to 53 percent. The Munich system operates with self-service fare collection. Fare evasions are few. Based on an inspection sampling, evasions range from as low as 1.3 percent of random checks onboard the U-Bahn to 3.2 percent at high traffic points (also on the U-Bahn); an average of 1.7 percent of the riding public has been found to travel without valid tickets. Of this group, only 44 percent are found to travel without any tickets at all; the rest were found to be in violation of the tariff laws or held improper tickets of one kind or another. Between 1974 and 1975, there was a decrease of

more than 5 percent in the number of persons trying to avoid paying any fare by traveling without a ticket.

## U-BAHN VERSUS STREETCARS

The expansion of the U-Bahn network is expected to continue at a steady pace. The system is being expanded at the rate of 2-3 kilometers per year, matching the yearly appropriation of approximately 200 D.M. (approximately \$85M) for all fixed facilities but not including an allowance for additional rolling stock.\* It is expected that sufficient funding will be available through 1985 to complete the second phase of the system. Beyond 1985, plans call for the extension of the lines into the suburbs on aerial structure and the construction of a circumferential line. The system is being built by a City department established expressly for this purpose. As sections are completed they are turned over to the Transit Agency for operation. The Transit Agency is also responsible for acquiring and maintaining the rolling stock.



Figure 20. Sign at U-Bahn Construction Site

Some transit officials conjecture that as the U-Bahn network is expanded it might replace the LRT network. There are a number of factors which contribute to this thinking, in addition to the previously mentioned concern about the unreliability of LRT service, such as concern for the costs of maintenance and replacement of obsolete equipment. Some of the equipment is now 25 years old; the most recent vehicles were acquired some 10 years ago. Maintenance costs have increased substantially but the Agency has so far resisted acquiring new equipment because of the possible alternative of converting streetcar lines to bus service. The cost of maintaining the streetcar vehicles is exceedingly high due to a policy which requires vehicle disassembly, subsystem inspection, and rust removal every six years or 500,000 kilometers, whichever comes earlier. For all practical purposes, this means that the vehicles have to be completely rebuilt. The

\*When the U-Bahn network was opened in 1972 in advance of the summer Olympics, the Transit Agency acquired more vehicles than it could use in normal operations, hence a surplus of vehicles will exist for a few more years.

cost of this maintenance ranges from 60,000 to 100,000 D.M. (approximately \$25,000 to \$43,000) per vehicle, amounting to a substantial share of the cost of a new bus. Buses, on the other hand, are normally replaced every 8 years, but in reality most are kept in service as long as 12 years. Given this rough equivalence of cost, i.e., over the life of a bus, LRT maintenance costs approach replacement costs (not on a seat-to-seat basis, however, since at least two standard size buses are required to replace one typical LRT vehicle), and the decision makers are questioning the soundness of policies which would retain a streetcar system they view as obsolete. Their views are also colored by the observation that in the history of the Munich LRT system a continuous series of equipment modifications were required to meet changes in operating procedures. The equipment modifications have been costly and sometimes traumatic. Removal of conductors, when self-service fare collection was implemented, required significant changes in door and interior design; later, door operations were further changed to improve safety, etc. Vehicle retrofitting was time-consuming and costly. Moreover, because of the small market for LRVs, vehicles are built almost by hand, contributing to the high cost of new equipment.

Another item of concern is the high cost of track maintenance. This may be, however, a unique feature of the Munich system and may be alleviated with a change of vehicle design. The majority of vehicles in operation are 3-axle powered cars and 3-axle trailers. The central axles of both vehicles are connected to the front and rear powered axles by linkages which permit the middle axle to move laterally on curves. The turning capability of the vehicle is improved considerably but considerable hunting (side-to-side motion) is experienced on tangent sections. The lateral impact of the wheels during their hunting motion damages the rail, requiring excessive track maintenance. Approximately 40 newer vehicles are shorter and lack wheel support at the articulation.

In addition to its uncertain future, the LRT system also suffers from institutionally created difficulties which hinder many expansion and improvement projects. In recent years, attempts to relocate LRT lines in conjunction with ROW clearance for U-Bahn construction met with considerable objections from the residents of streets programmed to carry the relocated LRT. The public was in opposition to tree removal and to neighborhood disruption which would be caused by the new lines. The matter often resulted in the TAB calling for public hearings, leading to a lengthy process of project review and evaluation. The fact that German law provides about 60 percent funding for new line construction has not mitigated public opposition to these projects.

As part of the continuing dialogue on the future of the LRT system, an attempt has been made by a working committee to establish basic criteria which might be used to decide the conditions which might favor U-Bahn, LRT or bus service. Arrived at in a very pragmatic way, these criteria have been outlined as follows (on the basis of an assumed load factor of 70 percent and headways of 3 minutes).

- For lines carrying up to 4,000 passengers per day, regular bus service is suitable.
- For 7,000 passengers per day, articulated buses are preferable; for 10,000 passengers per day, a light rail system would be preferred.
- At a volume of 25,000 passengers per day, the U-Bahn system is preferred.

These figures are considerably lower than the numbers used by planners in this country. Incidentally, at the time of the trip the highest load carried on the U-Bahn since its opening was 36,000 passengers per hour during an unexpected torrential rain.

## FIELD TRIPS

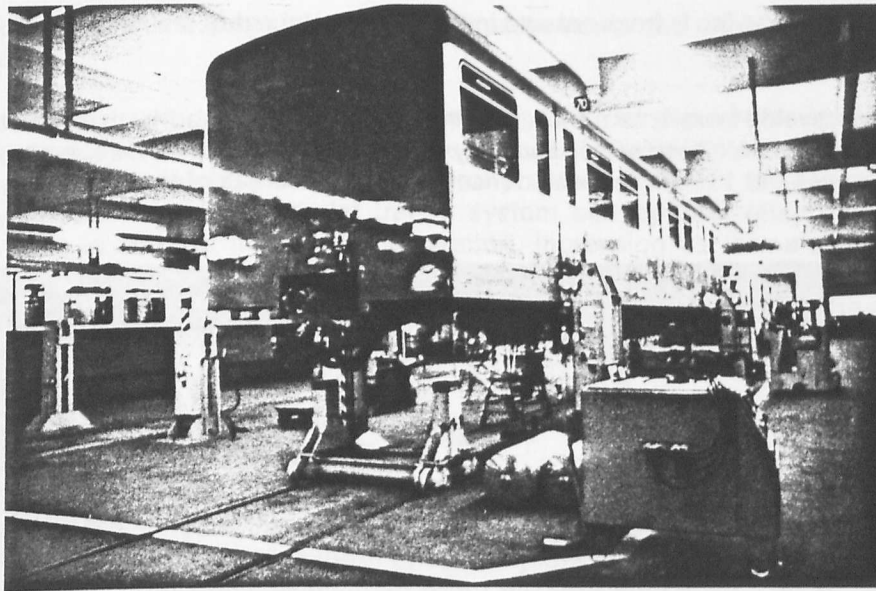
Travel on the S-Bahn is a pleasant experience; the quality of the ride is high; it is smooth and free of noise. The S-Bahn operates in a minimum unit of 3 vehicles. The cars at each end are powered and the center car is unpowered. Power is 1,500 volts AC furnished through a catenary mounted in the tunnel a few inches below the roof. Because the U-Bahn is powered by 600 volts DC delivered by third rail, the two networks are not compatible. The S-Bahn, operated by the Bundesbahn, carries a driver and one additional operator on each train. (This may account in part for the large deficit of this service.)

Traveling on the U-Bahn, one finds the ride somewhat less smooth than on the S-Bahn. The U-Bahn vehicles operate in pairs, but at the interface, a solid wall prevents movement from one vehicle to the next. Both first and second generation vehicles are constructed this way. The third generation of vehicles, being ordered at the time of the trip, will be provided with windows at the interface but transfer of passengers between cars will still be impossible.

The U-Bahn maintenance shops are impressive by their size, orderliness and subdued level of activity. Since the system enjoys a surplus of vehicles, maintenance and repair activities take place in what seems to be a fairly relaxed manner. Each car is brought to the facility for washing every six days and for periodic maintenance every two weeks. A special shop is used for major repair involving electrical subsystems. Vehicles are placed in working position through special lifts which elevate the vehicle to a height permitting disassembly of the trucks and their removal to adjoining shops (Figure 21). Motors and gears are reconditioned at yet another shop located in another part of town, requiring transportation by truck.

An opportunity was provided for a ride in a U-Bahn vehicle cab with a driver and Mr. Gawron on the return to the City from the maintenance facilities. The driver, a woman, had been working for the Munich system since 1969. She explained the operation of the automated U-Bahn control system. Three operating modes are possible. In the first mode the operation is entirely manual. The driver sets the speed and operates the brakes according to a chart which indicates the prescribed speed for various portions of the line. No special instructions are given to the driver for speed reductions in case of bad weather when rails are wet and traction is reduced. All drivers are required to operate their trains manually between the maintenance facility and the first station, as a precaution to insure that their operating skills are maintained at a high level of proficiency. In the second operation mode, the central control station is still manual. Finally, in the third mode, the train operates entirely automatically. The only function retained by the driver under full automation is the opening and closing of doors at stations. Stopping at stations under full automation was precise. Since trains are of various lengths, the driver must punch in the length of his train before the start of the automated run. The control system will then position the train at the proper place on the platform.

One of the highlights of the Munich system is the major interchange at Marienplatz, used by S-Bahn, U-Bahn and LRT. The Marienplatz station (Figure 22) is located in a major auto-free zone. It consists of 4 underground levels, a mezzanine and surface LRT platforms. Because of construction difficulties each station and U-Bahn line occupies 2 tunnels, each containing one track, located at successive depths below the surface of the street. High volumes of passengers are handled at the Marienplatz station. On a Saturday 100,000 passengers have been counted on U-Bahn Lines Nos. 3 and 6 and 100,000 passengers on S-Bahn Lines 1 through 6. Passengers board from one side of the vehicle while others alight from the opposite side, in what is referred to as the *Spanish technique*. During the time I spent watching the operation of the system it seemed that all passengers followed the public address instructions, boarding and departing the vehicles on the assigned platforms.



**Figure 21. Vehicle Maintenance Shop, Munich**



**Figure 22. Marienplatz Station, Munich**

The S-Bahn station at the central railroad station is equally impressive with its extensive mezzanines and shopping areas. The S-Bahn Ostbahnhof station is also a major transfer point for many streetcar and bus lines. In the northern part of the City, Scheidplatz station serves as a major interchange between U-Bahn, LRT and bus lines. At this station, the physical break between suburban LRT lines and the lines operating to the center of the City can be observed. Lines 12 and 13 originate at Scheidplatz while Lines 15 and 25 are their continuation toward the center of the City. Line 13 was traveled for some distance in the outbound direction. The line operates on reserved ROW on conventional ballasted trackage. It primarily traverses residential areas and crosses streets with relatively low traffic. Average speeds attained on this line are in the

range of 20 kph. Service is frequent and in the middle of the day, trains appear to run with a 50 to 70 percent load factor.

Line 24 was traveled from its terminal at Ostbahnhof toward the suburbs in the southeast. For some time this line runs on city streets in a variety of ROW, but it too achieves speeds in the range of 20 kph as it moves out toward the less densely populated areas of the City (Figure 23).



Figure 23. View from the Operator's Cab, Line No. 24

## SUMMARY OBSERVATIONS

Located in one of Germany's four largest cities, Munich's transit system resembles the systems of larger European metropolitan areas such as Berlin, Paris and London more than it does the systems of medium size cities like Dusseldorf and Gothenburg. The City's continued growth in population and car ownership has shifted the transit emphasis to high capacity rail and suburban bus service. Unlike other large metropolitan areas, however, the LRT system has been retained and upgraded to play a significant role in the City's overall transit picture. The absence of extensive traffic signal improvements to favor transit, as at Dusseldorf, is perhaps indicative of the growing concern with its restraint on automobile movements. No doubt, the increasingly difficult task of maintaining smoothly flowing surface street transit movements in the face of growing automobile congestion has been a source of frustration which contributes to some officials' nonsupportive attitude toward LRT.

However, it cannot be said that Munich's traffic and transit planners are strangers to innovative and radical change. The highly successful auto-free zone which created the extensive pedestrian mall in the immediate vicinity of the Marienplatz station is indicative of the willingness to undertake projects that involve major change.

In the face of a continuing period of economic hardship - even in the midst of German affluence - it seems difficult to visualize the gradual replacement of LRT service with buses or with a comparably extensive network of grade separated U-Bahn. Neither the much larger operating cost of an all-bus system nor the large capital investment of a much more extensive U-Bahn



network could justify, in the long run, dropping improvements and refinements of the existing LRT network.

It may be the City's size, it may be its growing industry and commerce - for whatever reasons, Munich attitudes most closely parallel many of the attitudes concerning transit in large American cities. While Munich could be described as a city where light rail is in trouble, it more appropriately shows how a multimodal transit system can operate effectively in a major metropolitan area in spite of increasing congestion, increasing car ownership and gradual movement of the population to the suburbs. A corollary observation is that multimodality in transit, and its success as measured by a larger number of passengers utilizing the system, does not do away with the universal bane of transit - its increasing operating deficits.

## ZURICH

The visit to Zurich took place on November 17, 1976. A pedestrian mall on the Bahnhofstrasse, which is restricted to automobile traffic but is traversed by streetcars, fronted the hotel. Masses of people seemed to go about their business unconcerned about the quietly moving streetcars which slowly inch along, taking advantage of every break in the crowd.

The next day was spent in meetings, generously arranged by Mr. H. Barbe, and on a field trip. Participants in the meetings included Mr. Urs Zobeli of the Zurich police department, Mr. Ernst E. Berger of the Transit Agency (Verkehrsbetriebe der Stadt Zurich) and Mr. J. Meyer from the City's Planning Office. They were all generous with their time and helpful with their explanations of the Zurich transit system. In the afternoon, Mr. Berger was kind enough to serve as escort on a brief tour to the end of streetcar Line No. 4 where construction for extension of the line was taking place. On the return trip construction sites were visited where improvements were being made to existing streetcar trackage.

## GENERAL STATISTICS

Transit usage in Zurich has remained quite stable (at approximately 200 million passengers per year) despite a decrease in population within city limits. (Between 1968 and 1976 the population decreased from 440,000 to 380,000). In the area covered by the Zurich transit system, which encompasses some 16 different communities, employment has increased in the last 20 years, from 250,000 to 330,000 jobs. About 100,000 commuters travel to Zurich daily, 60,000 by train. About 20,000 automobiles are driven to Zurich daily, while 15,000 automobiles make the commute trip outward. Car ownership is approximately 310 cars per thousand population; it is projected that the upper limit on car ownership will be 340 vehicles per thousand population.

The changes in population and employment have been accompanied by expansion of transit services. New bus lines have been added as feeders to the streetcar network and tangential bus service has been established. The streetcar lines in Zurich are oriented essentially in a radial pattern with each line traversing at least one of the three key activity centers in the city: the central station area, the Parade Platz and the Bellevue Platz. In the inner city, transit service is almost exclusively by streetcar; only one line is serviced by buses.

Because of the narrow streets, severe transit/automobile interaction problems arise. In an attempt to resolve the conflict, strict parking regulations are enforced. Some 4,000 curb parking spaces have been removed and parking fees can be rather high, up to 14 Swiss francs per day (approximately \$7.00). In general, automobiles are restricted from sharing the streetcar tracks. In Swiss law a streetcar has the ROW over automobiles and pedestrians. Stopping of automobiles is prohibited on light rail tracks but during the rush hour many stopped vehicles do contribute to

traffic congestion. Streets are typically 33 feet (11 m) wide and carry two traffic lanes in addition to the streetcar trackage. Traffic signals are set in favor of the streetcars in an attempt to keep the transit moving. I have seen one such narrow street in a busy shopping area where merchants insisted on retaining parking spaces next to their stores. As a result, vehicles park diagonally, allowing inches between their bumpers and the passing streetcars.

In 1975, the statistics of travel in and out of the Zurich CBD showed that 42 percent of trips were taken on public transit (including railroad) and 41 percent by automobile; the remaining 17 percent were pedestrians or bike riders. For the city as a whole, the statistics show that 30 percent of the trips are taken on transit, 50 percent by private automobile and 20 percent are made by pedestrians or bike riders. For the region as a whole, only 25 percent of the trips are taken on transit and close to 75 percent are by private automobile.

At Zurich there are no specific land use effects that can be attributed directly to the streetcar network. There are no visible corridor effects, mainly because of the extensive networking of streetcar lines. A possible exception to the rule is found in the southern end of the City where a new development containing some 2,000 apartments has been erected. It will be served by an extension of the streetcar Line No. 8. In order to make the ROW available the builder enlarged the street within the original building lines. This line was in construction at the time of this visit and should now be operational. This project, a 4-kilometer extension, has the characteristics of LRT and is the only recent development of the Zurich rail transit system. Some 15 years ago a 1-kilometer extension was constructed. There is, however, considerable line reconstruction in process in the center of the City to improve service.

Further statistics on the physical elements of the transit system at Zurich are as follows. The streetcar system consists of 14 lines traversing 102.55 kilometers. The fleet consists of 223 powered vehicles of which 131 are 4-axle cars and 92 are 6-axle vehicles. In addition, the fleet operates 91 unpowered trailers and 36 powered trailers. The vehicles are generally lighter than their German counterparts, each weighing roughly 45,000 pounds and being some 63 feet in length. They accommodate 45 seated passengers and up to 100 standees. The cars are lighter than the German vehicles because they are designed to operate at a lower top speed, 60 km per hour. This limitation is brought about by the poor line of sight on the various routes in Zurich. All lines operate in mixed traffic, except for new extensions such as that on Line No. 4.

A new generation of vehicles is being procured, the so-called Tram 2000. This is a 6-axle one-directional articulated unit, powered by two 600-volt DC monomotors located in the front and rear trucks. Traction is controlled through a chopper and the vehicle is equipped with 4 different types of brakes. The fourth brake is a retarder brake. These vehicles, unlike the rest of the fleet, will be all-electric and contain no pneumatic systems. The manufacturer, Schindler, and the Transit Agency claim that the all-electric system produces a lower noise vehicle less susceptible to operational problems in winter.

The streetcars operate at a maximum headway of 6 minutes and at that frequency of service, are capable of carrying 15,000 passengers per hour. Up to 35,000 passengers per hour have been measured on one line going to the suburbs of Oerlikon, but at lower speeds with headways of 1-1/2 minutes over a 5-km stretch of line.

Supplementing the streetcar system there is a fleet of 75 trolley buses, 64 of which are articulated. In addition, there are 230 regular buses, some of which were acquired between 1951 and 1959. Fifty-seven of these buses are articulated, most of these were acquired between 1965 and 1970.

Between 1950 and 1975 there has been relatively little change in the level of service provided, as measured by the annual cumulative vehicle-kilometer index. This index changed from 26 million

vehicle-kilometers in 1950 to nearly 30 million vehicle-kilometers in 1975. During the same period of time the ridership increased from an aggregate of 160 million in 1950 to 209 million in 1975.

The annual report of the Zurich Transit Agency, from which most of this data has been extracted, also presents a fairly detailed description of the safety statistics of the system. The report indicates that in 1975 there was a reduction of 6.2 percent in the number of reported accidents of all kinds. Accidents involving bodily injury decreased by 7.3 percent while collisions dropped 15 percent compared with the previous year.

More specific safety statistics follow. In 1975, there were 459 accidents involving bodily injury on the streetcar network compared to 190 on the trolley bus network and 153 on the regular bus network. Looking at streetcars only, there were 9 fatalities in the various accidents and 349 accidents with bodily injury involving passengers, 112 accidents involving bystanders and 11 cases of personnel being injured. Of the 894 collisions with other vehicles, 811 occurred with automobiles, 7 with motorcycles, 5 with bicycles and 71 with other types of vehicles. The corresponding figures for collisions with automobiles are 134 incidents on the trolley bus network and 175 incidents on the conventional bus network. The system also recorded 136 other incidents caused mainly by disengagement of the trolley from the power distribution wire (trolley buses). These incidents increased by 23 percent compared with the experience in 1974, but they are partly accounted for by the fact that 2 new trolley bus lines were introduced during the year.

## SIGNALS AND PRIORITY

In the City of Zurich there were 284 signalized intersections, 120 of which are traversed by streetcars. Five separate computer systems control the various traffic signals but their function is mainly to alter the signal timing in accordance with various preprogrammed tables. The computers are interconnected, but only interface information is communicated from one to the other. Zurich's traffic people have opted for computerization of their signals on the basis of studies which show that principal benefits accrue from improvements in traffic safety and personnel economies. (There are still intersections in Zurich which are controlled manually by traffic personnel.) Additional benefits are reduction of congestion on densely traveled streets and priority for streetcars. The computers interconnect 108 of the 284 signalized intersections. Other devices, described as "coordinators," are used to create a green wave progression (as used at Dusseldorf).

The computers activate different traffic signal cycles according to the time of day or day of the week. Different programs can be called into operation as pedestrian and automobile traffic volumes reach predetermined values. Where traffic is heavy, it is not practical to change signal timing according to the preset schedules, and fixed cycles are maintained. At signalized intersections under computer control, streetcars are given priority. According to Swiss law, no limitation can be placed on the amount of green time given to the transit vehicle since it has priority over pedestrian and automobile traffic.

The most sophisticated computer installation in operation controls traffic in the area surrounding the central railroad station. This computer, manufactured by Elliott, coordinates automobile and transit signals at 3 extremely busy intersections. The computer program, consisting of 250 commands, maintains a smooth flow of complex through and turning movements. The computer also activates signals upstream of the central station when severe congestion develops. Detectors positioned 250 meters away from the intersections are used to provide information to the computer. Where the minimum of 200 meters required for safe detection of streetcars cannot be met due to geometric constraints, transit vehicles are not given priority.

The Zurich police operating the computers indicate that the control system has the capability to implement the City's transportation policies. Five different types of computer programs are available to control a variety of traffic conditions. The programs assign the highest priority to public transit, followed in succession by automobile traffic, and then special cases such as emergency vehicles. The programs contain statistics for a.m./p.m. traffic, for holiday versus workday traffic, and can also account for seasonal differences in traffic.

Four different types of detectors are used: pedestrian-activated detectors, metal detectors located in the street, code receivers which are carried only on streetcars, and the newer system called SESAM, an acronym for Selected Signal Access Manipulator. The code receiver communicates information to the computer transmitted by the streetcar. The signal emitted by the streetcar identifies its line number, and therefore, whether it will turn or go through the intersection, and provides information on the length of the train. This data is then used by the intersection controller to adjust the signal in favor of the passing streetcar.

The SESAM device has been built to Police Department specifications by ASEGA, a Swiss electronics firm, and has been refined into a very rugged piece of equipment selling for about 200 to 300 S.F. (approximately \$80-\$150). SESAM has been installed on 300 of Zurich's buses and, to facilitate priority control of all intersections, streetcars are equipped with transmitters for both SESAM and the normal code described above.

## FIELD TRIPS

The new LRT extension of Line No. 4 connects with a new residential development in the southeast. Most of the line was completed but the last 100 yards or so were still being paved over at the time of the visit. Most of the electrification had been installed and service was scheduled to begin in December, 1976. The line displayed several interesting design concepts. It approaches the residential development in new ROW paralleling a collector street. The ground surrounding the tracks is planted with grass (Figure 24) creating a very pleasant visual effect (in the middle of November there are still many green fields to be seen in the Zurich area). As the line traverses the residential development, it also runs parallel to one of the feeder streets and only 3 to 4 feet away from the sidewalk. Pedestrian traffic and children playing during normal streetcar operating hours are not protected by any physical barrier. Only a different pattern in the pavement serves to call attention to the fact that the rail is just a few feet away from the public access area (Figure 25).

Because the last few meters of this track extension were still under construction, it was possible to observe construction details closely. A highly labor-intensive approach was used to encase the entire area between and around the tracks with precisely laid cobblestones whose joints were being filled carefully with bituminous sealer. Cobblestones, as well as the sidewalk detail mentioned above, were selected by the architects in lieu of concrete or asphalt (in spite of their higher costs) as a means of livening up the otherwise monotonous appearance of the trackage in residential areas.

The technique used for track drainage was also easily visible. At various points, small holes less than one inch in diameter are drilled in the bottom of the rail's U-shaped cavity which encloses the wheel flange. These holes are easily clogged by debris. Drainage is maintained in day-to-day operation by transit agency employees who walk the track and unplug the holes.

## SUMMARY OBSERVATIONS

Fundamentally the system in Zurich consists of light rail operation in mixed traffic, i.e., a streetcar operation. Typical of many ancient cities in Europe, the narrow streets of Zurich are often clogged by automobile traffic and transit. The innovative use of computers to control and

coordinate traffic and transit movements in one of the City's most congested areas - the vicinity of the central railroad station - is noted with particular interest as it suggests that a practical way can be found to control, in nearly optimum fashion, the complex automobile and rail movements on modern light rail transit lines.



Figure 24. Grassed-Over LRT Track, Zurich



Figure 25. Pavement Treatment on Line No. 4, Zurich

## THE HAGUE

On November 19th, I visited The Hague where several appointments were secured with officials of the Ministry of Transport. While Amsterdam and Rotterdam also operate streetcar systems, the visit to The Hague was particularly important because of the City's pioneering efforts to upgrade streetcar performance to light rail standards. Significant streetcar improvements are also being made at Amsterdam and Utrecht. These cities are building new light rail systems. For the purposes of this survey, The Hague was emphasized as the representative LRT city in Holland.

### MEETING WITH DR. F. VAN DAM

Dr. van Dam, who directs the City's transit department, provided a brief overview of transit policy as it affects light rail in Holland. The highlights of this conversation are as follows:

The transport ministry at The Hague coordinates traffic and transit activities as well as finances for all forms of public transport in Holland. Some 2 billion guilders (1 guilder is equivalent to approximately 40 cents) represents the annual budget provided by the national government to railroads, regional buses and urban transit. The ministry also has the responsibility for overseeing legislation that affects the coordination of traffic signals with automobile and transit movements and determines the prioritization of public transport. The ministry provides between 50 and 80 percent of capital grant needs. The expectation is that future national government contributions will increase to 100 percent of capital requirements. Holland's national policy favors public transport over private vehicles, particularly in congested areas.

Cities applying for capital grants must indicate that they have followed this policy approach in the design of their systems. The pro-transit philosophy stems from a policy which seeks to preserve the historical character of Holland's cities. To this end, changes in land use normally associated with a conversion to heavy automobile usage are not welcomed. For intercity transportation, government policy has supported the development of an extensive network of regional buses and railroads.

The most recent demonstration of Holland's pro-transit policy is found in the City of Utrecht. A streetcar system operating in that City was abandoned in 1938. Recently it was decided to construct a new rail line with characteristics that closely fit the United States definition of light rail transit. Conventional rail transit had been considered, but it was rejected because of the unavailability of suitable ROW (a light rail line can be constructed on a narrower ROW). The light rail line will operate on reserved ROW with crossings protected by barriers or traffic lights. Extensive penetration of the line into the center of the City is delayed for an uncertain future. In the suburbs, light rail trains will have absolute priority when inbound only. Within the city boundaries they will receive conditional priority. Dr. van Dam expressed the opinion that because of economic constraints this may be the last rail transit system to be built in Holland for some time to come.

In Holland decisions on granting priorities to LRT have considerable legal underpinning. Absolute priority can be granted when detection can be made in sufficient time, at least 30 seconds, before the train reaches the intersection. Absolute priority could be granted even for trains operating as closely as on 3-1/2- to 5-minute headways (both directions). The frequency of train operation is considered to be more important than the volume of automobile traffic at an intersection. The concept of absolute priority is supported by the law favoring transit. Light rail will get the green light in any event; controlled signalization will assign that green time in a more nearly optimum fashion. Hence, the ability to anticipate the trains arrival is most important in maintaining smooth traffic and transit flow through the intersection. Holland's law imposes no

speed limits on public transport but does limit the speed of automobiles to 50 kilometers per hour in built-up areas. Light rail and streetcar operations have precedence everywhere except when crossing high priority streets. The concept of priority also extends to buses in modified form, giving them precedence at departure from stops.

A uniform policy regarding gates at crossings does not exist. Decisions concerning their need is based on a case-by-case analysis. Some new legislation in the planning stage will combine standards, operations and traffic considerations for light rail, railroads and other forms of public transport. This legislation will be somewhat similar to the German BOStrab, but it may not be as extensive in content as its German counterpart.

At intersections traversed by rail transit, maintenance of adequate lines of sight is considered of paramount importance. An adequate line of sight is necessary to maintain safety under normal conditions, but even more so when the intersections might be occupied by emergency vehicles normally exempted from obeying red signals.

Although some studies were carried out by the Ministry on the subject of equipment standardization, geometric constraints in major cities have made it difficult to achieve uniformity in vehicle design. Of the three largest cities in Holland, The Hague is the newest, dating back to the 19th century. Its streets are wider than those of Amsterdam and Rotterdam which date back to the 16th and 17th centuries. Hence, while The Hague can utilize wider rolling stock, this is not possible in the other two cities. The Hague vehicles are patterned after the PCC designs while the equipment in Rotterdam and Amsterdam is patterned on German designs. At Utrecht the equipment has not been picked as yet but it may well be similar to the German Type B vehicle.

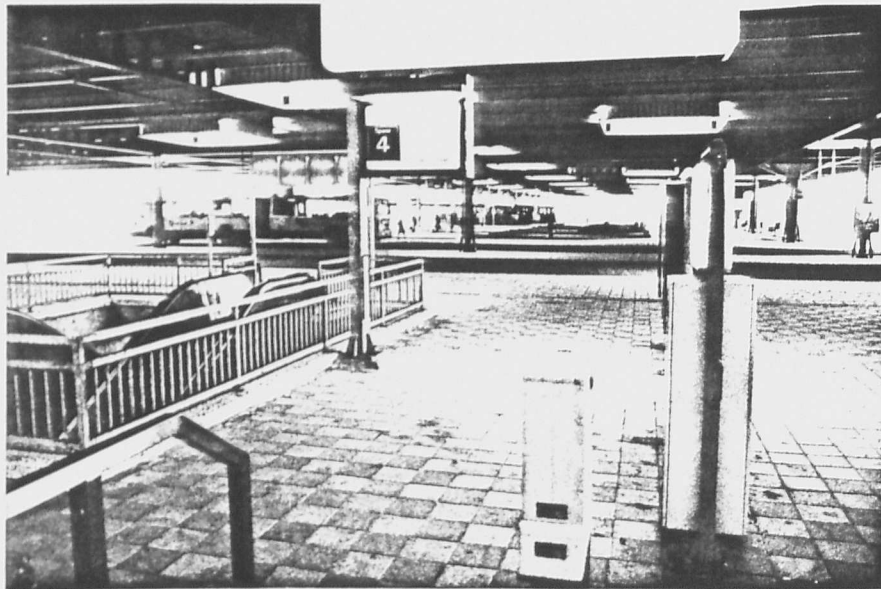
Several points of interest to planning of new light rail applications were also mentioned. Holland's planners do not favor the utilization of highway ROW for rail transit as they felt this would contribute to the disintegration of the community. Another disadvantage would be long distances between stations typical of operation in suburban areas. Finally, there is the prevailing feeling that a light rail line located in highway ROW would not integrate well with the other forms of urban and suburban life. In Holland, public transport's ability to integrate with the urban form is of major importance. At Rotterdam, at the Zuidplein Metro station, extensive integration was accomplished between transit and shopping facilities.

## FIELD TRIP

I was accompanied by Mr. T. H. M. Nyman of the City's planning department on a trip to the central railroad station and on several of the City's transit lines. The central railroad station is located in a modern highrise office complex which also contains a major interchange with LRT and bus lines (Figures 26 and 27). LRT traffic into the central station area, consisting of Lines Nos. 3, 6 and 7, is controlled through a central computer station utilizing Vetag-type control devices. The Siemens computer, the large display panels, the controllers with their TV cameras and other communication gear are housed in a separate building across the street from the central station. The installation controls heavy traffic operating at headways as close as 90 seconds in peak hour and 2 minutes at other times. Conflicting movements of the lines converging on the station are regulated with a block type control. The control blocks are designed to separate vehicles at normal stopping distance and no unconditional reds are provided. Switches can be reset by hand from the control center, should the driver of a light rail train cross a red signal inadvertently. In that sense, the installation is different from conventional railroad control practice. Drivers can request a green signal by activating a button in the cab. This is in addition to passive detection via inductive loops located in the track. As a safety measure, all signals are set on red in case of computer failure and manual reactivation of the system is required. The system is operational but was still being debugged at the time of the visit.



**Figure 26. LRT Station Platform at the Central Railroad Station, The Hague**



**Figure 27. Transfer from LRT to Bus Lines at the Central Railroad Station, The Hague**

Mr. Nyman related the following statistics of interest concerning the transit system in The Hague. The system operates 234 trams and 200 buses. All LRT vehicles are equipped with Vetag but, at the time of the visit, only 18 buses were equipped with the same devices; the rest of the bus fleet was expected to be equipped with Vetag equipment by March, 1977. There are 186 signalized intersections and about 10 percent are equipped with absolute priority controllers. There was, at the time of the visit, only one experimental installation of Vetag in operation in The Hague.



For all practical purposes, priority was being assigned by standard detectors and controllers typical of those at Gothenburg and elsewhere.

Self-service fare collection, while successful at The Hague, does not enjoy as high a rate of compliance as noted in Germany and Holland. Official estimates of fare payment evasion are in the range of 2 to 4 percent of the traveling public. Between 7 and 10 percent of passengers riding in the second car evade payment of fares. The higher rate of fare avoidance is also consistent with the continuous increase in the rate of vandalism, doubling on a yearly basis.

The safety of the transit system is reasonably good, even in the difficult operating conditions found on the narrow streets of the Dutch cities. (While taking a trip on Line No. 1 in Amsterdam a considerable length of line was traversed in densely populated suburbs where LRT, automobiles and pedestrians appear to operate reasonably well in totally unsignalized and uncontrolled intersections.)

An incident was witnessed as we came upon a vehicle stopped at an intersection where an investigation was being conducted. An elderly lady, upon leaving the tram, had her foot crushed between the vehicle entrance and sidewalk. It was said that some 7 to 8 pedestrian fatalities are experienced yearly, mainly at station crossings. Some bad spots do exist in the system. For instance, at one station where Lines 9 and 11 branch off, the poor line of sight was responsible for 4 pedestrian deaths between May and September of 1976.

In the early afternoon, a ride was made with Mr. Nyman on Line No. 9 to visit the segment reconstructed to LRT standards in 1974. The particular stretch traverses 8 intersections where some priority is given to the light rail vehicle. The ROW located on the median of the street was protected with hedges on both sides. None of the intersections have gates. The minimum headway on the route is 3-3/4 minutes during peak hour; normal headway is 7-1/2 minutes. Some of these intersections carry relatively heavy vehicular traffic, 1,500 to 1,800 vehicles in the peak hour (Figure 28). LRVs are generally given precedence except at those intersections which traverse high priority roads. At one of the intersections traversed, a delay of 26 seconds was timed, perhaps because the signal timing had been changed.

There was only one experimental Vetag installation (Figure 29) in operation. In 1977 the experiment will provide data on the device's operation during summer conditions. The devices, installed at a T-type intersection, control through and turning movements of the light rail vehicles. The proliferation of Vetag installations at The Hague is somewhat curtailed by the unavailability of qualified personnel to design and oversee the installation of the equipment. Apparently, only a small work force is available and considerable delays are experienced.

On the last leg of the ride the difficulty of operating streetcars on very narrow streets became very apparent. The vehicle was forced to stop on a narrow street because a car had not parked close enough to the curb and extended an inch or so into the LRT ROW. The driver dismounted and tried to locate the owner through a shop-to-shop search. The search was unsuccessful but the LRV was not stopped for very long. With the aid of the driver of another stopped train, who monitored our side sway, the train was able to proceed very slowly, barely clearing the parked automobile. This incident, not at all uncommon, caused a 20-minute delay.

## CONVERSATIONS WITH MSSRS. VAN DILLEN AND VEGTER

A meeting with these gentlemen had been arranged by Dr. van Dam. Mssrs. Van Dillen and Vegter are both engaged in traffic research at the Ministry of Transport and they provided additional details on Holland's philosophy of traffic control. The work they described was related primarily to the preemption of signals in favor of bus operations, but the observations would be applicable



Figure 28. Line No. 9 Intersection, The Hague



Figure 29. Site of Vetag Installation in The Hague

to light rail as well. They indicated that in designing a preemption scheme it is necessary to maintain a minimum green time for crossing traffic. The earlier the detection of the arriving vehicle can be accomplished, the more latitude there is for clearing the intersection of conflicting traffic. To assist in this endeavor it is preferable to locate the station downstream of the intersection so that the traverse can be forecast with confidence. To increase the accuracy of the forecast time of arrival, multiple detectors can be used. Alternate loops can be located immediately after the station stop to provide intelligence about the departure of the vehicle.

The research work done by the Ministry, assisted by the Technical Institute at Delft and another institution, shows that the allocation of priority to transit can be made sensitive to traffic volumes. Messrs. Van Dillen and Vegter were aware of the impact of propagating traffic disturbances caused by the extension of red signals to favor passage of transit vehicles, but had not studied the problem extensively. The work at the Ministry is not designed to provide guidelines, but rather to help evaluate various City plans. To support the evaluative activity, computer simulations are carried out and experiments are conducted on various controllers and related devices. The experimental work concentrates on testing devices produced by various industries under the Ministry's guidance.

Some thinking is being given to the possibility of requiring Vetag equipment on all regional buses operating in the northwest of Holland. This would necessitate equipping highway intersections with the associated detectors and controllers. At the moment, only the buses in Delft have all been equipped with Vetag as are all of the signalized intersections in that City.

## SUMMARY OBSERVATIONS ON THE LINE

Although the stay in Holland was unfortunately too brief to allow for exploration in greater depth of the many aspects of light rail installations, the impression remains of a highly efficient system dedicated to slow but steady upgrading through utilization of more advanced equipment. The policies favoring public transport over private automobiles are typical of similar policies in other West European countries, but in Holland they seemed to require fewer controls and apply fewer constraints than observed elsewhere. Of all the countries visited, Holland appeared to have been hardest hit by the recent economic recession and by inflation. Transit development seems to have been seriously affected by the country's overall economic problems. The limited improvement work in evidence, at least at The Hague and Amsterdam, appeared to be keyed to modest upgrading of existing streetcar operations to LRT standards.



# CHAPTER 2

## TRANSIT AND URBAN TRANSPORTATION TRENDS IN SEVERAL EUROPEAN COUNTRIES

A REPORT ON A EUROPEAN TRIP BY  
DR. VUKAN R. VUCHIC

To collect data for the "Study of Low-Cost Methods for Improving Light Rail Transit (LRT) Service" from the countries which are most advanced in LRT development and deployment, a trip to Europe was undertaken in the fall of 1976. Major findings of the trip are included in this chapter.

There are three major sections in this chapter. The first one covers actual and administrative aspects of the trip itself, such as the cities and organizations visited, duration, etc. Technical and policy findings from the trip, i.e. a summary of the materials collected, constitute the second part. Brief summaries of the most interesting developments in the cities visited (and some others) are presented in the third part.

### TRIP DESCRIPTION

The cities and agencies to be visited were selected after careful consideration of the current events and developments in the issues to be studied. To obtain as complete a picture as possible it was necessary to visit several countries and the most progressive cities with respect to urban transportation generally and LRT specifically. The itinerary therefore included 13 cities in five countries. During the 20-day trip it was possible to visit a great number of agencies and institutions, and to contact leading persons in these fields because of careful preparation through correspondence as well as numerous previous personal contacts.

The most interesting were visits to the agencies operating the outstanding LRT systems: The Hague, Brussels, Cologne, Hannover and Mannheim. Discussions with the officials of national transit associations, particularly VOV in Cologne, with the director of the Ruhr Transit Federation, and with the officials in the German Ministry of Transport gave excellent insight into the trends in urban transportation policies. The same issues were, however, also discussed with the officials (mostly directors) in the transit agencies visited, persons who are extremely well versed and continuously active in the policy discussions on urban transportation. Countries, cities and agencies visited are listed in Table 3.

Other trip activities included visits to several universities (Belgrade, Munich and Hannover), contacts and lectures in professional societies (Belgrade and Hamburg) and field visits to transit lines and facilities in most cities. The most detailed field visits were in Brussels (pre-metro and Metro LRT lines), bus and Metro storage yards and maintenance shops, Mannheim (several excellent new LRT lines including tunnels, new LRT vehicles and buses, and maintenance shops), outstanding traffic signal installations with numerous special arrangements for LRT in Dusseldorf, several new partially grade-separated lines in Cologne and Bonn, and Metro in Milan.

### MAJOR FINDINGS AND CONCLUSIONS

Despite having continuously followed the developments in urban transportation in Europe through professional literature, correspondence and numerous personal contacts, this trip did

Table 3. Summary of Visited Countries, Cities and Agencies and Other Activities

Location		Visited agencies/persons					Other activities		Comments
Country	City	Transit Agency	Gov't Officials	Transit Organizations	Other Agencies/Officials	Field visit	Lecture		
The Netherlands	The Hague	x		<sup>1</sup> x		x		<sup>1</sup> National Assoc. of Transit Agencies	
Belgium	Brussels	x				<sup>1</sup> xx		<sup>1</sup> Extensive visit	
West Germany	Munich		x		<sup>1</sup> x	x	x	<sup>1</sup> University of Munich	
	Mannheim	x				xx			
	Ludwigshafen					x			
	Bonn		<sup>1</sup> x			x		<sup>1</sup> Federal Ministry of Transport	
	Cologne	x		<sup>1</sup> x		xx		<sup>1</sup> Assoc. of German Transit Agencies (VOV)	
	Düsseldorf			<sup>1</sup> x		x		<sup>1</sup> Ruhr Federation <sup>2</sup> Traffic Engineer; DÜWAG director	
	Essen					x			
	Hannover	x		<sup>1</sup> x		x		<sup>1</sup> University of Hannover	
	Hamburg	x			<sup>1</sup> x	x	x	<sup>1</sup> Transit Federation (HVV)	
Yugoslavia	Belgrade				<sup>1</sup> x		xx	<sup>1</sup> University of Belgrade Urban Planning Institute	
Italy	Milan	x				x			

yield a great number of additional facts and provided improved understanding of trends and numerous influences in this complex area. Changes in conditions and attitudes were particularly obvious in comparing these discussions with ones which took place, for example, in 1971, 1973 and 1976 with the same persons. The major findings, obtained facts and personal observations are summarized herein by major topics, from the most general to very specific technical ones.

## CONDITIONS AND ATTITUDES

The 1973/74 energy crisis, economic slowdown and reduced or diminished population growth have changed attitudes toward cities in Europe considerably. Instead of reliance on extrapolation of past trends with respect to population, auto ownership and usage, the spreading of cities, etc., the emphasis is now on a careful analysis of conditions existing at present, better utilization of existing facilities and, particularly strongly, improvement of the quality of the urban environment.

This change has resulted in some slowdown in rapid transit construction and, even more so, in freeway construction, but also in an increasing emphasis on better design and regulation of streets, intensified favoring of transit and pedestrian traffic, particularly through their separation from auto traffic. Bus lanes, LRT medians, signal priority treatments and pedestrian streets have been introduced in recent years at a faster rate than before.

Rapid transit construction has been slowed down, for example, in Hamburg, Milan and Amsterdam, but construction of LRT, limited to shorter sections and having shorter implementation periods, continues. Actually, in some cases it has been intensified through the shift of attention from rapid transit: the best example is Rotterdam where a line initially planned to be rapid transit is now being built as an LRT line. In several cities (The Hague, Braunschweig, Mannheim, Amsterdam) LRT is being substituted for some bus lines in order to achieve a greater comfort and reliability of service; in some cases, also to reduce operating costs for labor.

Federal governments are increasingly involved in giving financial assistance to transit, particularly for capital improvements, with the exception of Yugoslavia. In West Germany capital investment funds, obtained from gasoline taxes, have been available on a regular, stable basis since approximately 1967 and have supported construction of major infrastructure objects (tunnels, viaducts, yards, etc.) in more than 20 cities. In Belgium the government has contributed so far \$600 million for LRT and Metro construction in Brussels alone. In addition, it is assisting LRT construction in Antwerp (population 900,000), Ghent and Charleroi. In Italy \$500 million have been allocated for transit construction, but cities must have acceptable plans to qualify. Milan got a major share and will get more if by the end of 1977 the remaining sum is not fully taken by the other 7 cities which may qualify. In The Netherlands the government supplies both capital and operating assistance (the latter since 1975).

The changing attitudes toward cities and the urban environment which will be discussed below, have resulted in policies aimed at decreasing the use of automobiles in central urban areas through various disincentives. For example, supply of parking is limited, thus affecting its availability and/or cost to auto drivers (Hamburg has a ceiling of 30,000 spaces in the central area and does not permit further construction; London has introduced an ordinance which stipulates not the minimum, but the maximum number of parking spaces which each new building must have). Auto-restricted zones are another measure (best examples: Bremen, Gothenburg, Munich). Provision of a higher quality transit service, followed in principle for many years, has been more actively implemented since the late 1960s, and particularly during the last 5 years (introduction of an extensive network of bus lanes in Paris has been such a major step, discussed for many years, but implemented very recently, and with very substantial passenger increases). Opposition to these measures by auto industries and automobile clubs, which prevents most such schemes in Great Britain, is felt very slightly in Germany, but does not appear to be at all significant in The Netherlands and Belgium.

Parallel with the limiting of auto traffic there is a great intensification of improvements for pedestrians. While European countries have traditionally paid much more attention to pedestrians than has been the case in most U.S. cities, most of that attention was focused on pedestrian safety and convenience in moving on existing streets with auto traffic. Now that has grown into the provision of entire networks of pedestrianways, largely independent of streets with auto traffic. There is now hardly any city in the visited countries which has not converted one or several streets, or entire large zones to pedestrian traffic only. This conversion is always done with close coordination of transit services, resulting either in convenient access to subways (Munich, Cologne) or in transit malls with LRT (Mannheim, Munich, Rotterdam, Dortmund, Zurich) or buses.

## DIRECTION OF MAJOR EFFORTS

As a consequence of greater pragmatism in approaching urban transportation problems, there is an increasing effort to resolve problems, mostly institutional ones, which were considered until recently to be virtually insolvable. Particular emphasis is on the following three items:

- *Integration of transit services* to offer the passenger a single, unified system with logical and equitable fares. This is a major goal in all cities in which it has not been achieved. The successful examples of Hamburg, Munich and Frankfurt are now being followed, among others, by Milan and by the Ruhr Region. Both of these are extremely complex, with many operations and jurisdictions. Thus the Ruhr Region incorporates 21 municipalities, among which are 16 cities, some with populations of about 1 million. Its total population is 8.3 million. It is presently served by 18 transit agencies, regional rail of the Federal Railways and bus services of the Railways, Post Office, and 6 private companies. A complete integration of the tariff, coordination of schedules and improved network efficiency are planned for the near future.
- *Implementation of TSM* and its various components vary considerably. While some cities have a well-formulated policy toward the use of the automobile (Hamburg, Brussels) or very advanced transit preferential treatment measures (The Hague, Amsterdam, Gothenburg), others have only begun such efforts (Milan) because of little cooperation by traffic authorities.
- *Attitudes toward transit investment and operating costs* in the visited countries, particularly in West Germany, The Netherlands and Belgium, are characterized by an emphasis on two major goals. The first one is to improve the level of transit service in order to attract more passengers. The second one is to reduce, or slow down the increase in operating costs, particularly labor. Since these costs have recently been growing rather rapidly, the second goal has been getting increasing attention.

## Capital Investments

Capital investments, if properly planned, can achieve both of the above goals simultaneously: for example, placing an LRT line in a separated right-of-way (a median, aerial structure or tunnel) results in a faster and more reliable service. That directly increases level of service. At the same time higher speed and operation of larger train consists (e.g. two articulated cars) reduce labor costs for operation. Separated right-of-way usually also involves a lower track maintenance cost.

If transit stations are designed without regard to operating and maintenance costs, they may cause considerable increases in these costs compared with on-street operation. This has been the case in some oversized stations, particularly in West German cities. The trend is now



toward more careful planning for operations which will require lower costs than the system required prior to upgrading of facilities, or at least not cause an increase which is greater than the increase in ridership caused by the upgrading can reasonably justify.

Some of the investments into construction of transit facilities were influenced more by certain trends of "fashion" than by rational planning and careful feasibility analysis. Examples of this policy were investments into upgrading LRT systems to extremely high rapid transit standards even in medium size cities. With the changing trends it is now recognized that LRT systems which will not realistically be converted into rapid transit (a great majority of them), need not be built to such high standards. This will result in reduced investment costs for many LRT systems. A number of facilities presently under construction do not reflect this change since they were designed at the time of the most optimistic (and least realistic) assumptions about prospects for future financing. Many facilities designed more recently (e.g. the current improvements to LRT in The Hague) already reflect the trend toward functional, simpler design with low operating costs.

### Operating Costs and Operator Productivity

Most European transit systems have already achieved remarkable progress in increasing productivity of their operating personnel, the bus and LRT drivers. This productivity is measured in vehicle capacity and speed offered per operating employee (passenger-miles carried is not a good measure for this purpose since it is influenced by vehicle utilization, i.e. efficiency of scheduling, which is not necessarily related to the basic operating characteristics of a given transit mode). During the 1950s typical streetcar systems in European cities were operated as 2-car consist trains with 220 spaces and a 3-man crew at speeds typically about 14 km/h. This resulted in 1027 space-km/h/operating employee. After upgrading to LRT by providing separate rights-of-way, introducing articulated vehicles and one-man operation (possible through self-service fare collection), an LRT consist today often offers 420 spaces (e.g. the new LRT Line 1 in Bonn), and it is operated by one man at at least 20 km/h, resulting in a productivity of 8400 space-km/h/operating employee. Even if somewhat increased back-up personnel are added, the increase in productivity is substantial. As a contrast, productivities of typical transit drivers in U.S. cities operating a 70-space bus (53 seats, 17 standees), or a 100-space trolley, at a speed of 15 km/h (9 mph) in slow urban traffic are only, respectively, 1050 and 1500 space-km/h/operating employee. That productivity has not been changed for decades with the exception of relatively few routes operating on freeways. Labor costs per space-km (or space-mile) have therefore increased proportionately to labor wages plus fringe benefits.

The next step in productivity increase is expected in full automation of rapid transit (no personnel on trains), which is not only seriously discussed, but is planned for Helsinki and possibly for some German cities. Probably even more significant is the interest in developing a mini-rapid transit or light rapid transit: a mode which would have vehicles similar to LRT (probably somewhat smaller), but be fully grade-separated and automated.

### Roles of Government and Planning Agencies

Federal (national) governments are, due to their greater financial participation in transit, increasingly involved in monitoring actions of agencies. Scrutiny of plans is increasing and evaluations of projects are required. However, the government does not directly influence the choice of modes.

Cooperation between city planning agencies and transit planners varies greatly: from a very close one in Gothenburg, to a rather loose one which depends on "aggressiveness" of transit planners in some other cities. However, in most of the cities visited cooperation appears to be

greater than is typical for U.S. cities. In Germany a law is being introduced which specifies that a transit agency must take part in all relevant aspects of urban planning.

## Vehicle Standardization

Standardization efforts also vary considerably. A very successful effort was undertaken during the late 1960's in several countries to standardize buses. In West Germany alone thousands of standard "VOV buses" have been produced since that time. Other countries, like France, Belgium, Austria and Switzerland, also adopted models with many features in common with the VOV bus and often superior to typical transit buses operating in U.S. cities. Among these superior features are, for example, excellent suspension, better acceleration (although on some models exceeding the passenger comfort level), much lower noise levels, large windows, spacious double-lane doors, extremely efficient internal design (virtually all areas, except those used for the driver or for steps at doors, are used for passengers), and many others. Presently a new version of the standard bus, the *VOV Bus II*, is being tested in W. Germany. It features a low floor (540 mm or 21.2 inches) and only two steps (an additional step if between the aisle and seat areas, i.e. along their entire length). There was an opportunity to ride this as well as a new model of articulated bus in Hamburg and to discuss its features with their designer, Mr. O. Schultz.

With respect to light rail, rolling stock built between the late 1950s and early 1970s was highly standardized for most cities: the cars purchased by Cologne, Frankfurt, Wurzburg, Dortmund, Essen and many other cities differed from each other only in such details as body width (due to different existing clearances), seat arrangements, number and locations of doors, etc. This was not a result of a coordinated effort for standardization per se, but mainly due to the fact that the dominant manufacturer, DUWAG, was building one basic model which proved to have excellent characteristics. (Several cities, such as Munich, Bremen and Stuttgart, had vehicles with different basic designs.) With the major construction of high-type LRT systems (Stadtbahn) operating largely on separated rights-of-way, sometimes in tunnels, with high platforms, signalization, etc., several major systems ordered 8-axle cars of special designs, the Hannover model being the most sophisticated one, using thyristor choppers. Cologne developed its *B-car* which is the largest 6-axle LRV on the continent (27 m long, 2.65 m wide). This car has also been ordered by Bonn and more recently for the Ruhr Stadtbahn. The latest is *Model M*, ordered jointly by three cities in the Ruhr and Bielefeld in two versions: 6-axle and 8-axle. Thus, although all these cars are being built by DUWAG (in cooperation with several manufacturers of electrical and other equipment), they are now more diversified than during the 1960's because of a greater tendency on the part of each city to optimize car design for its specific conditions.

Fixed facilities, including clearances, track standards and design, electrical power supply, etc., have been standardized to a great extent because every system must comply with the very detailed set of standards (BO-Strab) which were developed by the federal government. An improved version is presently in preparation.

Similar to the trend in the U.S., transit vehicles have become increasingly technically sophisticated, particularly with respect to their electronic equipment. This has led to the following consequences:

- Improved performance and riding comfort (better motor control);
- Reduced maintenance of some parts (e.g. a skid prevention device has practically eliminated flat wheels);
- Increased overall maintenance cost due to greater vehicle complexity;

- Varied rates of energy consumption: it has been increased by greater vehicle weight, but decreased (some 20-30 percent) on the vehicles with thyristor choppers;
- Vehicle reliability (in terms of the absence of technical breakdowns) has been reduced;
- Vehicle purchase cost has increased appreciably: the Cologne B-car and the Hannover 8-axle car cost DM 1,300,000 (\$540,000) apiece.

Despite the similar trends in characteristics between European and U.S. transit equipment, it cannot be said that present conditions in the two areas of the world are in this respect similar. Reliability of the new European equipment has become lower, but this problem is not as serious as in some U.S. cities. The price difference which was heavily in the favor of European manufacturers has narrowed greatly. However, taking into account the low availability of many U.S. vehicle models, the price of European vehicles for a given delivery schedule is still lower. The difference between the U.S.-made vehicles and those produced in Eastern Europe (specifically, Tatra vehicle) does remain large.

It is interesting that while years ago there was a euphoria for building more and more sophisticated ("advanced") rolling stock, the attitudes of most high transit officials reflect the greater realism prevailing today: both operators and vehicle manufacturers express opinions that it would be very desirable that the vehicles be somewhat simpler and 20-30 percent cheaper. They complain, however, about the pressure by consultants, politicians and other decision-makers to use "the latest" in technological development regardless of how useful many of their features are for a given application and how much they increase vehicle costs.

#### ATTITUDES TOWARD DIFFERENT TRANSIT MODES

Decisions in selecting modes are based heavily on operating characteristics (desired level of service), with a major goal of attracting additional passengers. Also, selection of modes is based more on their respective quality of service than on their transporting capacities. Despite the increasing attention given to costs, they are considered as an important, but not necessarily the dominant factor. Operating costs, particularly labor costs, are given great attention. Their minimization is often considered more important than reduction of investment costs. In other words, if a vehicle which will increase a driver's productivity is more expensive than the one with lower productivity, it will be purchased unless the difference is unreasonably great. These considerations, combined with several other factors (such as land use planning aspects) lead to selection of rail modes for virtually all transit services involving high investment infrastructure, i.e. separate rights-of-way.

In the 13 cities visited there exists unanimous opinion that the main, heavily traveled lines should be served by rail modes. This is by no means the result of any bias against buses and trolleybuses: all of the visited cities have expanded bus services in recent years, particularly in outlying areas. However, the experience of all these cities is that the superiority of rail modes in their level of service, identity, absence of air pollution and noise, and mutual support with urban development combined with faster, more reliable operation resulting from private rights-of-way to which they are best suited, make these modes more desirable from the point of view of passengers, the operator, and the city. Consequently, in all the visited cities except Belgrade there has been major construction of LRT and/or rapid transit lines during the last 5 years. Plans exist for more such construction in the future in all these cities, including Belgrade.

With respect to the choice among rail modes, there is much less unanimity, however. The opinions about the roles of regional rail, rapid transit and light rail vary not only among different groups, but they have changed significantly during the last 3-4 years for the reasons mentioned

above. With the increasing construction costs and the trend to concentrate on improvements which can be sooner utilized, LRT has gained considerably at the expense of RT. This is obvious from several examples:

- Amsterdam has decided not to build railroad transit after completing its first line; at the same time several extensions of LRT have been built.
- Brussels, having speeded up conversion of one pre-metro LRT line into rail rapid transit has now decided not to convert other LRT lines in the foreseeable future.
- Milan is completing its Metro rapid transit Line 2, but will not construct other Metro lines in the foreseeable future. It is planning construction of a major circumferential LRT line, substituting for trolleybuses.

The situation in West Germany is particularly interesting. The decisions of West Berlin and Hamburg in the late 1950s to expand rapid transit and eliminate streetcars (modernization of these stopped at that time) led to an imposition of a rapid transit fashion for the use of rail rapid transit which extended to medium and even small cities where this mode is not at all applicable. The cities like Munich and Stuttgart, under directors formerly from Hamburg, declared that they would construct rail rapid transit systems and eventually abandon LRT. Some of the negative remarks about LRT from these cities, implying that rail rapid transit is always better as a "permanent solution" than LRT, have also obtained some publicity in this country (e.g. an interview with Mr. Engelbrecht, Director from Munich, in a recent issue of "Mass Transit"). Other cities, including Dusseldorf, Cologne, Hannover and several others began to talk exclusively about rail rapid transit *U-Bahn*, although the systems they have been constructing are the most typical examples of modern LRT and there are no chances that they will be converted into rail rapid transit in the foreseeable future.

Observing characteristics of LRT systems developed in different cities, one can clearly see the extremely wide variety of network concepts, operating practices and rolling stock characteristics which this mode can have. There are some opinions that the Zurich and Amsterdam LRT systems have excessively low performance or that the approach adopted by Cologne, Bonn and the Ruhr Region is overly ambitious for LRT. The evaluation of which variation is the "proper" one actually depends on many factors, including the existing network, physical and political conditions, etc., so that it actually varies considerably among cities. There is no single type of LRT which is the best for all applications.

In 1976 one finds the upgrading of LRT continuing through construction of private rights-of-way, tunnels, malls, etc., but earlier unrealistic ambitions to convert these systems into rail rapid transit have been greatly deflated. Cologne and Hannover have realistic attitudes toward their LRT systems, and Stuttgart has reversed its position: it has given up its intentions to build a "pure rail rapid transit system."

Consequently, it is quite clear that the role of LRT in relation to other transit modes has increased considerably in recent years. Not many entirely new LRT systems are being built for two reasons:

- In the countries in which streetcars were abandoned and LRT does not exist, this mode is seriously discussed, but transit financing has not been resolved (Great Britain, France).
- In the countries like The Netherlands, Belgium, and West Germany, cities which need rail transit already have it: they need only improvements of existing systems and their expansion, both of which are being done.

As mentioned, Amsterdam and The Hague have built in the last 5 years new LRT lines, substituting for buses; Gothenburg has increased its LRT network from 139 to 164 km in the last 15 years, but is now static because the city's population has stabilized.

A review of the construction of new LRT lines in West German cities since 1970, given in Table 4, shows that this activity has not been negligible in Germany.

The construction listed in the table shows only entirely new lines or extensions of existing networks, but it does not by any means show the entire effort on LRT construction in West Germany. The vast majority of funds have been expended on reconstruction and upgrading of existing lines, particularly in city centers. New grade-separated sections, mostly tunnels, for LRT have been constructed since 1967 in the following West German cities: Bielefeld, Bonn, Bremen, Cologne, Duisburg, Dusseldorf, Essen, Frankfurt, Hannover, Ludwigshafen, Mannheim, Mulheim and several other Ruhr cities, and Stuttgart. At the same time new rapid transit lines have been built in Berlin and Hamburg, and new rail rapid transit systems opened in Munich and Nuremberg. In all cases this construction was done together with major reconstruction of streets, intersections, or entire urban areas, connecting the upgraded lines with malls, individual buildings or construction of new shopping or office areas, railroad and long distance bus stations, etc. Good illustrations of the magnitude of this construction are found in Cologne (Koln), which now has 24 km of fully grade-separated LRT lines, a longer network than the lengths of rapid transit networks in some cities (Rotterdam, Glasgow). Stuttgart, Frankfurt and Hannover also have lines which are quite similar by their physical and operating features to rapid transit. Thus the table is given to indicate that expansions of networks are being undertaken, but it does not reflect the full financing effort for transit in each country since the focus has been primarily on radical upgrading of the networks within cities.

In some of the cities the LRT systems were nearly abandoned: Bielefeld and Braunschweig in Germany and Charleroi in Belgium were very close to converting them into bus lines during the mid-1960s. A complete reversal of policies resulted in upgrading these systems into high-quality LRT systems; the process, similar to construction of entirely new systems, continues at the present time.

With the upgrading of LRT systems in many different ways (large vehicles, 2-car or 3-car trains, tunnels, signalization, high-level platforms, off-vehicle fare collection, etc.) the concepts of LRT and rail rapid transit are becoming more similar than they were before. The basic distinction remains the full separation of right-of-way over its entire length for rail rapid transit lines, which gives this mode its major difference over LRT, precisely defined by Lehner at the LRT Conference in Philadelphia, 1975. The other major differences are:

- Higher investment cost;
- Longer construction;
- Higher performance;
- Higher passenger attraction.

The question of when a bus line should be converted to LRT was answered rather precisely in The Hague. Since reliability is one of the most important characteristics of transit service, LRT is usually introduced to increase reliability by operating at longer than minimum headways. In The Hague standard buses have a capacity of 60-70 persons and disturbances on lines occur when headways of approximately 3 minutes are operated in mixed traffic, or approximately 1-2 minutes when interference by other traffic is very light. The delays are generated at stops due to variations in boarding/alighting times. Since 3 buses are substituted by one 2-car train in The Hague, the

Table 4. Expansion of LRT Networks in West Germany Since 1970

City	Network length (km) as of 12/31/69	Length of New Lines (km)	Year Opened
Bielefeld	23.6	0.5	1970
		0.9	1971
Bochum	112.6	4.9	1971
Braunschweig	13.5	2.9	1970
		2.7	1972
		2.0	1974
		6.6	(under constr.)
Bremen	54.1	3.4	1973
		2.7	1976
Dortmund	86.3	4.2	1976
Dusseldorf	130.8	0.4	1977*
		1.1	1978/9*
Frankfurt	132.8	2.3	1975
		1.4	1976
Hannover	86.0	2.2	1973
		1.2	1976
Karlsruhe	39.2	1.2	1970
		0.6	1971
		2.7	1975
Cologne	127.7	1.7	1970
Krefeld	36.4	3.2	1970/5/6
Mainz	18.9	1.1	(under constr.)
Mannheim	48.5	4.2	1970
		1.0	1972
		0.7	1974
		4.0	(in preparation)
Munich**	125.6	2.2	1970
		1.4	1970
		1.0	1973
		2.2	(in preparation)
Nuremberg**	69.5	0.3	1970
		0.8	1972
		0.6	1974
Stuttgart	130.0	1.5	1970
Total:		opened to traffic since 1970:	54.4
		under construction	9.2
		in preparation	6.2
Grand total			69.8

\*Planned opening dates.

\*\*Rapid transit lines also opened since 1970.

Note: In addition to these new lines numerous lines or sections have been relocated to separate rights-of-way, including tunnels, and upgraded in other ways. For example, both Bielefeld and Kassel relocated 20% of their networks into new rights-of-way.

Source: Reported by VÖV in *Verkehr und Technik*, issues 4/1976 and 8/1976.

headways with LRT become three times longer, allowing a stable operation. Thus in The Hague, a peak hour passenger volume of 1500-4000, depending on traffic conditions, is considered to warrant a separated right-of-way and introduction of LRT. In other cities capacities of vehicle units are often different: articulated buses carry 100-120 persons; LRT carries 150 (6-axle, single unit) to 400 (8-axle, 2-car trains, such as in Hannover). The ratio of LRT capacity bus unit thus may vary from 2 to 4, sometimes more. Again, as is always emphasized in responsible professional literature, this factor of peak-hour passenger volumes is by no means a single, fixed criterion for mode selection. In The Hague as well as all other cities, many other factors can contribute and be either in favor of or against LRT.

Recent experiences show that introduction or major upgrading of LRT lines has a significant impact on passenger attraction. Substitution of a good bus line by LRT with high frequency of service in The Hague (the new Line 9) resulted in an increase of passengers by 18 percent during the peaks, 32 percent during off-peaks, and an overall increase of 22 percent. The new line gives a better connection with the central city area (which may account for some of the increase), but it offers a slightly lower frequency of service. A detailed survey on this line shows that most passengers value mostly the higher speed, reliability (because of private right-of-way) and greater comfort of rail vehicles than buses.

A dramatic passenger increase in Brussels after the opening of the first pre-metro LRT line in 1969 has been quoted many times in transit literature. A similar phenomenon has now occurred in Hannover. Opening of a tunnel through the city center, improvement of a central median right-of-way and introduction of new cars has resulted in a 40 percent increase of passengers. A small part of this is caused by abandoning two lightly traveled bus lines paralleling the LRT alignment closely, but most of the patronage growth is caused by the higher level of service and shorter headways (two routes each at 8-min headway during off-peak hours), which became economically feasible due to the higher ridership.

## TECHNICAL DEVELOPMENTS IN LRT

Among the most significant trends noticed in LRT technical innovations were the following:

- *The classical 4-axle cars are definitely giving way to articulated vehicles.* This is obvious from a review of the cities which have been the most persistent users of 4-axle cars. Brussels, which relied on 4-axle cars until the early 1970s, now utilizes 6-axle cars, and has ordered 100 8-axle cars. The Hague, operating trains of two 4-axle cars, is planning to change to articulated equipment: better space utilization and the problems with supervision of the second 4-axle car in 2-car consists are the main reasons. Milan has had single 4-axle cars; it is now obtaining 144 very long (about 30 m) 8-axle cars, even for the lines operating mostly on streets. Belgrade is considering purchase of articulated cars. Gothenburg, which does not need additional cars now, and smaller Belgian cities (Antwerp, Ghent) are among the few cities which remain without articulated vehicles.
- *Among articulated vehicles, the 8-axle is becoming more popular than the 6-axle car,* although many cities remain with the 6-axle type.
- *Trolley poles are becoming things of the past.* Brussels, Milan and Belgrade are substituting them with pantographs. In the entire country of West Germany, trolley poles are found only in Hamburg, which does not intend to retain LRT.
- *The Hague has built medium-height platforms at LRT stations and even at street island stops.* The 30-cm high platform matches the first step and reduces the height passengers must climb from about 85 cm to 55 cm. For comparison, the low-floor VOV Bus II has a floor

height of 54 cm (21 inches) only due to numerous compromises, a step up to the floor under seats, a sloped aisle, etc. Construction of the islands is rather inexpensive.

- *Pedestrian crossings are not only allowed, but facilitated by pavements flush with rails.* In the pedestrian malls (Mannheim) LRT operates with a very high frequency and long train compositions (including 12-axle cars) without any protection or separation, although train speed is limited to 25 km/h. For high-speed lines, pedestrian crossings are built mostly at stops, allowing access to both directions.
- *Great emphasis is being placed on regular, easy-to-remember schedules, and on using the same basic headways for all lines, e.g. 7-1/2, 15 and 30 minutes.* Reliable, predictable service is considered much more desirable than any type of "flexible scheduling," at least on all of the regular transit lines.
- *With careful design, fixed time signal systems can be far superior to vehicle actuated ones with respect to both auto traffic and transit vehicles.* Convincing proof of this was provided by one of the leading experts for traffic signals, Dr. von Stein in Dusseldorf. His system of providing special time slots for LRT travel within green bands of signal progression for other traffic is a truly impressive technical achievement.
- *With respect to TSM in general, many European cities are ahead of U.S. cities, but they also have a long distance to go to achieve fully coordinated handling of all modes.*
- *Separation of transit vehicles, particularly LRT, has had priority in most urban transport improvements for a number of years and the results of this policy are paying off.* In most of the visited cities separated LRT rights-of-way amount to between 50 and 85 percent of the network length. The only exceptions are Milan (22 percent) and Hamburg.
- *Self-service fare collection is a generally used system, fully accepted by the public.* The important experience of European transit operators, which is not well understood in the U.S., is that articulated vehicles, with the much higher level of productivity and efficiency they can offer, cannot be fully utilized as long as fare collection is a slow, one-by-one procedure at the entrance door. An explanation of why self-service started and how it was introduced is provided in the companion volume entitled *Light Rail Transit Operational Considerations*.

## **BRIEF REVIEW OF THE VISITED CITIES**

Since the most significant developments in urban transportation in Europe generally, and technical developments in LRT specifically, have been summarized above, this section will contain only a brief review of the most important features and trends in the visited cities.

### **THE NETHERLANDS**

*The Hague*, capital of Holland, has an excellent LRT network which consists of private rights-of-way in suburbs and some street running in the city center. During the early 1970s there were plans to construct tunnels for the downtown sections. However, the plans were abandoned for two major reasons. First, population growth has slowed, reducing projected capacity requirements. Second, traffic management schemes and improved traffic engineering have been introduced which increase speed and reliability of service on surface streets at moderate cost.

The LRT network has been extended in several directions to connect new suburban developments or substitute for bus lines. All the extensions are on separate rights-of-way with



signalized crossings and well designed, unsignalized pedestrian crossings. Station platforms are elevated 30 cm above rail heads, facilitating boarding/alighting. The most recent new line is No. 9 to the west, which has an operating speed of 25 km/h (14 m/h) on the new section. It attracts 22 percent more passengers than did the buses which preceded it.

A number of street lanes have been separated for LRT; in some cases they are shared with buses. LRVs have special signals at most intersections, in some cases actuated. The latest development is the introduction of Philips' Vetag signal system which "recognizes" a vehicle through inquiring its code. Thus, it can distinguish transit buses from other vehicles and set signals accordingly. It can also be used for setting LRT switches, directional signs, etc.

There is no legal restriction on LRT maximum speeds, but a practical limit is 70 km/h (44 m/h). At grade crossings LRT is supposed to have the ability to make an emergency stop if necessary. Running in pedestrian malls is limited to 30 km/h (19 m/h).

Fare collection is mostly by self-service; tickets are sold at many shops and stores throughout the city at Fl. 0.60 (25c), but if a person purchases one on-board from the driver, the price is Fl. 1.15, or nearly double.

*Amsterdam* has a rapid transit line under construction. It had been planned as the first line of an extensive network. Major protests against rapid transit by those concerned with drastic changes in Amsterdam's unique urban environment, historic character and difficult terrain led to the decision that the emphasis will be shifted to modernization of LRT. The city has already introduced a great number of low-cost improvements favoring this mode such as curbed medians, pedestrian malls with LRT, special signal phases, parking restrictions, etc.

*Utrecht* has a new LRT line under construction. This city abandoned streetcars 38 years ago.

## BELGIUM

*Brussels* follows a policy of no additional office space nor parking in the central city; residences, cultural and commercial activities are, on the other hand, encouraged to maintain the diversity and prevent excessive specialization and loss of the desirable urban environment.

Because of its ambition to make Brussels "the capital of Europe," the Belgian government has been making major investments in its transit system. Progress during the last 8 years has been dramatic. By 1971 two tunnels for pre-metro (LRT designed for later conversion to rail rapid transit) were opened, each one used by 5 LRT lines. Since 1971 one of these tunnels (No. 1, to the east) has been extended and converted into rail rapid transit and another two tunnels have been constructed and opened for LRT. While the rail rapid transit line is being extended through the center to the west, it has been decided that the remaining upgraded lines will remain LRT rather than be converted into rail rapid transit. Four-axle cars are being substituted by 6-axle cars and 100 8-axle cars are on order.

The goal is to expand the existing 21 km of tunnels with 34 stations to 60 km of tunnels. Total length of LRT lines will be 75 km. They will connect with 250 km of bus routes serving outlying areas. Thus the central city will be served by rail rapid transit and LRT, largely separated from traffic interferences.

## GERMANY

*Munich* continues to construct its excellent RT system. Some of its officials imply that LRT is only a "temporary solution" until rail rapid transit substitutes it. However, the LRT network is extensive and of very high quality (over 2/3 of its length on separate rights-of-way) and it has been extended

in some suburban areas (see the preceding table). Realistically, it should be expected that LRT will remain a major transit carrier for at least several decades, if not indefinite.

*Mannheim and Ludwigshafen*, twin cities on opposite sides of the Rhine river, have together with their surroundings a population of 1.6 million. Transit systems of the two cities are fully integrated and several lines connect them over two bridges. Their LRT system has been continuously modernized and expanded with the growth of the urban area. Presently the system is technically impeccable: many private rights-of-way, separate signals for LRT, excellent tracks and power supply systems. The vehicles are modern, but not excessively complicated.

Three features are particularly interesting. One is an elaborate system of tracks in a wide median along a ring street which carries many different lines: prior to each intersection where LRT turns, a separate track is provided for the turning cars so that other cars can travel straight or turn right without delay. Second is a recently constructed line to a new suburban development at Vogelstang. The LRT line follows a beautifully designed median, then leaves the highway which serves the development from its periphery and penetrates into its center: its shopping and school area. The LRT station is located within the building complex. The third feature is a mall in the main shopping street (Planken) for pedestrians and LRT only, the LRT operates at intervals not much longer than 1 min. per direction during rush hours. The mall is considered to be a major step in the modernization of the central area.

Plans for Mannheim/Ludwigshafen, influenced by the "Hamburg School," called for rapid transit systems substituting LRT. Pursuant to the plans a substantial tunnel complex was constructed in Ludwigshafen. Although used by LRT, this complex is obviously greatly overdesigned and can have no rational justification. The plans are now being scaled down and it is rather obvious that rail rapid transit will not be seriously considered any longer. Further gradual improvements of LRT should be expected, including a tunnel in an area of heavy congestion in Mannheim.

*Bonn* has also constructed a facility which may be considered too large for its size: an underground line operated as LRT. However, the project is justified partly on the basis of the special status of Bonn as the capital of West Germany. Incidentally, this aspect, clearly very important also in the case of Washington, D.C., is intentionally ignored by the critics of the Metro. Washington does not belong only to its local neighborhoods: it has a major significance for the nation. This factor cannot be evaluated by any cost/benefit analysis.

The interesting feature of this line in Bonn is that it has a section in the subway with high platforms, then runs in a street median with signalized crossings, and finally, in the suburb (Bad Godesberg) it runs on the street. This clearly demonstrates one of the most significant features of LRT: its diversity of usage with respect to right-of-way type and operating regulations.

*Cologne* is continuing to upgrade its very complete radial/circumferential network. It has excellent examples of different right-of-way types such as tunnels, elevated lines, at-grade crossings, etc. Its LRT system is one of the highest quality systems in operation today. Most cars are 30 m long, 2.50 m wide. With the maximum frequency of 46 cars/h, the system offers a capacity of between 11,000 and 12,000 spaces per hour. With the coupling of cars this capacity could be raised considerably.

It is interesting that the subway section in Cologne has at-grade crossings of tracks of different lines which have no significant impact on operations. The tracks are signal controlled.

*Dusseldorf* has, as mentioned above, the most sophisticated traffic signal system with special provisions for LRT. A number of these installations were visited. They were also discussed, with their designer, Dr. von Stein, and technical materials about them were obtained.

*Essen* and other Ruhr cities are currently involved in the preparation of a transit federation for the entire region, and in construction of a regional rail transit system. Conceived to guarantee high population mobility which, the experience has shown, decreases unemployment, the system has undergone several modifications so far. Because of the extremely high cost of the initially planned rail rapid transit network, it appears now that a smaller system of LRT will be built.

In addition to discussing this present state of the Ruhr Region transit, the LRT was observed line operating in a freeway median, one of the first in the world (opened about 1960).

*Hannover* has opened a new tunnel through which two high speed LRT lines are operated, increasing the original patronage by some 40 percent. Another tunnel is under construction. The 8-axle cars which have been purchased for the modernized lines have very advanced electronic equipment, including thyristor chopper control, but apparently do not have excessive maintenance problems.

The transit agency has developed, under the sponsorship of the Ministry of Transport, a control system for the lines merging at the tunnel entrance. The system allows delayed vehicles to speed up by signal override at intersections (vehicles running on schedule cannot use the override), so that regularity of headways is maintained.

*Hamburg* has an outstanding system of rail rapid transit and regional rail, operating with extreme precision and reliability. Abandonment of streetcars has been pressed for many years, but has been delayed by the pressures from citizens. Three suburban diesel rail lines, feeders to the rail rapid transit are functionally a kind of LRT. Their crossing controls have recently been changed from signal only to signal with barriers. The cars, being powered by diesel engines rather than electric motor, have performance more similar to railroad cars than to LRT. They do not have magnetic track brakes.

## YUGOSLAVIA

*Belgrade* has a situation in transit planning typical for several cities: following an act of the legislature a specially formed group is planning a metro rail rapid transit of 58 km length, 85 percent in tunnels, despite difficult geological conditions. In addition, a new regional rail network is planned. The transit agency and the Urban Planning Institute are pressing, however, for a modern LRT system, utilizing the existing network which is over 90 percent on private rights-of-way. It is quite obvious that a modernized LRT would offer improvements to otherwise poor traffic conditions much sooner than the metro. But even more significant is the fact that the cost of the metro/regional rail project is much higher than the financial resources the city can realistically expect to obtain.

My two invited lectures on planning of rail transit were well attended.

## ITALY

*Milan* has extremely heavy transit ridership. Its two Metro lines are very well used. In addition, the city has regional rail, streetcars and LRT (the latter mostly on suburban lines), trolleybuses and buses. After long delays in fleet modernization, 144 8-axle LRT vehicles have been purchased. It is interesting that the experience with articulated buses has been contrary to that with LRT: articulated buses have not proved practical on busy urban streets. Trolleybuses are not planned for modernization (the opposite trend is found in Switzerland).

The major effort in Milan is now integration of all transit services in the region with respect to network, scheduling and fare collection.



## CHAPTER 3

# AT-GRADE OPERATION OF RAIL TRANSIT IN NORTH AMERICA

A REPORT BY  
H. KORVE, G. FOX AND R. SAUVE

This chapter provides a general overview of current and planned light rail practice in North America with regard to at-grade crossings. The major existing and planned LRT systems in North America are reviewed. The three largest U.S. systems - San Francisco, Boston, and Philadelphia - are reported in depth. The investigation of these systems involved detailed field inspections and interviews with local transit and traffic engineering authorities. For the other seven systems reviewed - Edmonton and Calgary (Canada), Chicago, Cleveland, Pittsburgh, Toronto (Canada) and Buffalo - data is provided which covers important examples of at-grade LRT type operation for both existing systems and systems under construction. These 7 systems were investigated in less depth because they generally exhibited fewer varieties of crossing situations.

North American cities that operate LRT that have not been included in this report are:

- *Mexico City, Mexico*, which operates 250 PCC cars over 170 km of track. All operation is shared with motor vehicles but some transit priority treatments, such as motor vehicle left turn prohibitions, are provided. This system has the unique feature of loading passengers via doors on the left side of the vehicle whenever possible.
- *Newark, New Jersey*, which operates 26 PCC cars over a single 6.8-km route but only has one at-grade crossing.
- *Veracruz, Mexico*, which operates 6 routes, totalling 16 km, with 15 vehicles primarily (94 percent) in mixed flow on-street. However, there are few traffic controls in the city itself and there is relatively little auto traffic.
- *New Orleans, Detroit, and Yakima*, which are primarily historical operations, technically not relevant to this study.

Each LRT city surveyed is discussed in a separate section. Key elements that have been investigated for each system and reviewed in each chapter include:

- Types of right-of-way (mixed flow, median operation, private right-of-way).
- LRT and traffic control strategies used at crossings including operating rules, control devices, priority considerations and techniques, and detection methods.
- Future plans for upgrading and expanding.
- Safety experience.
- Jurisdictional constraints.
- Contracts.

The following summary of these LRT system elements provides a general summary of at-grade operating experience and future potential.

## SUMMARY OF FINDINGS

Both general and specific aspects of this investigation are summarized. Review of the 10 primary new and existing North American LRT systems has resulted in the following general conclusions:

- All of the cities with LRT have made strong commitments to improve their systems and recognize the importance of the LRT systems in providing transit service.
- Many cities with LRT have only recently decided to improve and upgrade their operations. In many cases, improvement implementation is still in the planning stage.
- Cities in both Canada and the U.S. are presently constructing LRT systems with large portions of line segments operated at-grade. Priority and control treatments for at-grade LRT crossings are being given serious study and consideration, and are not felt to be unduly hazardous or detrimental to the operation. Some form of priority will usually be granted to LRT over motor vehicle traffic.
- Special priority treatments are presently only developed for LRT where special LRT turning or crossing problems exist.
- At those crossings where special priority is granted to LRT, operation is usually much smoother and safer than without the treatment.
- Crossing control treatments lack uniform application or consistent approach both within and between systems, and are based mostly on outdated technology and standards.
- Most running delay and accident hazards for LRT occur in mixed traffic operation, still the most common right-of-way treatment.
- Most existing LRT systems are moving toward improved control of at-grade crossings and line segments. Improvements include:
  - Adding painted or raised medians to formerly mixed flow operation
  - Preemption of traffic signals by LRT
  - Special traffic signal timing along LRT routes to give it conditional or absolute priority
  - Grade separation of severely congested line segments
  - Selective installation of passenger platforms
- There is a general lack of developed data regarding LRT accident and delay histories at specific sites. There is also little comprehensive analysis being done on available data designed to pinpoint problem locations and develop plans to correct them.
- Three cities - two in Canada and one in the U.S. - are constructing entirely new LRT systems.

## SYSTEM CHARACTERISTICS

Table 5 presents the number of double track route miles and kilometers and number of existing and future rolling stock for each of the cities surveyed. The largest system is Philadelphia,

followed by Toronto, Boston, and San Francisco. The smallest systems are those under design or construction - Edmonton, Calgary, and Buffalo.

**Table 5. LRT System Characteristics**

LRT System Location	Route Miles of Double Track (kilometers)		Rolling Stock Existing (on Order)	
	Miles	Kilometers	Existing	On Order
San Francisco	19	(30 km)	115	(100)
Boston	24	(36 km)	296	(175)
Philadelphia	87	(139 km)	350	
Edmonton*	4.5	(7 km)	14	
Calgary**	8	(13 km)	--	(27)
Chicago***	9	(14 km)	700	
Cleveland	13	(21 km)	55	(48-67)
Pittsburgh	10	(32 km)	95	
Toronto	40	(64 km)	370	(200)
Buffalo**	6.4	(10 km)	--	(47)

- \* Scheduled completion, Spring 1978
- \*\* Begin construction 1978
- \*\*\* CTA rail system with at-grade crossings (entire system has 143 km of line)

## RIGHT-OF-WAY

LRT systems often operate on a variety of mixed flow, semi-exclusive and exclusive rights-of-way. The three systems studied in detail reflect this right-of-way diversity. The percentages of different right-of-way treatments for these systems are summarized in the following table:

**Table 6. Percent of LRT System Rights-of-Way by Type**

System	Mixed Flow	Private Right-of-Way and Median	Subway or Elevated
San Francisco	70	12	18
Boston	22	63	15
Philadelphia	98	--	2
CTA Red Arrow	--	100	--

Both the San Francisco and Philadelphia CTA LRT systems operate predominantly in mixed traffic flow, while the Boston system operates primarily on medians and on private right-of-way. The Red Arrow division of SEPTA operates 2 LRT lines almost entirely on exclusive right-of-way with at-grade crossings.

## CROSSING CONTROL STRATEGIES

A variety of LRT crossing control strategies are used. The selection of an appropriate strategy is dependent on several variables, particularly the type of right-of-way treatment and the type of crossing traffic.

### LRT Operation in Mixed Flow

LRT in mixed flow is almost always governed by the same traffic laws with regard to traffic control, right-of-way and speed as other vehicular traffic. Traffic controls include stop signs as well as traffic signals, and sometimes intersections are uncontrolled. LRT operates in mixed flow on both two-way and one-way streets which are generally minor arterials. There are exceptions to this, however, such as in San Francisco where all lines partially operate on a major CBD arterial. Traffic signal priority is usually given to LRT where it must negotiate movements which would otherwise present accident potential. Left- and right-turn LRT movements are sometimes given separate traffic signal phases or a leading traffic signal indication to allow the LRV to enter an intersection ahead of conflicting motor vehicle traffic. LRVs sometimes actuate their priority signal phases by magnetic or overhead wire contact switches, although many of the priority phases are fixed time. Mixed flow operation presents the most difficult environment for LRT in terms of operating speeds and safety, especially through commercial areas due to heavy auto, truck and pedestrian activity.

### Median Operation

Most LRT systems operate in part along protective medians, although this type of ROW does not generally predominate. LRTs operating in medians generally follow the traffic laws which apply to adjacent motor vehicles.

Both painted and raised medians are found. Many of these are narrow - 20-25 feet wide, although some are very wide. LRT medians are not always open for minor cross streets. Various fencing treatments are used, often inconsistently even within the same city. Fencing is sometimes found on both sides of the tracks or in between tracks. Unfenced medians are also found. Median openings at cross streets are usually controlled by traffic signals. Left turns across the LRT tracks are permitted in most cases and are sometimes controlled by separate turn phases. Accident problems have resulted at many locations from uncontrolled left turns across LRT ROW. The traffic signal that controls adjacent motor vehicle traffic controls LRT under normal circumstances. When special phasing for LRT or protected left turn phasing for motor vehicles is employed, separate LRT signal indications are usually provided. These special LRT signals can take the following forms:

- Standard traffic signals with signs to indicate they are for LRT
- Special LRT signals such as red and green "X" signal heads
- Programmed visibility or louvered traffic signal heads that are adjusted so that only the LRT operator can see them



## Private Right-of-Way

Private right-of-way is found on most LRT systems and includes tunnels, grade separations, aerial and at-grade crossing operations. Only the at-grade crossings were reviewed.

LRT operation on private right-of-way is the least common type of operation in most cities, due to its higher cost. The exception is the Chicago system which operates all of its at-grade rail lines on private right-of-way. LRT operates along private right-of-way under systemwide rules that determine exact travel speeds, stop locations, crossing policies, right-of-way rules and safety considerations.

LRT crossings of highways are usually controlled. However, the level and type of control varies widely between and within cities even for similar crossing situations. The degree of positive (in terms of assignment of vehicular right-of-way) control is somewhat a factor of roadway motor vehicle traffic volumes, LRT service frequency and the age of the installation. The different types of crossing control used are:

- No control.
- No control for autos but a stop for LRT.
- Warning sign control of motor vehicle traffic. Signs include "RR Crossings" and "Stop, Look and Listen" signs and railroad crossbucks.
- Flashing railroad warning lights.
- Stop signs for both LRT and motor vehicle traffic.
- Traffic signal control.
- Railroad gate and flashing light control of auto traffic.
- Traffic signal control with railroad gates.

Each transit property generally uses only a few of these methods to control its crossings.

The CTA in Chicago is the only property that presently uses gates to protect its crossings. These are placed at all crossings. The new Edmonton LRT system will use gates to control its private right-of-way line segment, as will the new Calgary system.

Priority is granted LRT under some of the control strategies. In Chicago, transit receives absolute priority at at-grade crossings. Sometimes priority is given LRT at signalized locations that are entry/exit points to private right-of-way line segments that interface with median or mixed flow operation. This is necessary because private line segments often emerge from the side of highways that contain median or mixed flow LRT.

## Pedestrian Crossings

*Pedestrian cross traffic in mixed flow LRT operation* is generally controlled by existing traffic signals and few special provisions are made. Passenger loading platforms are usually not provided due to the absence of available street space. Platforms have been shown to present an accident hazard to motor vehicles at locations where they were once provided. Philadelphia has developed sloping concrete barriers to protect platforms from encroaching autos.

*Pedestrian traffic in median operation* is also generally controlled by the existing fixed time or actuated traffic signal system. In some cases, special crosswalk treatments have been developed to accommodate or restrict pedestrian flow to allow LRT priority treatments to function. Platforms are nearly always provided in median operation even if the median is only painted. They are generally located on the outside of the LRT tracks, both on the near and far sides. In many cases, platforms are located side by side. Fencing is occasionally provided between or on the outside of median tracks to prevent midblock pedestrian crossings. Sometimes, especially in recent installations, fencing is placed between adjacent platforms to prevent crossings between them.

*Private rights-of-way* are usually fenced on either side. Signing occasionally warns pedestrians not to walk on the tracks. In Chicago, which uses third rail on most at-grade segments, devices similar to cattle guards are installed on the entrances to private rights-of-way. Pedestrians crossing private rights-of-way at at-grade crossings are usually expected to obey the auto control or to depend on personal alertness to avoid a collision. The primary exceptions are at crossing locations that have traffic signals with pedestrian indications and at some crossings in Chicago with special gates to control pedestrians.

## FUTURE PLANS

LRT system improvement plans are summarized in Table 7. Most of the existing LRT systems have improvement plans that include car procurement, train protection, new tracks, line expansions and intersection priority treatments.

San Francisco has nearly completed an ambitious downtown LRT subway project. LRT improvement plans in some of the other cities are now in the construction phase, while others remain conceptual. Of the three new systems, two are expected to be operational sometime in 1982 and the third is expected to be completed in 1978. This indicates that LRT is a mode recognized by its operators as both needing and worthy of large infusions of capital to improve its performance as well as to expand its capabilities.

## SAN FRANCISCO

San Francisco has a long history of transit development and its streetcar system is the third largest in the United States, after Boston and Philadelphia. The streetcar system consists of an arterial line running diagonally halfway across the City and branching into 5 separate routes. The principal transit agency is the San Francisco Municipal Railway, known as the MUNI, which operates a fleet of 880 buses and trolley buses as well as 115 PCC vehicles. The MUNI streetcar system has 19 miles (30 km) of double track carrying 16.8 million passengers yearly.

Table 8 indicates the LRT right-of-way percentage for existing conditions.

The table indicates the high percentage of the streetcar system that operates at-grade in mixed traffic.

## CROSSING CONTROL STRATEGIES

### LRT Operation in Mixed Flow

A large percentage of the MUNI LRT system operates in mixed flow both in downtown as well as in the outer areas of the City. All streetcar drivers operate under the *MUNI Rule Book* which sets out the procedures to be followed. The rule book primarily requires that streetcar drivers

**Table 7. System Improvement Plans**

	System									
	San Francisco	Boston	Philadelphia	Edmonton	Calgary	Chicago	Cleveland	Pittsburgh	Toronto	Buffalo
Conversion of Mixed to Median Operation	x		x							
LRT Control Priority at Selected Sites	x	x	x					x		
CBD Traffic Signal Priority Along Selected Lines		x	x							
General Trackage Improvement	x	x	x				x	x		
Line Expansion	x	x	x			x	x		x	
New Car Procurement	x	x	x				x	x	x	
New System (Expected Opening Date)				x (1978)	x (1982)					x (1982)
New CBD LRT Subway	x									

**Table 8. Proportion of LRT Right-of-Way by Type in San Francisco**

Right-of-Way Category	Percent of Total LRT ROW
Subway	18
Private Right-of-Way and Median	12
Mixed Traffic	70

"conform with the laws, ordinances and regulations of the state and City. Employees shall be familiar with and obey all such laws, ordinances and regulations." This indicates that streetcars must be driven under the same rules and standards as motor vehicles or buses.

Streetcars on the MUNI lines in mixed flow are generally controlled by the same traffic signals and stop signs that control motor vehicles. The primary exceptions are special cases where streetcars have a separate traffic signal phase as occurs at Market Street/First Street. At that intersection, a leading green arrow is lit during a right-turn, streetcar-protected phase which prevents conflicts between the turning streetcars and motor vehicles and pedestrians. The green right-turn arrow is marked with a "Streetcar Signal" sign.

On many of the outer lines 4-way stop intersections have been developed to coincide with the streetcar stops to minimize delay to streetcars.

No special priority is given to streetcars operating in mixed flow except at traffic signals with special phases for streetcars such as at the Market Street/First Street intersection. Along streetcar arterials that are interconnected, no special traffic signal timing has been developed.

There is no detection employed for the special streetcar phase at Market/First; the right-turn arrow is displayed every cycle of the traffic signal regardless of the streetcar demand.

### Median Operation

MUNI streetcars operate in raised medians along portions of the lines on Judah Street, Junipero Serra, 19th Avenue, and in painted medians along portions of its lines on Market Street, First Street, and Church Street.

The new treatment on Judah Street, completed during the winter of 1976, has a center median raised 3 inches above street level that separates one motor vehicle travel lane and one parking lane in each direction and contains the double-track N Judah Line as shown in Figure 30. On 19th Avenue the M Line operates in an unpaved median that separates twin 3-lane traffic flows. The



Figure 30. Layout of Judah Street Line Raised Median

Judah Street streetcar median is unfenced, while the 19th Avenue median exhibits portions with center and edge fencing and portions which are unfenced.

MUNI streetcar operators follow the same operating rules for median operation as they do for mixed operation.

Operations are generally regulated by the traffic signals and stop signs for parallel motor vehicle traffic. However, at certain locations where priority is granted streetcars, special green and red "X" signals are used only for streetcars to differentiate indications between streetcars and motor vehicles. At some locations only a green "X" is used, while at others there is a red as well as a green "X."

Priority or special traffic signal phases are granted LRT at certain locations where LRT needs priority for delay or safety reasons. The intersections and crossings for which priority is developed always involve LRT transitions between either median and mixed flow operations or median and private right-of-way operation. The location at which a transition between median and mixed flow is facilitated by traffic signal priority is at Ocean Avenue and Junipero Serra Boulevard. At that location, a special traffic signal phase handles K Line streetcar turn movements between median operation on the north leg of Junipero Serra Boulevard and mixed flow operation on Ocean Avenue.

The two intersections that have streetcar priority for movements between street median and private right-of-way are Duboce Avenue/Market Street and 19th Avenue/Rossmore Drive. At the Duboce/Market intersection, streetcars operate between the painted median on the northeast leg of Market Street and the private right-of-way on the west leg of Duboce. The traffic signal operation is 3-phase fixed time. A 10-second lead green "X" is first given to approaching streetcars, then nonconflicting right and left turning autos on the westbound Duboce approach are given green indications. The last phase is for the motor vehicles on the two Market Street approaches. At the 19th/Rossmore location, streetcars transition from median operation on 19th Avenue to private right-of-way operation on the east side of 19th Avenue. This occurs just south of Rossmore Drive. Streetcars must therefore cross northbound 19th Avenue motor vehicle traffic only. A traffic signal activated by streetcars has been installed to control northbound motor vehicles. All other intersections along the median operations are controlled by the motor vehicle signals.

At the 19th Avenue intersection with Winston Drive, a special left turn treatment has been developed. A double left-turn lane is provided for northbound 19th Avenue to westbound Winston Drive motor vehicle traffic. The inside left-turn lane also contains the northbound M Line, which leaves a protected median and operates at-grade through the intersection. Figure 31 is a photograph taken from this inside lane and shows both the double left-turn lane and the orientation of the M Line tracks at the intersection. The key operating feature at the intersection is that streetcars do not proceed when left-turning traffic gets a green left turn arrow, but rather only proceed in the northbound direction with the paralleling movement. As a result, traffic in the outside double left-turn lane does not conflict with northbound streetcars. however, some queueing does occur behind streetcars.

Simple detection methods are limited to use at some of the priority locations. At 19th/Rossmore the special phase for LRT does not occur during every signal cycle, but requires that a streetcar put in a "call" through a mechanical switch on the overhead wire. This detection system requires that the streetcar stop and wait for a green "X" display before proceeding. The other two priority locations, Ocean/Junipero Serra and Duboce/Market do not have or require streetcar detection because the special LRT phases occur every signal cycle. This is due, in part, to heavy streetcar approach demands as well as the coordination in each case of nonconflicting auto movements with part or all of the streetcar priority phases.



**Figure 31. Double Left Turn Lane for Autos and LRT at 19th Avenue and Winston Drive**

### LRT In Private Right-of-Way

MUNI private right-of-way operation takes two forms: in tunnels (Twin Peaks and Sunset) and on the reserved right-of-way occurring on portions of Duboce Street, between 19th Street and St. Francis Circle, and on portions of Church Street.

In tunnels, speed limits of 25 mph or 35 mph are set by the operating rule book. Block signals control entry into the tunnels and *minimum* times between stops are established so that operators do not speed. On reserved right-of-way a maximum speed of 25 mph is permitted and streetcars obey the standard motor vehicle traffic controls.

Standard block signals are used in the tunnels. At the locations where priority is granted streetcars, two sets of green "X" and red "X" streetcar indications are used. No other special control devices are used such as railroad warning lights or gates at any locations.

As mentioned above, priority is granted to MUNI streetcars at the Duboce/Market and 19th/Rossmore locations where transitions between median and reserved right-of-way operation occur. Additional priority is also granted to the inbound M Line streetcar movements at the St. Francis Circle intersection. This intersection is a complex five-legged intersection which contains two streetcar lines that diverge as shown in Figure 32. The intersection has nearly 4,000 motor vehicles entering it during the evening peak hour period. The combined M and L Lines operate on West Portal Avenue in mixed traffic flow on the same tracks. A raised median separates the two tracks. Switches separate the two lines; the M Line goes into exclusive right-of-way operation and the K Line traverses to protected at-grade median operation on Junipero Serra Boulevard. The vehicle phasing, which is shown in Figure 33, has no protected left-turn phases and the streetcars generally operate under the auto phases. Under the first signal phase, the West Portal Avenue, and the Junipero Serra Boulevard motor vehicle approaches, as well as the southbound M and K Lines and the northbound K Line streetcars receive green indications. The second phase is for the Portola Drive approach, and the third phase is for the Sloat and St. Francis Boulevard approaches. The fourth phase occurs after the third phase only if a northbound M Line streetcar is detected by a mechanical contact switch attached to the overhead wire. This special

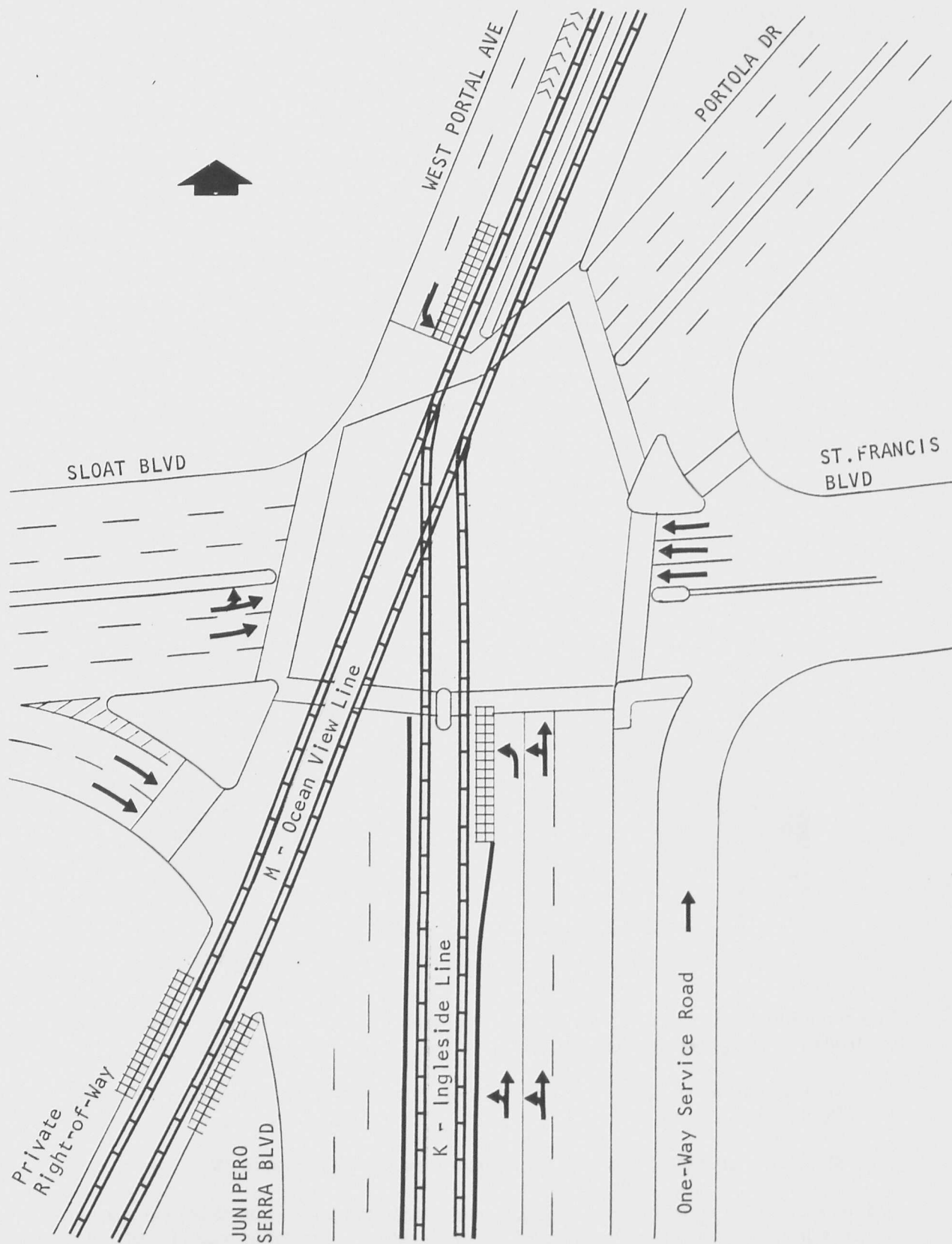


Figure 32. St. Francis Circle

signal phase exists because the M Line emerges at the intersection from a private right-of-way section which has poor sight distance. Northbound streetcars could not operate with any of the other motor vehicle phases without encountering heavy through traffic conflicts. Operation under such conditions would add delay and significant safety risks.

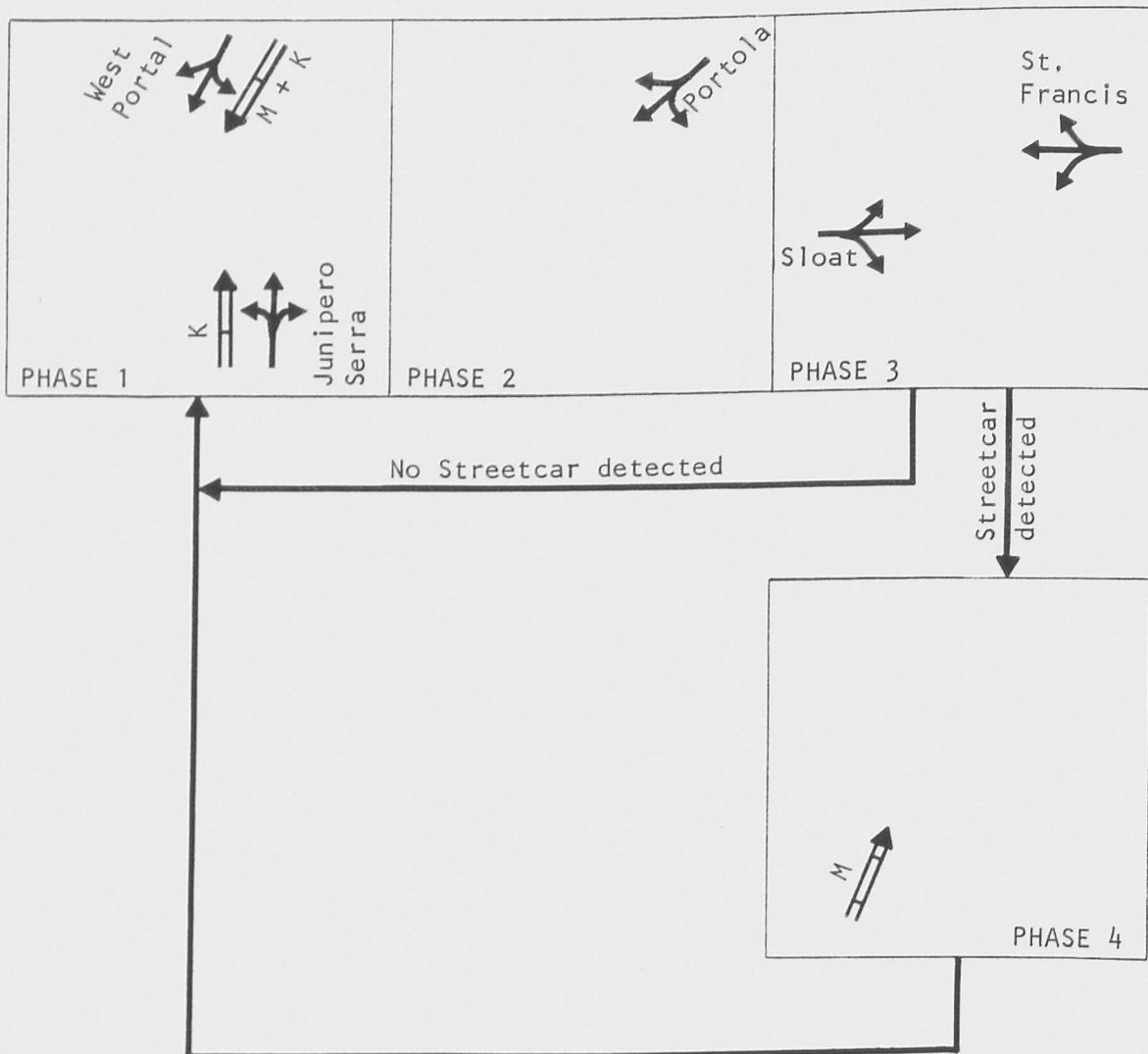


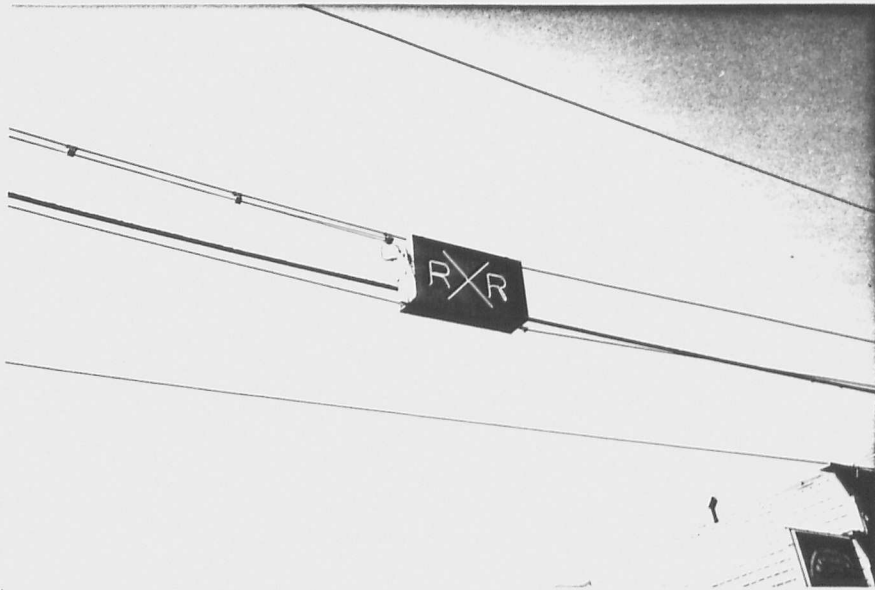
Figure 33. St. Francis Circle Signal Phasing

The 5 midblock MUNI streetcar crossings that occur on the private right-of-way portion are controlled by these two techniques:

- An overhead warning sign over the crossing location that is always illuminated as shown in Figure 34.
- Stop signs on each motor vehicle approach as shown in Figure 35.

At the Ocean Avenue midblock crossing, passenger stops are made on each M Line approach to the crossing. This provides a measure of safety by reducing the crossing speed of the streetcar and giving the operator an opportunity to see if the crossing is clear before proceeding. At some of the midblock crossings "Stop" signs control streetcar movements as well as auto movements.





**Figure 34. Ocean Avenue M Line Midblock Crossing Overhead Sign**



**Figure 35. Stop Sign Control for Motor Vehicle Crossing of the J Line**

### Pedestrian Crossings

In general, no special treatments are provided for pedestrians outside of "Walk/Don't Walk" indications for pedestrian crossing of streetcar tracks at some signalized intersections, fencing along some medians, and reserved operation and raised platforms along some route portions. The *MUNI Rule Book* states that "when approaching passenger stops (including loading islands or zones) or any place where pedestrians are standing or walking in the street, operators are to sound gong or horn to warn pedestrians...."

At most of the streetcar priority intersections pedestrian crossing of the streetcar tracks is controlled by "Walk/Don't Walk" signal heads. This is done to control LRT/pedestrian conflicts as well as to regulate crossings between median passenger platforms and sidewalk areas. Fencing is used along portions of the 19th Avenue M Line and can be found either between or on the outside of the double tracks. It is also used on portions of the reserved right-of-way on the J Line.

Raised pedestrian platforms are often not provided along the mixed flow portions of the system and passengers must board and alight on the street. The major exception is Market Street where there are 5-foot-wide raised platforms with chain link fences on one side. Raised platforms have also been developed along most of the Ocean Avenue K Line segment. Median operated lines generally have raised platforms at each stop as do the subway segments. Also, most reserved flow streetcar lines have formalized platform areas, although some stops are made within intersections such as on the southbound J Line stop at 21st Street.

## FUTURE PLANS

### System Upgrading

In 1972 MUNI initiated a major transit improvement program. This program includes the acquisition of 100 Boeing LRVs, rerailling and improvement of most of the surface streetcar trackage, construction of new storage and maintenance facilities, and the complete renovation of the entire power supply system. The delivery of new cars is expected to start in about 1979. As the cars are available, they will be put into service one line at a time.

As part of the BART system, a subway was constructed beneath Market Street to eventually accommodate all CBD MUNI streetcar lines. This would place an additional 12 percent of the system in subway and reduce the amount of mixed flow operation by 17 percent.

Improvements such as the new median trackage on Judah Street have been carried out under the MUNI Metro program. Consideration is being given to developing a raised median, similar to the Judah Street treatment, on Church Street between Market and 18th and on Duboce between Market and the Sunset Tunnel.

The Judah Street raised median treatment has spawned much community complaint and opposition due to restriction of driveway access, prohibition of left turns at intersections and loss of curbside parking adjacent to passenger platforms. This has led merchants along Judah Street to the west of 19th Avenue to oppose a similar treatment in their area. For this reason, it is expected that a painted transit-only median treatment with left turns allowed at intersections instead of a raised median will be developed west of 19th Avenue, as shown in Figure 36.

On West Portal Avenue, which passes through an intense commercial area that has metered angle parking (see Figure 37), MUNI is planning to remove the existing center trolley poles and the side poles on the sidewalks and move the existing tracks closer together. This will increase the separation between the streetcar tracks and parked motor vehicles, thus reducing the frequency of track blockage during parking maneuvers. In addition, passenger loading islands will be constructed at the West Portal intersection with 14th Avenue.

### Expansion

The MUNI Metro system will include some expansion of the M, K, and L Lines. Lines M and K are being extended to the new MUNI Metro Maintenance Center and will operate on tracks running in a counter clockwise loop around the Center. A new transfer station, being constructed at this time at the Balboa BART Station, will provide separate upper and lower station platforms for the M and K Lines.

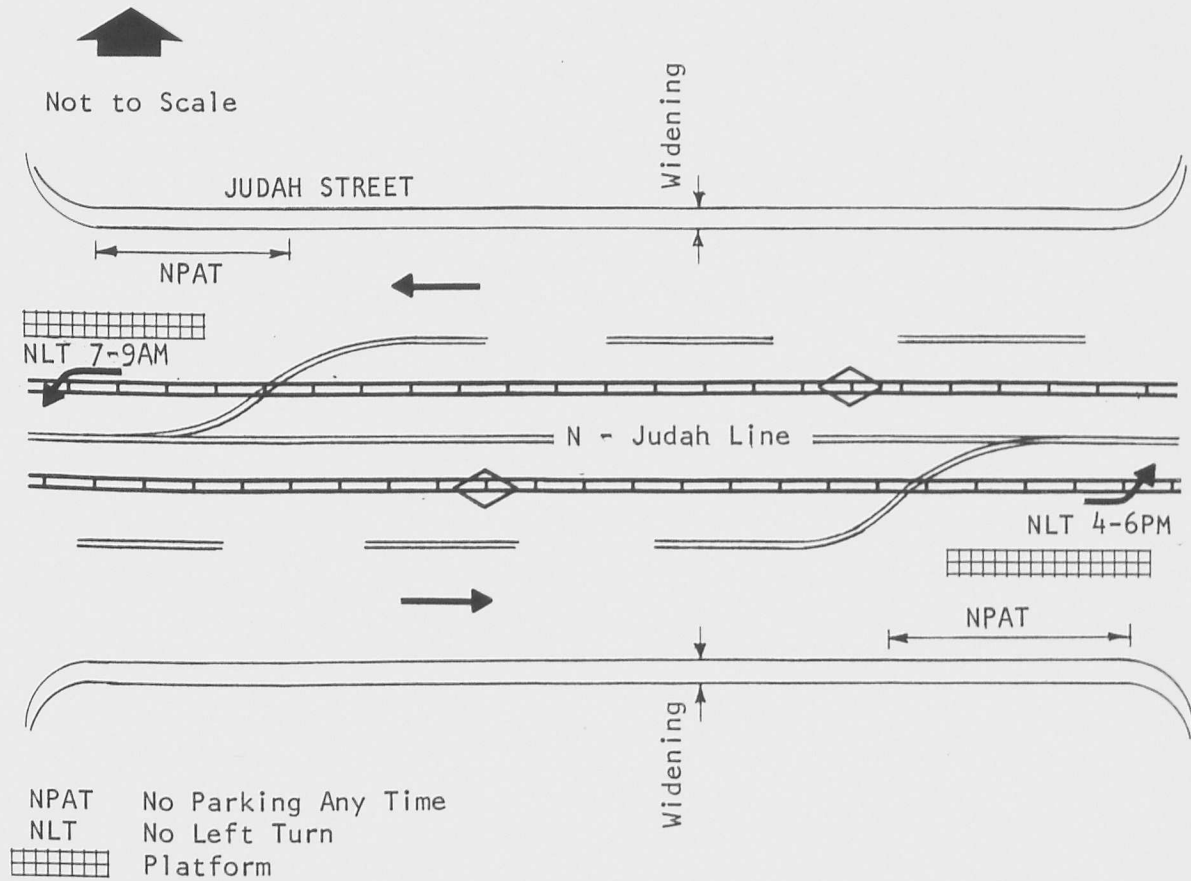


Figure 36. Judah Street Proposed Treatment West of 19th Avenue

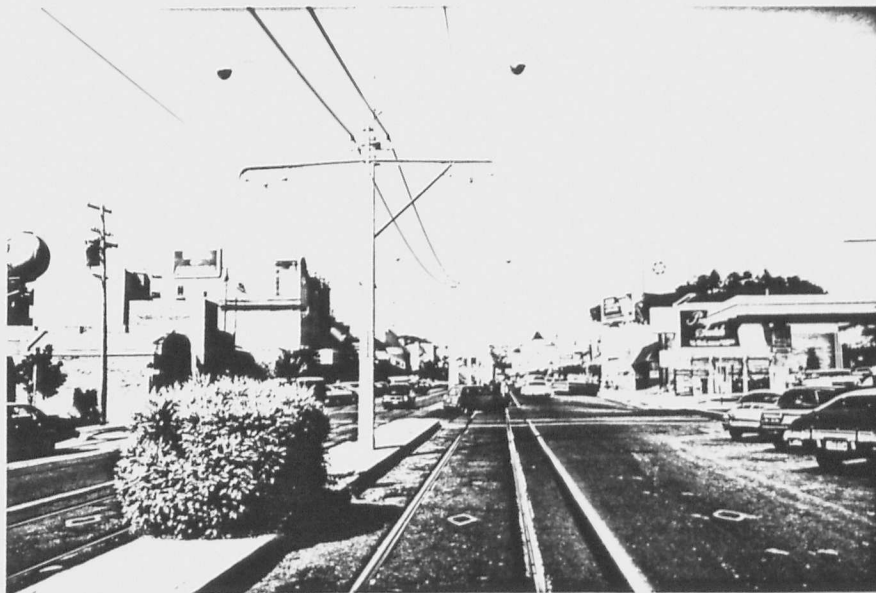


Figure 37. Market Line Mixed Flow Operation Through Commercial Area on West Portal Avenue

At the point along Ocean Avenue where the K Line will enter the Maintenance Center, a preempt system will be installed to stop motor vehicle traffic while LRVs access the Center. The general layout of the entry is shown in Figure 38. Additionally, complicated switching at the center requires that the preempt system be tied in with the switching. LRVs exiting and entering the new center from Ocean Avenue will preempt eastbound traffic.

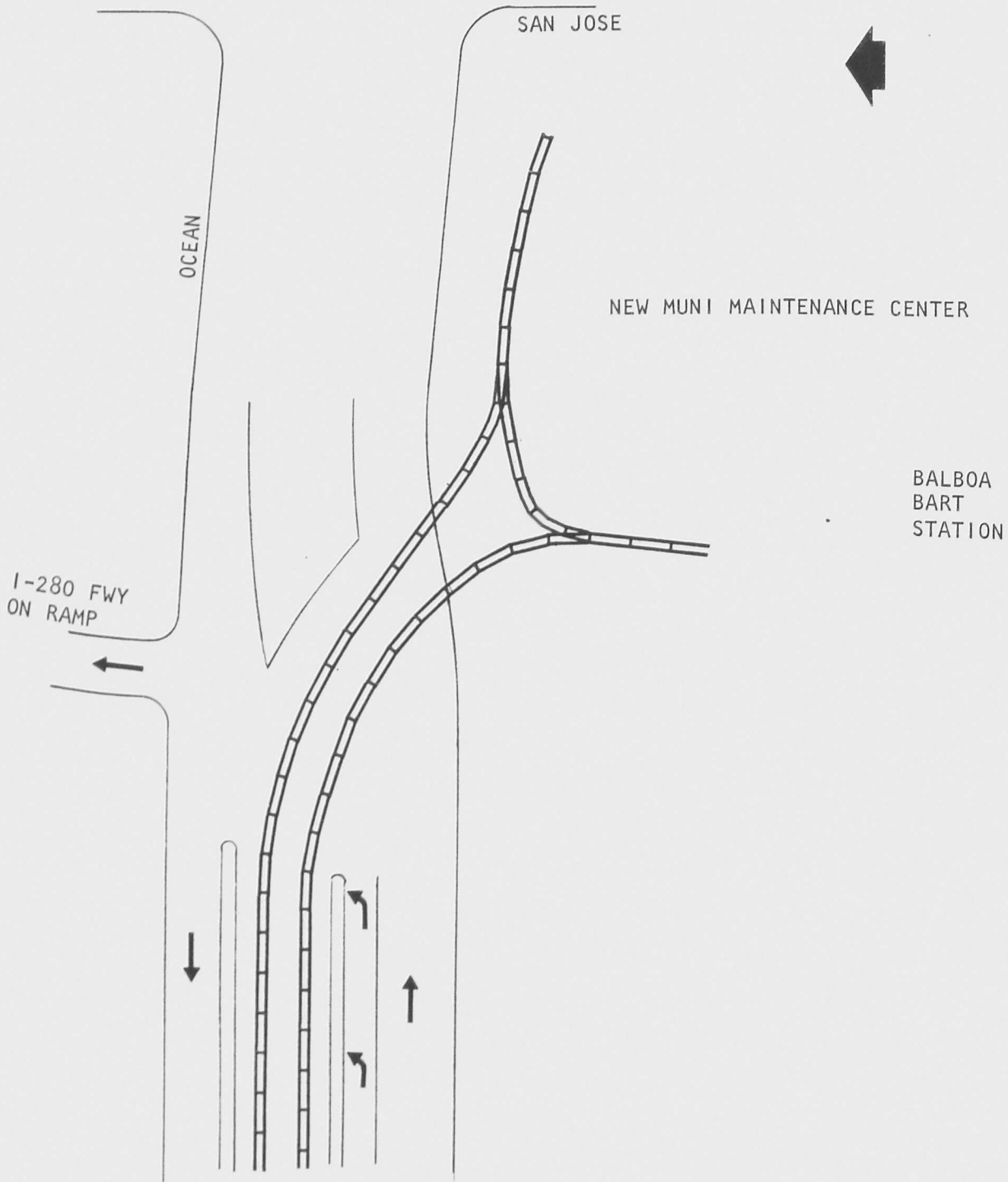


Figure 38. Ocean Avenue and San Jose Street at the Muni Maintenance Center

The M Line extension will operate in median on San Jose Street and will access the new center through the Geneva/San Jose intersection. LRVs leaving the center will be given priority over all Geneva and southbound San Jose Street approach traffic as shown in Figure 39.

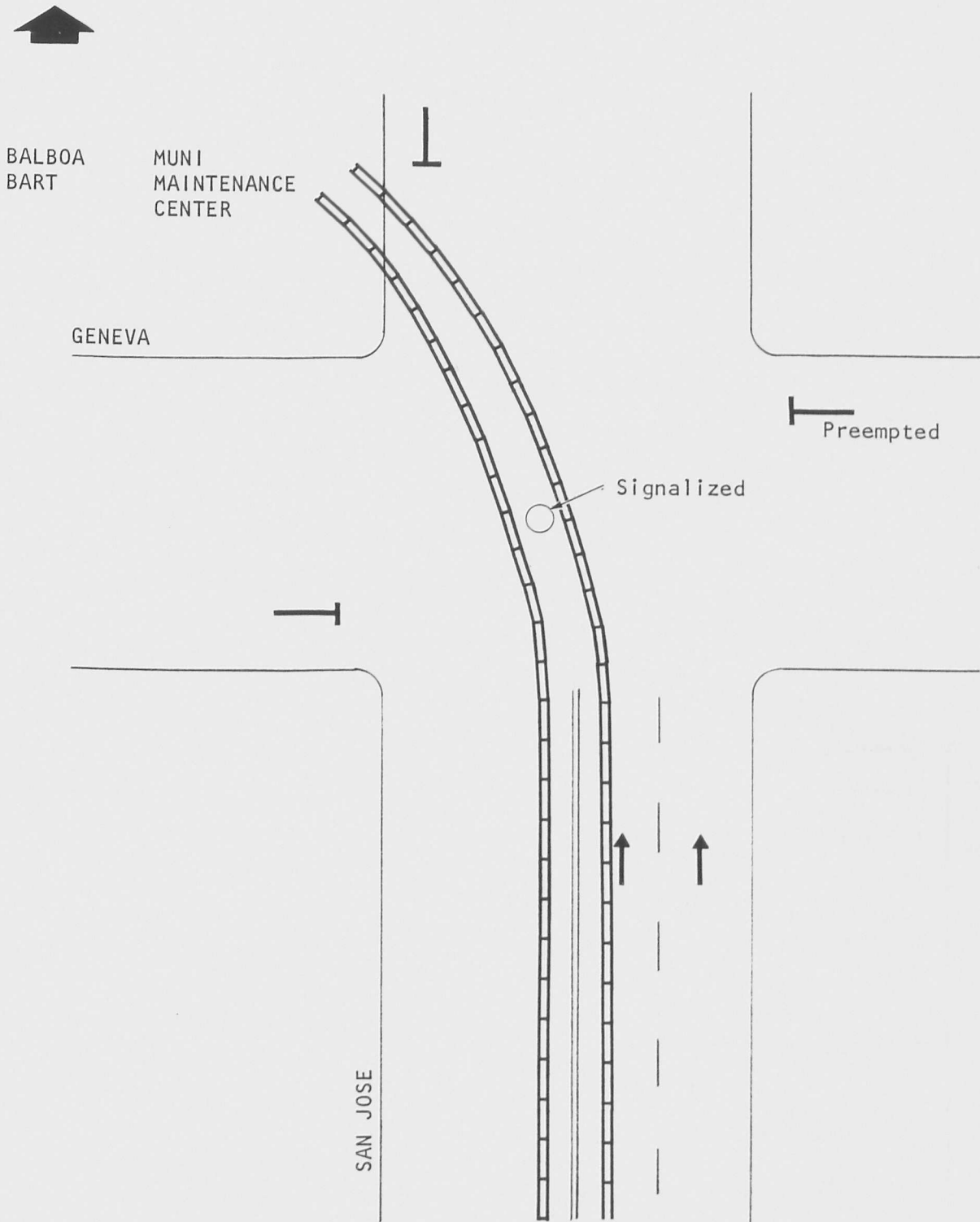


Figure 39. Geneva and San Jose Street at the Muni Maintenance Center

At other locations along the M and K Line extensions LRVs will not receive priority at intersections, due to low levels of traffic conflict. This corresponds with a general MUNI policy of incremental separation of light rail from auto and pedestrian conflicts by initial use of minimum channelization and control methods. Median separation together with channelization and stop sign treatment is installed initially to facilitate LRV movements. Complicated and costly traffic signal controls and preempt systems are subsequently utilized, if required.

## SAFETY

Accident data for MUNI vehicles is not readily available and no surveillance system is employed to monitor the accident experience. Some systemwide traffic accident history is available for 1975, however, and is shown in Table 9. This table presents the number and percentage of traffic accidents categorized by the objects hit by MUNI vehicles. It presents accident data for streetcars as well as motor and trolley coaches for comparison. Streetcars exhibit a higher percentage of pedestrian and MUNI equipment (bus) accidents and lower percentages of fixed and other object accidents than motor or trolley coaches. For all MUNI equipment, accidents with motor vehicles are the dominant accident factor. Examination of traffic accident rates per vehicle-mile and passenger-mile reveals, as shown in the table, that streetcars and trolley coaches have similar rates which are approximately double the rate per mile and 50 percent higher per passenger than for motor coaches. It is felt that streetcars have a much higher accident rate than motor coaches because of the difficult mixed flow environment that they experience on Market Street, with its high pedestrian and motor vehicle conflict levels as well as a very high volume of parallel flowing trolleys and motor coaches. When the MUNI Metro subway beneath Market Street is fully operational, the accident picture should exhibit a significant favorable change.

**Table 9. MUNI Traffic Collision Accidents, 1975**

Collision with	Streetcar		Motor Coach		Trolley Coach	
	No.	Percent	No.	Percent	No.	Percent
Pedestrian	48	8	54	3	65	4
MUNI Equipment	69	11	45	3	65	4
Other Vehicles	488	79	1331	88	1159	76
Fixed Objects	6	1	57	4	221	14
Other Objects	8	1	23	2	26	2
Derailment-Switch Occurrence	2	-	-	-	-	-
Total	621	100	1510	100	1536	100
Traffic Accidents per 100,000 miles	19.21		10.75		20.60	
Traffic Accidents per 1M Passengers Carried (1975)	28.4		18.7		31.8	

Source: MUNI

One intersection for which detailed accident history was available was the St. Francis Circle intersection depicted in Figure 32. The San Francisco Traffic Department prepared a collision diagram of the intersection for the 1966-1971 period. It indicates that about 20 percent of the 166 recorded accidents at the complex intersection involved streetcars. One third of the streetcar accidents were between northbound K Line streetcars and left-turning northbound Junipero Serra traffic. It also indicates the potential advantage of providing a protected left turn movement for streetcars where one does not now exist. This type of detailed accident history can be instrumental in providing input into the upgrading of existing systems. The removal of serious potential conflicts between streetcars, motor vehicles, and pedestrians reduces the number of expected accidents and eliminates sources of congestion and delay to LRT.

## BOSTON

In Boston the light rail system is operated by the Massachusetts Bay Transportation Authority (MBTA). The LRT network consists of the "Green Line" and a relatively small shuttle service at the end of the Ashmont portion of the "Red Line," a rail rapid transit line. The entire network consists of approximately 24 miles (39 km) of double track. As shown on Figure 40, of the 22 miles (36 km)

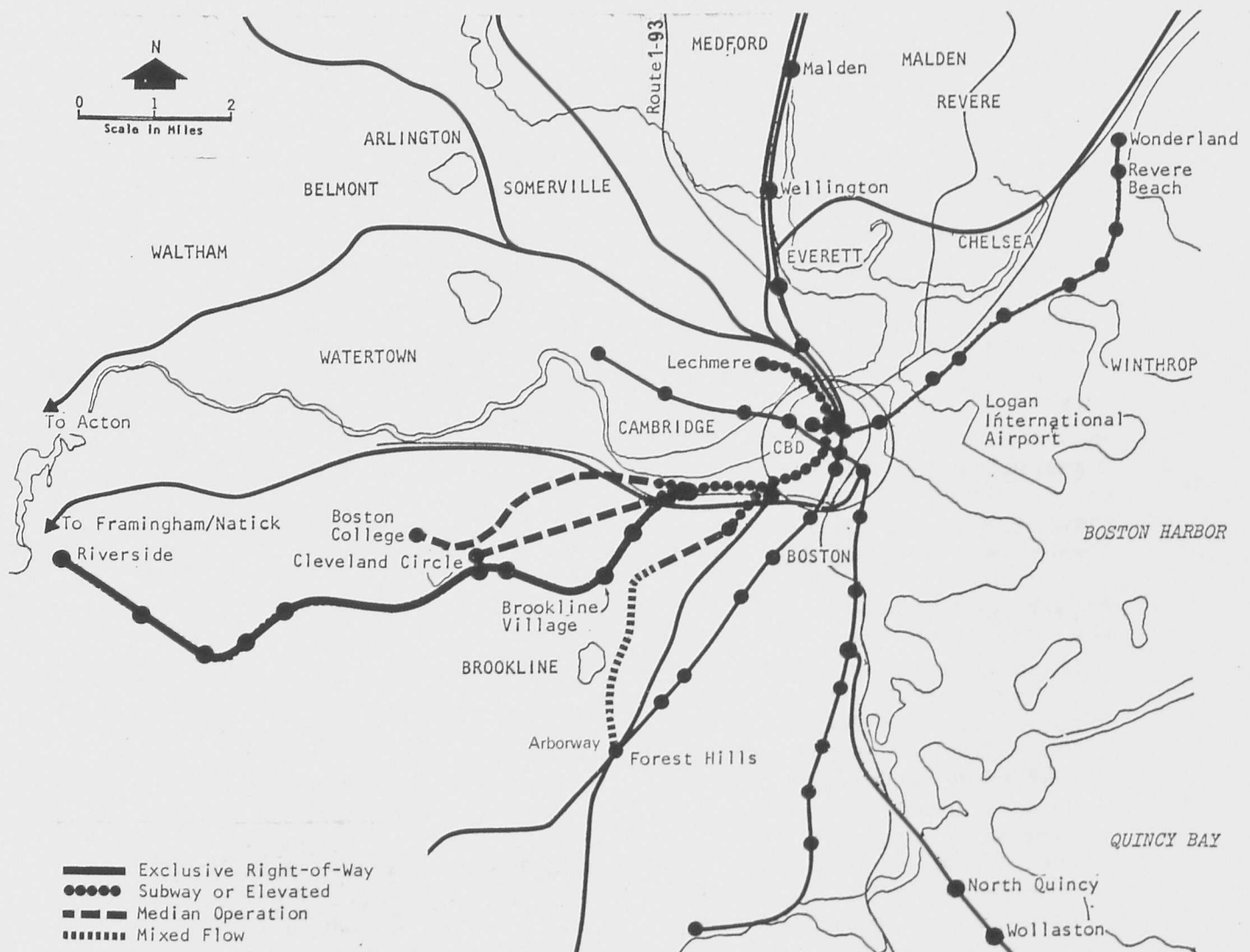


Figure 40. Boston LRT System

on the Green Line, about 45 percent of the line operates on exclusive right-of-way with 1 percent elevated, 14 percent in subway, 30 percent in dedicated right-of-way (primarily street median), and 22 percent in mixed flow. The CBD portion of the Green Line operates in subway. As the line leaves the CBD and divides into 4 branches it transitions to surface operation.

The most northerly line connects the CBD with Boston College. That line operates either in the center median or in the median located between the main roadway and the frontage road. The Cleveland Circle Line operates entirely within the street median, much of it through the neighboring city of Brookline. The Riverside Line operates on exclusive right-of-way throughout its length. Segments of the southernmost line (Arborway) operate in the median and the remainder in mixed flow.

Four of the 5 LRT lines still operate with PCC type cars. Most of these vehicles are up to 30 years old. One of them has recently been refurbished. The new Boeing LRVs are being introduced on the Riverside Line. Up to 3 vehicles are formed into a train. Each vehicle in a train carries an operator. The operator opens and closes the doors of his vehicle and collects fares. With doors closed, the train is controlled by the lead operator.

On the surface portion of the trip, loading occurs via the front door only. This is to allow operator control of fare collection. Traveling inbound (toward the CBD), the fare is paid on entering the vehicle. Outbound the fare is paid on leaving the vehicle. In the subway portion, the fare is collected at turnstiles and therefore all doors are used by passengers. At stations with platforms on both sides of the single track, doors are opened simultaneously on each side of the vehicle.

The differential fare system between the subway and surface portion of the trip (25 vs. 45 cents) is responsible for this method of control. When a patron enters the subway he pays 25 cents; if he remains in the LRV for the surface portion of the trip, he pays a 20 cent surcharge as he leaves the vehicle. This method of operation significantly lengthens the dwell time at stops on the surface portion of the trip. With a full vehicle, dwell times up to 1 minute have been observed. This is sometimes longer than in the subway. As a result LRVs can miss an entire signal cycle while boarding/unboarding passengers. Loading of passengers occurs via low platforms (maximum height of 6 inches) or from ground level. High platforms are used only on the rail rapid transit system. This means handicapped people may not be able to access an LRT.

## CROSSING CONTROL STRATEGIES

This section will examine the various vehicle and pedestrian crossing control strategies employed by MBTA for each right-of-way type.

### LRT Operation in Mixed Flow

Mixed flow operation occurs only on the Arborway portion of the Green Line. The street carrying LRT is typically 40 to 50 feet wide with one transit line in each direction, and is shared by LRT and autos with parking on each side. There are no platforms. Passenger loading occurs in the street. Curb parking is prohibited at each LRT stop. Usually the street is not wide enough for autos to pass an LRV, as illustrated in Figure 4I. Maximum travel speed is governed by the speed limit of the street, usually 25 mph. Parking vehicles would block the tracks. Several bus lines share the same stops for portions of the line. Left turns are permitted along the entire route. Most intersections are controlled by stop signs on the side street approaches. Several intersections are controlled by standard fixed-time traffic signals. Special signals for LRT are not used. All except one are 2-phase operations. Pedestrian signals are generally not used. Turning of the tracks from one street to another is uncontrolled at 2 locations (i.e. collision avoidance depends on driver alertness) and controlled by special phases at a multiphase traffic signal at the third location.





**Figure 41. LRV Blocks Autos Following in Mixed Flow**

The line traverses a mixture of land uses ranging from institutional (hospitals, etc.) to strip commercial. Only in the commercial area does auto traffic interfere with and delay LRV movement. This occurs primarily in the afternoon, the period of peak shopping activity.

Traffic volumes on the streets carrying LRT in mixed flow are generally low. Most of these streets are classified as minor arterials. The low traffic volume is reinforced or encouraged by the impediment to auto traffic presented by the LRVs.

### Median Operation

LRT in a raised median is the dominant method of street operation. The major variable between the 3 lines that employ this method is the width of the median and the level of attractiveness. Figure 42 illustrates the narrow median typical on Huntington Avenue on the Arborway Line. The median is only about 20 feet wide, has center power poles, 2- to 3-foot-wide platforms (generally located on the near side of intersections) and no landscaping. The separation between passengers and LRT on the one side and autos on the other allows only enough space for passengers to stand single file. Low curbs, generally less than 4 inches in height, barely define the edge of the median for the auto driver. Intersections are either controlled by stop signs on the side street approaches or by 2-phase fixed-time traffic signals.

LRVs must obey vehicle signals and are not afforded any priority treatment. Most of the traffic signal installations are substandard with only one indication facing a given approach. This means vehicles, and especially pedestrians, may have great difficulty knowing whether they are being given an indication to go or to stop.

Generally, left turns are allowed across the tracks. Left turns are prohibited by the placement of a yellow wooden barrier, located across the median opening between the tracks. This has the result of also eliminating all cross street auto movements.

Figure 43 illustrates the raised median typical along Commonwealth Avenue on the Boston College Line. The median generally is separated by 6-inch curbs, has a landscape strip between

the tracks and the adjacent auto lanes, has 5-foot or wider platforms (some with passenger shelters), and left turn lanes where left turns are permitted. Median openings are provided only at relatively major streets, and, with one exception, are controlled by traffic signals. Frontage roads on both sides of the main travelway provide for local circulation and parking along much of the line.



**Figure 42. Narrow Median, Huntington Avenue, Green Line**



**Figure 43. Raised Median Typical Along Commonwealth Avenue, Boston College Line**

Left turns are generally controlled by special traffic signal phases or prohibited by signs. Platforms are located either on the near side or on the far side of an intersection. A consistent pattern is not apparent. LRVs are controlled by the same traffic signals as motorists where left turns are prohibited. Where left turns are signal controlled, a separate traffic signal, differentiated from other signals by an identifying sign, controls the LRV movements. Louvers or other shielding devices are not used. Consequently, auto drivers can see the LRV signal and this can lead to driver confusion. LRVs experience delay at signalized intersections due to the absence of any transit priority treatment. Restricted speeds between signals resulting from poor track conditions further limit the operator's flexibility in timing the LRV approach in order to make a green light.

One major intersection is not signalized - Commonwealth Avenue and Brighton Avenue. None of the approaches of the intersection are controlled. As illustrated in Figure 44, the dominant auto movements are along Commonwealth Avenue. Since the LRT crosses from the center median to the side median separating the frontage road from the main roadway, this involves considerable conflict. This situation is further complicated by multiple roadway choices facing the auto driver and the fact that all vehicle movements are allowed. Caution and common courtesy by most drivers coupled with good visibility allow this intersection to operate relatively well. Although such a treatment is conducive to accidents, it does illustrate that LRT can successfully operate in a street environment - and a poor one at that.\* Figure 45 illustrates the wide raised median typical along Beacon Street on the Cleveland Circle Line. In some areas the median is wide enough to permit angle parking against the median curb or to allow a split in the roadway vertical alignment. Median openings are not provided at every cross street. Intersections are controlled either by stop signs on the side streets, by 2-phase traffic signals with left turns allowed or prohibited by signs, or by multiphase traffic signals with left turns allowed only during a left turn phase. LRV movements are controlled by standard traffic signals. Where auto left turns are signal-controlled, the MBTA signals are either standard traffic signals identified by a sign, as shown in Figure 46, or are programmed visibility traffic signals which mask out the indication from the view of conflicting vehicles. The LRV is in a highly visible location, nearly all intersection conflicts are controlled or have been eliminated, and the LRV operator has a clear view of all potential downstream obstructions. Delays to LRT are confined to signalized intersections and passenger stops.

Figure 47 illustrates LRT operation on a side median located to the right of the main travel lanes and adjacent to a frontage road. This design provides no special problems midblock. It is no different from center median operation. However, at intersections problems arise. Since no special phases for LRT exist, the parallel autos in the two roadways on either side of the LRT tracks move together. Turns, especially right turns, are usually not restricted. Many conflicts involve situations where the LRV operator or the auto driver is unaware of the conflicting vehicle on his "blind side." This situation leads to delay for LRT and can also lead to accidents.\*\*

A special signal phase, which operates on a fixed cycle regardless of the presence of an LRV, controls the crossing of LRT from the center median to the side median at one of the two locations where such a crossing occurs. The lack of actuation by LRV increases delay for autos when no LRVs are present, and results in excessive waiting time for LRVs which have just missed their green phase during periods of low conflicting auto demand. As a result, LRVs were observed traversing the crossing when the signal for them was red.

\* This intersection is slated for reconstruction to reduce the number of conflicts.

\*\* Plans are being prepared for relocating the LRT in the median.

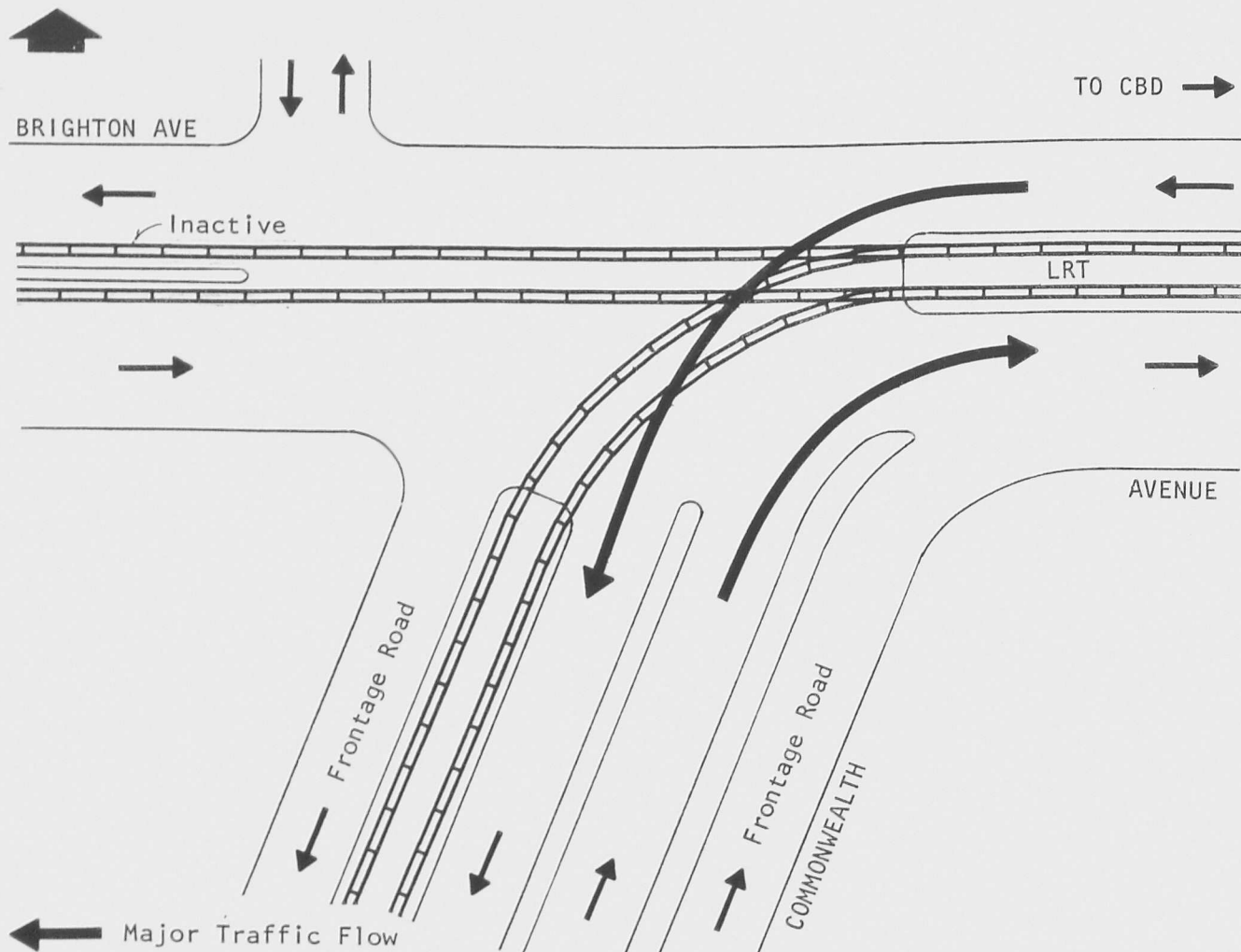


Figure 44. Commonwealth Avenue and Brighton Avenue Intersection



Figure 45. Wide Raised Median Along Beacon Street, Cleveland Circle Line



Figure 46. MBTA Traffic Signal, Cleveland Circle Line

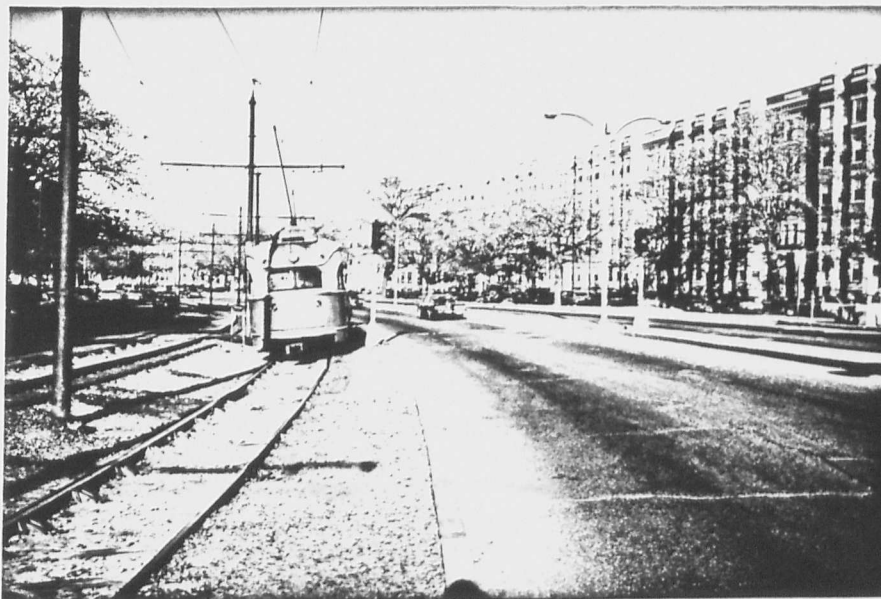


Figure 47. Side Median Along Commonwealth Avenue, Boston College Line

## EXCLUSIVE RIGHT-OF-WAY

The Riverside Line operates along exclusive right-of-way for its entire length. There are no at-grade crossings. The entire right-of-way is fenced. At stations, however, pedestrians are allowed to cross the at-grade tracks in order to reach the other platform.

## Pedestrian Crossings

Control of pedestrian crossings is a function of LRT right-of-way types and ranges from no control to pedestrian grade separation. In areas where LRT runs in mixed traffic flow, pedestrians are typically allowed to cross the tracks anywhere along the line. Only major intersections are controlled by standard traffic signals. Pedestrian signals or push buttons are generally not employed. Pedestrians observe the vehicular indications. At one location, pedestrian crossings are controlled by a pedestrian-actuated signal which requires that all vehicles stop while pedestrians are permitted to cross in any direction.

With median operation, pedestrian control ranges from no control to fencing along the right-of-way. Identified pedestrian crossings are either unprotected, controlled by standard traffic signals or, in the case of some midblock crossings (usually combined with a transit stop), controlled by pedestrian-actuated traffic signals. If such a crossing includes a frontage road, only the crossing of the main roadways is signalized. Pedestrians were observed climbing over median fences in disregard of traffic signal indications. If a pedestrian is observed on the LRT right-of-way, the LRV operator will sound his horn and slow down. If necessary, the LRV will even come to a complete stop. None of the pedestrian-actuated signals are connected with LRT arrivals. Pedestrian calls are satisfied after completion of the appropriate clearance interval or after passage of vehicle platoon (if part of an interconnect system).

Signalized pedestrian crossings are controlled by a wide variety of signal indications. These range from pedestrian indications or vehicle indications on both ends of the crossing to one or no indications on a given crossing. As illustrated on Figure 48, pedestrians attempting to cross from the median platform to the other side of the street have no signal indications to guide them. This leads to guessing by the pedestrian which could trap him in the middle of a wide crossing or lead to accidents, and could also lead to a disregard of pedestrian signals when they are available.

## FUTURE PLANS

MBTA is in the process of upgrading the entire Green Line. The upgrading will consist of a new roadbed, new power supply, new low level platforms and, in many cases, new intersection control. In mixed flow operation, a new roadbed is the primary improvement. Much of this work has already been completed on the Arborway Line. On the Cleveland Circle Line, the intersection with Cleveland Circle has been reconstructed and sophisticated traffic signal control is being installed. When completed, special signal phases, coupled with MBTA signals and variable message signs, such as illustrated in Figure 49, will control the movement of the LRV through this intersection complex. LRV detection will be used to initiate the special phasing. On the Boston College Line, in addition to a new roadbed and passenger platforms and shelters, a sophisticated computer-controlled arterial traffic signal control system with LRT priority is being installed. Where possible, platforms are being eliminated or relocated to a far side location to speed up travel and complement the signal control. A key feature of this concept is a transit priority system that uses successive detection at the approach to an intersection to predict the arrival time of the LRV and then, to the maximum extent possible, provides the LRV with a green indication upon its arrival. Only if conflicting vehicular demand must be satisfied will LRV be forced to slow down or stop. Advance wayside signals will be used to control the speed of the approaching LRV. With a near side platform, LRV detection will occur at the station stop.

On the portion of Commonwealth Avenue with side median operation, the entire street will be reconstructed and LRT relocated into the center street median.

Part of the Green Line improvements to accommodate the new Boeing LRVs is the installation of a 3-speed single rail block control system in the subway. All subway stations are also being renovated to increase passenger comfort. Low level platforms are being retained.



**Figure 48. Lack of Signal Indications at Pedestrian Crossing, Commonwealth Avenue at Harvard Street**



**Figure 49. Variable Message Signs to be Used at Cleveland Circle**

The only expansion project planned is an extension of the Green Line by 1.8 km from its northern terminus at Leachmere to Somerville. Implementation of this project has low priority.

## SAFETY

Accidents involving autos are reported by the Massachusetts Police. Data recorded on standard State forms is available to the City on a standard computerized summary form. However, the computer data does not provide any details on the accident information. Overall accident statistics are generally not readily available. None of the Boston accident data has been converted into accident rates. Accidents involving transit vehicles are reported by the Transit Authority and do not involve the police. The Transit Authority keeps its own computerized files on all of their accidents. These may be vehicle accidents and/or personal accidents involving transit patrons on board the vehicles.

MBTA recently completed a 5-year accident study of the Cleveland Circle Line. The summary of the accidents for 1972, 1973, 1974, 1975 and 1976 showed a total of 179 accidents on that line. Of these, 159 accidents involved LRT vehicle collisions; the remainder consisted of incidents of personal injury sustained by passengers on board LRVs. Of the 22 crossings studied, 8 are signalized. Forty-six (29 percent) out of 159 accidents occurred at signalized crossings. Most of

the accidents occurred at unsignalized crossings. The accident rate for that portion of the line works out to be 18.7 accidents per 100,000 LRV miles. This compares favorably to experience in other cities such as San Francisco. The dominant accident type (64 percent) involved vehicles colliding with the front end of an LRV. Collisions with the right side of the LRV constituted 31 percent of the accidents. These accident types are usually susceptible to correction by traffic engineering techniques such as signalization, phase changes, turn prohibitions and channelization.

## JURISDICTIONAL CONSTRAINTS

Traffic improvements that also involve transit usually become a joint project involving the City, MBTA and the State and Federal governments. The contracts are usually handled by the State and the actual design is usually performed by a consultant with the State as the client. MBTA and/or the City merely become interested parties to this design. They have no direct control over the project despite the fact that the MBTA often originates the project idea. Signalization and detection involving transit vehicles is handled by MBTA through the same consultant. The City becomes involved with working out a joint design but does not determine such items as timing strategies.

## RULES OF OPERATION

MBTA operating rules govern the actions of LRV operators when confronted with various traffic situations. The following paragraphs describe some of the sections relevant to at-grade operation.

### *OBSERVANCE OF TRAFFIC REGULATIONS.*

*Employees operating Authority passenger vehicles on public highways must comply with all traffic regulations of the Department of Public Utilities, the Registry of Motor Vehicles, and those of the cities and towns in which the Authority operates.*

*They shall not operate at a speed greater than is reasonable and proper, having regard to the traffic and use of the way and the safety of the passengers and the public. Operators and drivers must keep their vehicles under control at all times and be ready for any emergency that may arise. . .*

### *CARE OF PERSONS ON OR NEAR TRACKS.*

*Operators must use extreme caution when approaching and passing persons on the structure or in the subway or tunnels or upon private rights-of-way and reduce speed to not more than 6 miles per hour. . .*

### *SPEED AND SLOW SIGNS*

*Speed restrictions and running time schedules must be adhered to as closely as possible.*

*Speed signs, consisting of the letter "S" and figures underneath indicating miles per hour, are displayed at the right of the track, at curves and other points to denote maximum rate of speed at which cars or trains may be operated, if operating conditions permit.*

*When approaching a place where a "SLOW" sign is displayed, operators must gradually reduce the car or train speed so that the speed of the car or train will be no greater than 6 miles per hour when the car or train arrives at the area displaying a "SLOW" sign. The rate of speed must not exceed 6 miles per hour within the limits of the "SLOW" area. . .*



#### **VIEW OF OPERATOR.**

*Operators must observe pedestrian and traffic conditions in all directions and make certain that it is safe to do so before moving any passenger vehicle. . .*

#### **CONTROL OF CAR PASSING CROSS STREETS, VEHICLES, ETC.**

*Operators must use caution:*

*When meeting or passing vehicles which may suddenly turn upon the track.*

*At all intersecting streets where the view is obstructed.*

*At all places where, due to posts, fences, or other obstructions to view, there is a possibility of a person or vehicle suddenly appearing on the track.*

*When passing standing or moving vehicles on narrow streets, operators must assure themselves that there is sufficient room to pass. . .*

### **PHILADELPHIA**

In Philadelphia, the light rail system is operated by the Southeastern Pennsylvania Transportation Authority (SEPTA). SEPTA's City Transit Division (CTD) operates primarily within the city limits on 12 routes. As shown on Figure 50, 98 percent of the 87 miles (139 km) of right-of-way is shared with auto traffic. The remainder consists of a subway operation. A 1-mile section of Line 36 to Eastwick operates in a street median. SEPTA's Red Arrow Division operates 3 suburban lines outside Philadelphia's city limits. Two of the lines, to Sharon Hill and Media, operate primarily on exclusive rights-of-way with at-grade crossings. Both routes share the same tracks for the first 2 miles (3.2 km) between the 69th Street Terminal and Drexel Hill. Of the 8.5 miles (13.7 km) of track to Media, 1.5 miles (2.5 km) consist of single track. One mile (1.6 km) of the 5.3-mile (8.5 km) route to Sharon Hill is single track. The single track sections are located on the outer ends of the line where passenger volume is relatively low and headways can be long.

The third suburban line consists of the Norristown High Speed Line. The 21-km line is built to rapid transit standards with a fully grade separated right-of-way, high platforms and third-rail power distribution. Although it operates with 1- or 2-car trains and has on board fare collection, it will not be considered as LRT operation in the context of this report.

The system operates 350 PCC cars. These cars are at least 30 years old. Some of the better cars have been refurbished. The Sharon Hill/Media lines are served by both Brill and St. Louis cars. All vehicles operate as single units. Fares are collected upon entering the vehicle through the front door. Both front and rear doors can be used for exiting.

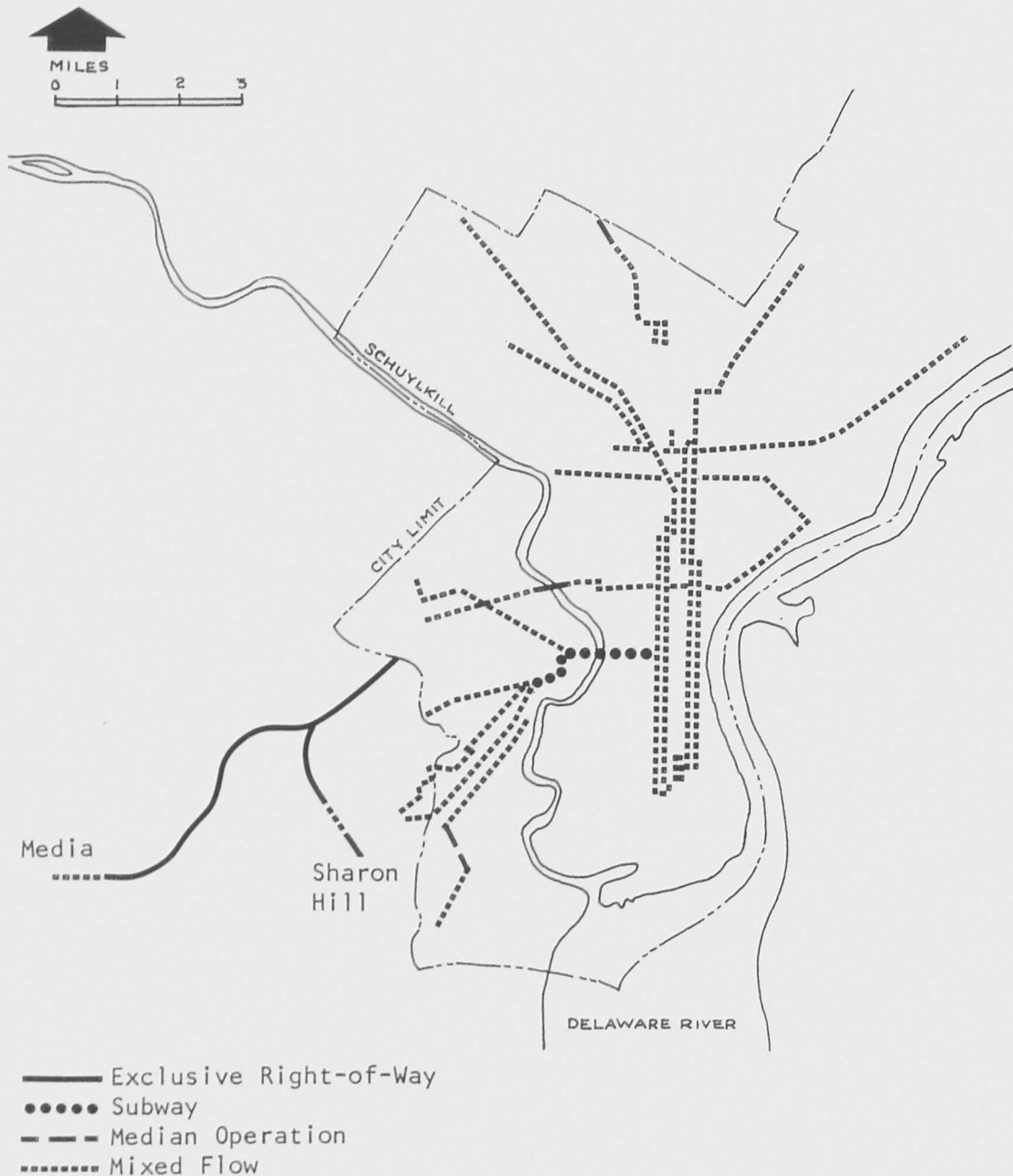
On CTD lines, most passenger loading occurs on the street. Only a few low level passenger platforms are provided. Low level platforms are provided on many stops on the Sharon Hill/Media Lines of the Red Arrow Division.

### **CROSSING CONTROL STRATEGIES**

This section will examine the various vehicle and pedestrian crossing control strategies employed by SEPTA for each right-of-way type. This discussion will differentiate between CTD and Red Arrow Division lines.

#### **LRT Operation in Mixed Flow**

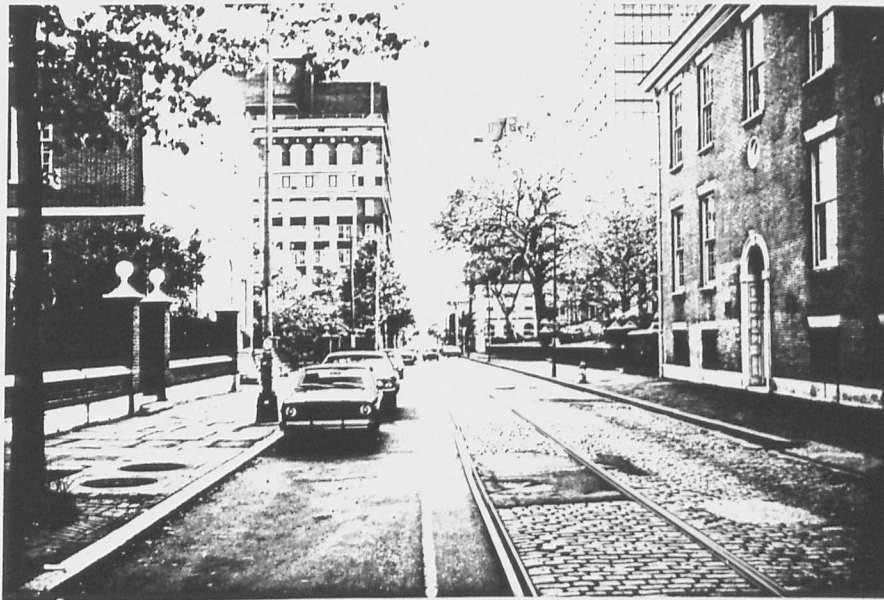
Mixed flow operation is the dominant mode for the CTD lines. Line characteristics range from single track operations on narrow one-way streets to double track operations on wide arterials.



**Figure 50. Philadelphia LRT System**

Much of the north-south trackage through Central and South Philadelphia operates on 26- and 34-foot-wide one-way streets. With parking on both sides this leaves only one lane open for traffic flow (See Figure 51). Blockages of that lane occur when vehicles park and when trucks deliver fuel oil in winter. Through the redevelopment area, these streets have been widened substantially with the LRT track located to the right of the centerline and immediately adjacent to the parking lane.

Passenger access to streetcars operating on one-way streets occurs via street loading. Parking is prohibited at transit stops. Autos parked along the curb upstream of the transit stop protect boarding passengers from being struck by moving vehicles.



**Figure 51. Single LRT Track on Narrow One-Way Street**

Two-way streetcar operation occurs on streets 40 feet wide and wider. The narrow width is prevalent on older arterials. Basically, the same operational problems exist as with a narrow 1-way street. However, wider 2-way streets (70 feet or more in width), while minimizing such problems as interference from parking vehicles, introduce new problems such as difficult passenger access at stops with no provisions for defined passenger waiting areas, and interference from vehicles moving in ill-defined travel lanes. Lane striping is generally in poor condition. Several wide arterials have little or no striping. This results in an unorderly traffic flow and increased friction, reducing travel speed and capacity. Where there are no raised platforms, passengers must cross several lanes of moving traffic to access a streetcar. In several locations, raised platforms have been installed. They feature a sloping concrete crash barrier on the upstream side and barrier chains on the curb side of the platform (see Figure 52). Autos are allowed to travel on either side of the platform.

Mixed flow operation also occurs on State Street through Media and on Springfield Avenue/Woodlawn Avenue through Aldan on the Sharon Hill Line. Sections of Woodlawn Avenue are so narrow that a truck not parked flush against the curb can block the streetcar. As in Philadelphia there are no platforms. Passengers access the streetcar from the street.

The streetcars are controlled by the same rules and traffic control devices as motor vehicles. Many intersections are controlled by stop signs. In many cases the stop signs face the streetcars, forcing them to wait for a gap in opposing traffic before proceeding. Standard traffic signals control the movement of motor vehicles and streetcars at signalized intersections. At less than a handful of locations, special turn arrows are used to control streetcar movements. At one such location, the streetcar turns left from the roadway into private right-of-way. Many of the traffic signals are old and in a state of disrepair. It is not uncommon to see one or more signal lenses missing and/or the lamp burned out. Mast arms are beginning to make an appearance. On wide streets without mast arms the far side indications are often very difficult for an approaching driver to see.

At signalized intersections no priority is given to streetcars. Most of the approximately 3,400 traffic signals in the City are fixed-time, single-dial and not interconnected. Only 250 in the CBD



**Figure 52. Raised Station Platform in Median**

are interconnected on a preprogrammed basis. Three programs are used. The system can handle additional variations. About 300 signals are semi-actuated. There are no fully actuated controllers in the City. Most of the traffic signals are 2-phase. Three-phase signals are frowned upon because they reduce intersection capacity. To achieve progression on streets not in the central interconnect system, the signals are adjusted manually. Without a master controller, the individual signals soon fall out of step and progression is lost.

Special phases are provided at two locations. In each case a streetcar must make an unusual movement. Even at those locations, streetcars are delayed while conflicting traffic demands are satisfied.

Streetcar detection is employed to actuate special phases. In the case of the 40th Street Portal, the detector is buried between the rails.

### Median Operation

CTD operates in a raised median along a short stretch of Line 36 on Island Avenue. The initial 2 blocks of that stretch consist of a painted median identified by overhead "Trolley Only" signs. A similar painted median exists for less than half a mile on Line 15 on Girard Avenue and on Line 6 on Ogotz Avenue in North Philadelphia, as illustrated on Figure 53.

For several blocks the common track shared by the Media/Sharon Hill Lines west of the 69th Street Terminal is located in the inner lane of a divided arterial. A narrow raised median separates the two directions of traffic. As illustrated on Figure 54, the track area is paved with asphalt while the adjacent auto lane is paved with concrete. The color differential tends to keep most autos out of the track area.

Intersections are either controlled by stop signs on the side street approaches or by standard traffic signals. The traffic signals are fixed-time signals. No special signals for detection of streetcars are used. At locations where special turn signals are provided for motor vehicles, the streetcars obey the traffic signal for through motor vehicles.



**Figure 53. Painted LRT Median**



**Figure 54. Contrasting Pavement on Media/Sharon Hill Lines, Red Arrow Division**

The only priority afforded streetcars is to exclude motor vehicles from the painted or raised median. At the painted median, this is enforced through signing. None of the traffic signals along that section provide streetcars any priority.

Along the several blocks of median type operation on the Media/Sharon Hill Lines, left turns for motor vehicles are prohibited through signing at several intersections and are controlled by a special turn phase at the one location where left turns are permitted. This signal operates on a fixed cycle.

## EXCLUSIVE RIGHT-OF-WAY

Excluding subway operation, all surface running on exclusive right-of-way occurs on the Sharon Hill/Media Lines of the Red Arrow Division. Each of these lines operates mostly on private right-of-way, sometimes fenced, with at-grade crossings. Passenger stops for both directions of travel are always located on the inbound side of a crossing.

This means that in the inbound direction, the stop is located on the far side and in the outbound direction, the stop is located on the near side. At the stops, shelters are provided for inbound passengers only.

There are 29 crossings along the 8.7 miles of the Media Line. This is the equivalent of a crossing every 0.3 miles. On the average, crossings on the Sharon Hill Line are spaced less than 0.2 miles apart. Transit stops are located at most of these crossings. Traffic volumes on the cross streets range from 400 to 25,000 vehicles per day. Most crossings carry less than 5,000 vehicles per day. At many crossing locations there are no nearby signalized intersections. Therefore, these crossings can be treated as "isolated" crossings.

All forms of traffic control devices are used to control the crossing of LRVs along the Media/Sharon Hill Lines. They range from no control to traffic signals. Most of the control devices are quite old and few meet modern traffic engineering standards. Crossings controlled by simple railroad crossing signs are usually low volume minor streets. Auto drivers must exercise caution before crossing the tracks. Often sight distance is restricted due to such factors as large ornamental shrubs. At these locations the LRV does not stop; however, its speed is restricted.

At several locations, warning lights are used. They flash amber on the cross street and red along the tracks. These lights are usually supplemented by a unique "Stop, Look and Listen" sign similar to the one illustrated in Figure 55. In this case autos may proceed without stopping and LRVs must stop and wait for a gap to cross.

As illustrated in Figure 56, more heavily traveled crossings are controlled by semi-actuated traffic signals. When no train is in the vicinity, these signals display either flashing green or flashing yellow facing the cross street and solid red toward the tracks. When a train approaches and activates the signal, the indication facing the street changes to solid red and the one toward the tracks to solid amber.

Currently, the most sophisticated forms of crossing controls used are traffic signals. Some are supplemented by actuated warning bells. The traffic signals are mostly fixed-time, displaying the same phases whether an LRV is present or not. The movement of LRVs is controlled either by standard traffic signals or by track signals located a few feet above the ground. The track signals are interconnected with the remainder of the traffic signals at the particular crossing. Most of these signals are quite old and placement and phasing sequence in many cases are not up to modern standards. Signing is generally very poor at these locations. This factor, coupled with outdated traffic signals, confuses many auto drivers as they attempt to negotiate the more complicated crossings.

LRV receives priority at crossings controlled only by crossbucks. Motor vehicles at these locations must yield the right-of-way. At crossings controlled by actuated flashing lights an LRV, after coming to a stop at the crossing, actuates the lights and almost immediately receives a "go" indication. If the stop is combined with boarding/unboarding passengers, the delay to LRV is minimal. However, where there is no station, such as on all inbound trips where the station areas are usually located on the far side of the crossing, the LRV is unnecessarily delayed.



**Figure 55. Typical Warning Sign on Media/Sharon Hill Lines, Red Arrow Division**



**Figure 56. Typical Red/Yellow Flashing Lights on Media/Sharon Hill Lines, Red Arrow Division**

At crossings controlled by actuated traffic signals, LRV delay is held to a minimum. After detection and completion of the clearance interval the LRV receives a green indication. At crossings controlled by fixed-time signals, the LRV must wait until its phase in the signal cycle occurs. Delay is then a function of the moment in the signal cycle during which the LRV arrives at the crossing and the duration of the cycle.

Arriving LRVs are detected by track circuits. These are usually located at the crossing. If a near side stop is also present, the detector is located between the stop and the crossing. This way the signals are not actuated until the passengers are loaded/unloaded. Timers to prevent consecutive actuations by a platoon of LRVs are not used.

Delays to LRVs along the Media and Sharon Hill Lines due to traffic amount to approximately 10-20 percent of the total running time. Running time is as long as 30 minutes to Media and 23 minutes to Sharon Hill.

## PEDESTRIAN CROSSINGS

No special treatments are provided to handle pedestrian crossing of light rail tracks. On the CTD system the same traffic control that applies to streets without light rail tracks applies to streets with LRT tracks.

Only in rare cases are platforms and fencing used to channelize pedestrian movements. On the lines of the Red Arrow Division, some of the right-of-way is fenced and at some stations a low fence between the tracks discourages crossing in front of or behind a stopped streetcar.

There are virtually no pedestrian signals to control the crossing of pedestrians at intersections. Vehicular signals are used to control pedestrian movements. Since most of the signals are fixed-time, there are few pedestrian push buttons.

There are no barriers along most of the CTD right-of-way to prevent pedestrians from crossing the tracks. Jaywalking is common. Where the tracks are in a median, the crossings are either uncontrolled or controlled by a standard traffic signal without pedestrian indications. Along some lines, such as on Girard Avenue, there are raised center loading platforms. A chain fence directs pedestrians toward the crosswalk. Access to the platform at the crosswalk is controlled by a traffic signal. The sloping nose of the concrete platform is identified by flashing yellow lights. This is intended to warn approaching auto drivers. Years ago raised platforms were being removed because they were considered a hazard to automobiles. The old design had a concrete block at the upstream end and no sloping front. It is hoped the flashing lights coupled with a sloping nose will reduce accidents and accident severity.

Along the Media and Sharon Hill Lines pedestrians are either uncontrolled or they are required to observe the vehicular crossing lights. The signals are usually located in the center of the crossing, one signal per approach. The central location of the signals makes it very difficult for pedestrians to see the indications. At some crossings with standard traffic signals, the vehicular signals are placed in such a way that a pedestrian often sees no indication whatsoever during his crossing. As with the CTD, pedestrian indications are not used. Most of the traffic control devices at these crossings do not meet modern traffic engineering standards.

Occasionally, signs are used to warn pedestrians of the possible presence of streetcars. The most common is the "Railroad Crossing - Stop, Look and Listen" sign used along the Media and Sharon Hill Lines.

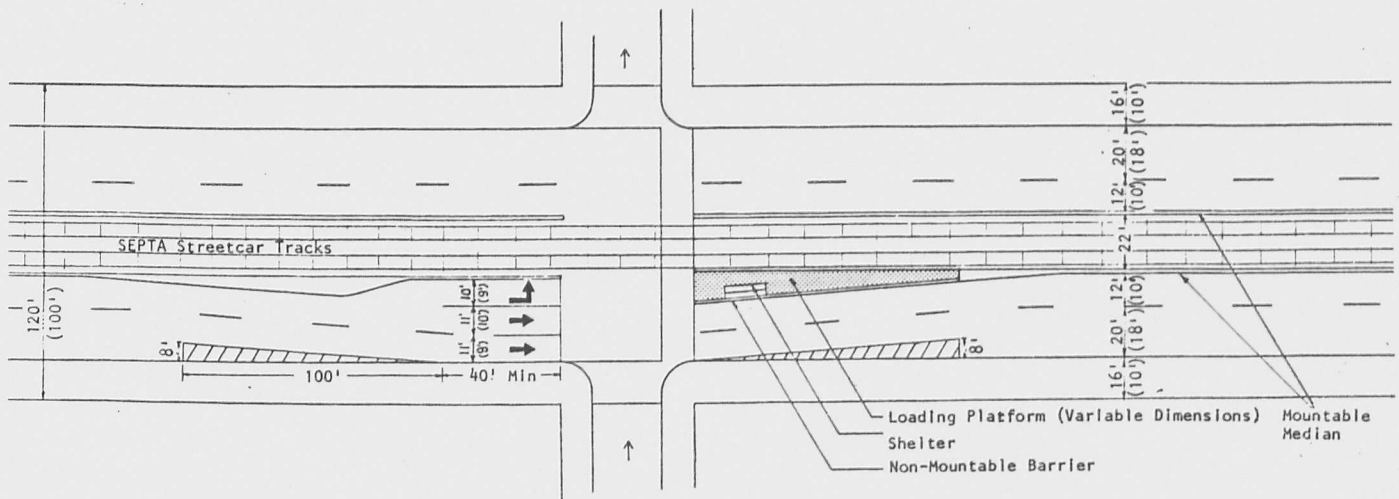
## FUTURE PLANS

### System Upgrading

Future upgrading of the CTD is planned to focus on operational improvements such as placing tracks in medians and modifying signal timing to favor transit speeds.



Along relatively wide streets such as Allegheny Avenue (Line 60) and portions of Girard Avenue (Line 15) in West Philadelphia, SEPTA is considering construction of a raised median as illustrated in Figure 57. With one-way cross streets (if the cross streets are two-way, the plan is to convert them to one-way operation) platforms would be placed at alternate blocks on the downstream side of a left turn lane. This conserves valuable street space. With one-way cross streets, traffic signals require no more than 3 phases. Where the cross streets must remain two-way, left turns are planned to be prohibited. If that is not possible, advance left turn arrows would reduce blockage of the tracks.



Source: City Traffic Department

**Figure 57. Proposed Median for Wide Arterials in Philadelphia**

Several streets are being considered for possible implementation of traffic signal progression favoring transit. Since most of the traffic signals in Philadelphia are not interconnected, the progression will have to be manually set at each controller with frequent monitoring to control slippage. Many streets that carry streetcar tracks are relatively narrow and carry low or moderate traffic volumes. Examples are Baltimore Avenue (Line 34), Chester Avenue (Line 13) and Germantown Avenue (Line 23). Alternate routes are available along these streets. By adjusting the signals to a lower speed which favors transit, most nonessential auto traffic would be diverted to parallel routes. Thus an indirect benefit of such an improvement would be a reduction in the likelihood of auto-streetcar conflicts, which in turn could reduce accidents and further increase transit speeds.

A major change in streetcar and street patterns is being considered for the area west of the 40th Street Portal. Four streetcar lines diverge to separate alignments after emerging from the tunnel. To reduce auto/streetcar conflict, several east-west streets would be converted to 1-way operation between 40th and 45th Streets, and portions of 2-way track would be converted to single track 1-way operation. As of spring 1977, this project had not received all necessary approvals.

Plans are being prepared to improve grade crossing protection and some passenger waiting areas along the Media and Sharon Hill Lines. Improvements being considered are intersection channelization, crossing gates with preemption, red/yellow flashers and track relocation. These improvements are estimated by participants in the Delaware County Public Transportation Study to cost about \$2 million. Grade separation of the east end of the line at the 69th Street Terminal

would add another \$1.2 million. These improvements are estimated to save 4 to 8 minutes per round trip on the Media Line and 2 to 5 minutes on the Sharon Hill Line.

## Expansion

As part of the I-95 freeway project, Line 36 may be relocated between the freeway and the parallel one-way frontage road. An extension to Philadelphia International Airport was being considered. It has been dropped in favor of extending the Broad Street Subway. A travel time of 20 minutes via subway vs. 30-40 minutes via streetcar was the deciding factor. The terminal station at the airport is just being completed. To minimize walking, each satellite will have a station. The remainder of the extension is enmeshed in negotiations between SEPTA, ConRail and Penn Central over the proper method to handle a single freight movement on shared track.

## SAFETY

Accident statistics for the CTD were not available at the time of the visit to SEPTA due to the transit strike which was then in effect.

Accidents involving SEPTA vehicles are investigated by SEPTA inspectors. Police are called only if the accident involves injury or death. SEPTA has a computerized file of all accidents.

Many of the accidents involving streetcars are rear end collisions. The PCC cars have relatively poor track adhesion. New vehicles such as the Boeing car have about 20 percent better traction. Many accidents involve sideswipe collisions. This is caused primarily by parking vehicles on narrow streets where side clearances are minimal.

Traffic accident data was recently compiled for the Media and the Sharon Hill Lines as part of the Delaware County Public Transportation Study. This study revealed that for the period of January 1970 through April 1976, a total of 76 accidents occurred at the 12 crossings shared by both lines. This converts into an average annual accident rate of 7.1 accidents per 100,000 LRV miles. During the same time period, 77 accidents occurred at 17 crossings of the Media branch. This calculates out at an accident rate of 4 per 100,000 LRV miles per year. The short stretch (0.8 miles) of mixed flow running resulted in 119 accidents and a rate of 66.

Eighty-two accidents occurred at 15 crossings on the Sharon Hill Line while 66 accidents occurred on the less than 1-mile stretch of mixed flow operation on Springfield Road and Woodlawn Avenue. The corresponding accident rates are 11 and 35, respectively. These figures show that LRT operation on separate right-of-way with substandard at-grade crossing protection is still safer than mixed flow.

## JURISDICTIONAL CONSTRAINTS

SEPTA was created as a self-regulating agency. However, the PUC controls such items as the installation of railroad crossing gates and the timing of gate closures. It also has jurisdiction over highway/rail and rail/rail crossings.

Transit improvements are usually initiated by the Traffic Department. After review and approval by SEPTA, the project usually must pass through State and FHWA and/or UMTA review. This is because most projects involve roadwork in addition to rail improvements. Over 50 percent of the streets in Philadelphia are state highways. The State maintains only the portion of the street to within 18 inches of the nearest rail. Improvement projects are handled by the State department of transportation as an intermediary with the Federal government.

## RULES OF OPERATION

For mixed flow and median operation the rule book states that:

*“ . . . on the street your speed must be governed by posted speed limits and traffic and street conditions. You must maintain a slow speed in the following specific instances: . . .*

*When passing a standing car going in the opposite direction, or a work or delivery truck. Sound gong and be alert to people stepping out from behind these vehicles.”*

The only operation on exclusive right-of-way of CTD is in subway. The subway is equipped with an automatic block signal system designed to prevent collisions. “Light signals, operating signs, . . . must be strictly obeyed.”

The traffic operation of RAD is governed by the following rules:

### *VEHICULAR RIGHT OF WAY*

*The meaning of right of way should always be interpreted as when to give the right of way to others and never to take the right of way. Never take the right of way unless the other driver or operator has shown clear signs that he will give it to you. Right of way will never be accepted as an excuse for collision with a pedestrian or other vehicle. . .*

### *SPEED*

*Operators must obey all local speed limits. Under all conditions, the speed of (LRV) cars must be reduced to a safe speed around curves. . .*

### *BLOCK SIGNALS*

*Each section of single track. . . is protected by electric block signals. . .*

### *IMPERFECT DISPLAY OR ABSENCE OF USUAL SIGNAL.*

*A signal imperfectly displayed, or the absence of a signal. . . must be regarded as a stop signal. .*

### *HIGHWAY CROSSING TRAFFIC SIGNALS*

*Car operators approaching a trolley actuated highway crossing signal which has either failed to change in favor of the rail car or is burnt out, must come to a full stop before entering the crossing, make traffic observations in both directions and proceed only when the crossing can be made without possibility of accident. . .*

### *GONG AND HORN*

*The horn signals to be given by operators are as follows:*

#### *Two Blows*

*At crossings except in boroughs where the use of the horn is prohibited. Length of blows to be governed by physical conditions at crossing.*

#### *Two Short Blows*

*When passing car at crossing or when passing standing car.*

In towns or boroughs where the use of the horn is prohibited, the gong will be used instead, and in accordance with the above instructions regarding the blowing of the horn.

## EDMONTON AND CALGARY

The two principal cities in the Canadian province of Alberta, Edmonton and Calgary, are engaged in the construction of initial segments of LRT systems. Construction of the 4-1/2 mile initial segment of the Edmonton system began in 1974 and is scheduled for completion in 1978. Construction of the 8-mile initial segment of the Calgary system is scheduled to start in 1978 to be completed 4 years later. The two systems plan to basically adopt the same type of LRT technology that developed in the late '60s for the A lines in Frankfurt, Germany.

Construction of rail transit in these two medium sized, highly automobile-oriented cities has become possible with the application of simpler European light rail transit technology which permits at-grade crossings and use of street and other available rights-of-way. It is relevant in this case to examine the approach adopted for the control of train operations, and particularly the control of at-grade crossings at intersections.

### EDMONTON

The starter segment of the Edmonton LRT system consists of 1 mile of subway through the CBD, and 3-1/2 miles of at-grade operation in a railroad corridor. On this segment, there are 9 at-grade street crossings, all midblock crossings shared with the parallel main line of the Canadian National Railway, and 1 at-grade crossing on the spur track leading to the depot and maintenance yard. Figure 58 indicates the layout of this line.

#### Crossing Control Strategies

The 9 at-grade street crossings along the 3-1/2 mile railroad corridor are all of the midblock type. The railroad right-of-way cuts diagonally across the street grid pattern, intercepting both north-south and east-west streets. The crossings are designed to operate for either LRT or railroad trains. Pedestrian crossings are provided in association with street crossings, and grade separated pedestrian crossings are provided at stations. These stations are all of the high platform type with facing platforms. Street crossings of the LRT line occur both adjacent to stations and at locations remote from stations. In the storage and maintenance area, part of the trackage is paved to facilitate access by service vehicles.

#### Control Systems

Operation of the Edmonton LRT system will be controlled by a 2-aspect block system using wayside signals. Trains will be operated by a single motorman who will maintain schedules by means of an instruction sheet similar to that used by bus operators. All grade crossings will be protected by conventional railroad flashing lights and gates. These gates will also serve the railroad. The gate condition will be made known to the LRT motorman by means of red and green 2-aspect signals. These signals will normally be set at red but will switch to green when the gate mechanism operates. As an additional safety measure, both the gate signals and the train protection block signals will be linked to an automatic train stop of the inductive type which actuates the train brakes in event of failure to observe signals. Should the gate fail to operate, the signal will remain at red, and the train will be stopped prior to the crossing.

This integrated system of train control and crossing protection will be accompanied by a 2-way communication system between each train and central control, allowing flexible response to unusual or emergency situations.

To enter or leave the line from the depot and maintenance yard, LRT trains will have to cross the Canadian National main line. This crossing will be protected by full interlock normally set for the railroad. An LRV motorman wishing to cross the tracks will be required to press a route request

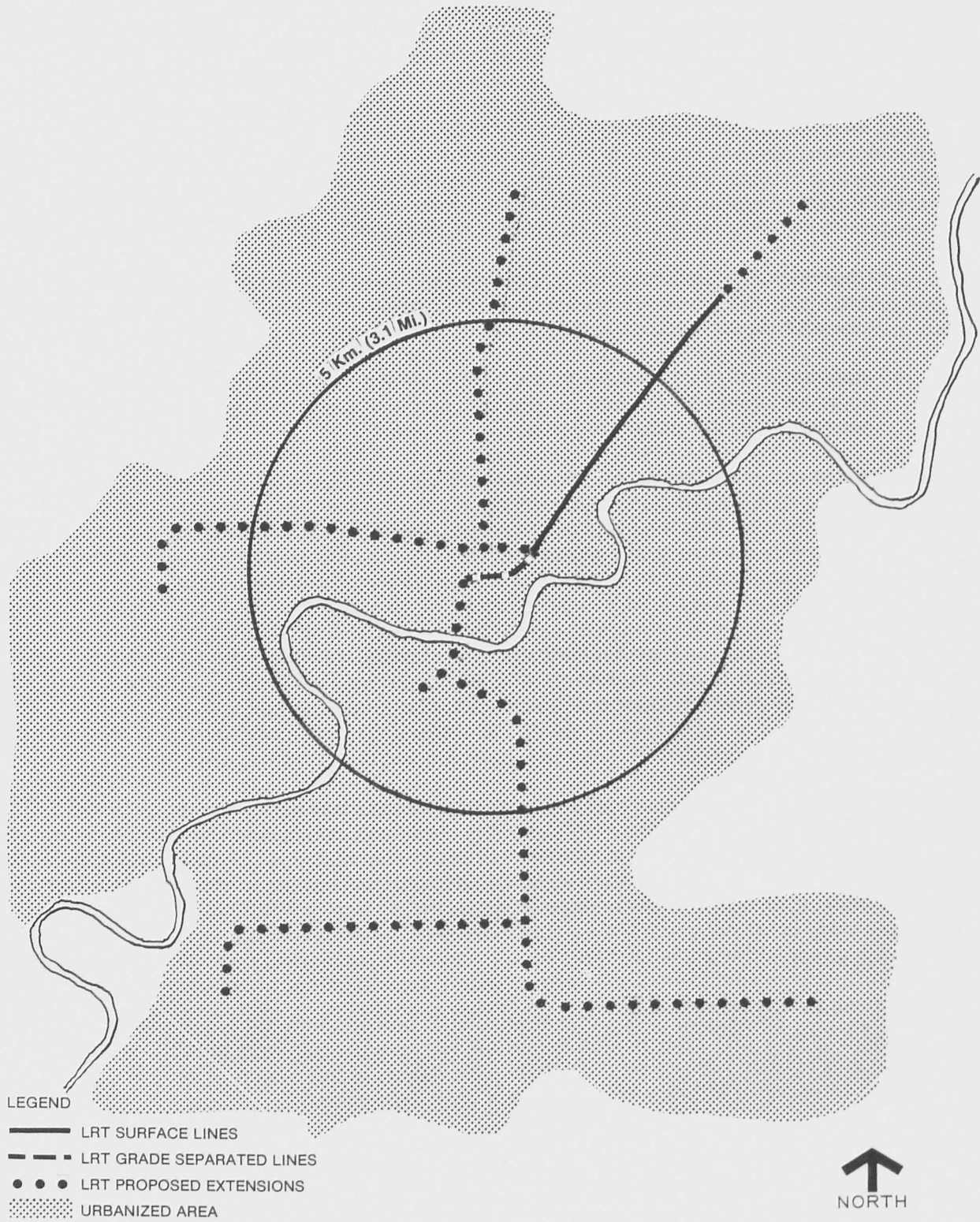


Figure 58. Edmonton LRT System

button mounted beside the track at window level. If the railroad is clear, the railroad signals will turn to red and the track will be set for an LRT crossing movement. Only when the track is set for LRT, and the signal protection actuated, will the LRT signal turn green permitting the LRV to cross. If a Canadian National train is in the approach zones of the crossing, the interlocking device will prevent setting the route for an LRT crossing.

A major concern in the design of this line is to prevent delays to traffic and unsafe conditions at the grade crossings. To achieve this aim, the traffic signal control system will be integrated with the LRT control system and LRT street crossing movements will be coordinated with street signal progressions. Three basic principles govern the design of Edmonton's grade crossing controls.

- *Coordination of traffic signals so that vehicles queueing at intersections will not block LRT crossings.* This is to be achieved by controlling the capacity of upstream signals to eliminate, so far as possible, queueing at signals which might block the LRT line.
- *Integration of traffic signals in the vicinity of the LRT system with LRT controls.* The objective here is to arrange for the LRV to cross a street between the traffic platoons resulting from the signal progression in the street.
- *Use of special traffic signal control techniques such as preemption of downstream signals and modification of signal cycles.* These techniques would be employed in the event of excessive queueing that might interfere with LRT operation. In order to schedule the LRT movements into the traffic signal progressions, one of the block signals at a station will function as a train release, releasing trains at times to coincide with the optimum crossing intervals.

The Edmonton system is particularly significant as it is the first new LRT system in North America. Although it only represents one particular type of crossing control strategy, the effectiveness of this installation will be monitored with interest.

## Future Development

The City of Edmonton Transportation Department will release plans for the expansion of the LRT system during 1977. These plans will chart the subsequent expansion of the initial line to provide coverage throughout the urbanized area. It is anticipated that much of the control and crossing technology will be based on experience to be derived from operation of the initial line and that additional grade crossing strategies will be required to implement this plan.

## CALGARY

In May 1977, the Calgary City Council decided to proceed with the construction of the initial segment of their LRT system. This 8-mile line will extend south from the CBD on segments of street and railroad right-of-way. While the final design of this system is not yet complete, the basic strategies for at-grade crossings have been determined.

Two general strategies will be used for at-grade crossings. Where the line operates parallel to a railroad, conventional railroad gates with flashing lights and bells are to be used. These gates are considered necessary because there is no other satisfactory method to prevent motorists from crossing the tracks immediately after a train passes and possibly colliding with a train traveling in the opposite direction. It is anticipated that these crossings will operate similarly to those in Edmonton.

As it approaches the CBD, and within the CBD, the LRT line will operate within street rights-of-way. A short segment will consist of conventional median construction and the CBD segment will operate on city streets in a transit mall shared with buses. In the mall, LRT lines will operate in the center of the street, with buses using the other traffic lanes. Conventional traffic signals will be used on the street right-of-way segments. These signals will be interconnected with the citywide computer-controlled traffic signal system. It is not anticipated that LRT will be given absolute priority. Instead, the existing traffic signal system will be modified to provide signal progressions, actuated by LRV detectors at specific locations, which will favor LRV movement. It is anticipated that a compromise will thereby be achieved between the operating requirements of the LRT system and the needs of traffic circulation in the CBD.

The Calgary LRT system represents a considerably more ambitious development than the Edmonton system in terms of its length and the versatility shown in right-of-way use and grade crossing techniques. The development of final designs and the subsequent experience with implementation will be of significant interest.

## CHICAGO

The Chicago Transit Authority (CTA) transit system is unique among North American rail rapid transit systems in that it operates over some 25 at-grade street crossings. These crossings, together with the use of magnetic track brakes, overhead power (on the Skokie line only), on board fare collection (on certain lines during off peak hours), and the former practice of operating some segments without continuous signaling made the CTA system a candidate for the study of certain aspects that are relevant to LRT. It should be stressed that the CTA system is not normally considered to be LRT since apart from 4 segments, the system is entirely grade separated, mostly third rail powered, and operates long trains on many routes.

The reason at-grade crossings exist on the CTA system lies in the historic evolution of the system rather than in a deliberate policy. For many years, Chicago was the focal point of an extensive network of interurban electric railways that served urban centers beyond the metropolitan area.

The CTA system uses third rail power distribution, except for the Skokie Line which uses overhead for the at-grade section of the route. The Skokie cars, equipped for both third rail and overhead collection, change from one mode to the other at the midpoint of the line without stopping. On the overhead section, a bow collector is used rather than the more common trolley pole or pantograph. The Evanston Line also once used overhead power collection, but was converted to third rail a few years ago. These overhead power distribution systems are remnants of the earlier interurban operations, all of which used overhead wires. When the first elevated railway was constructed in central Chicago, forming the Loop, some of the interurban lines used the elevated tracks to gain a high-speed access route to central Chicago. In later years, as the interurban services were cut back, the rapid transit system expanded its operations over segments of the former interurban trackage. These segments were generally not grade separated. Over the years, some of the at-grade lines have been relocated, grade separated, or abandoned, and today only 4 segments of the system have at-grade crossings.

## CROSSING CONTROL STRATEGIES

The locations and respective numbers of at-grade crossings are as follows:

Skokie Line - seven

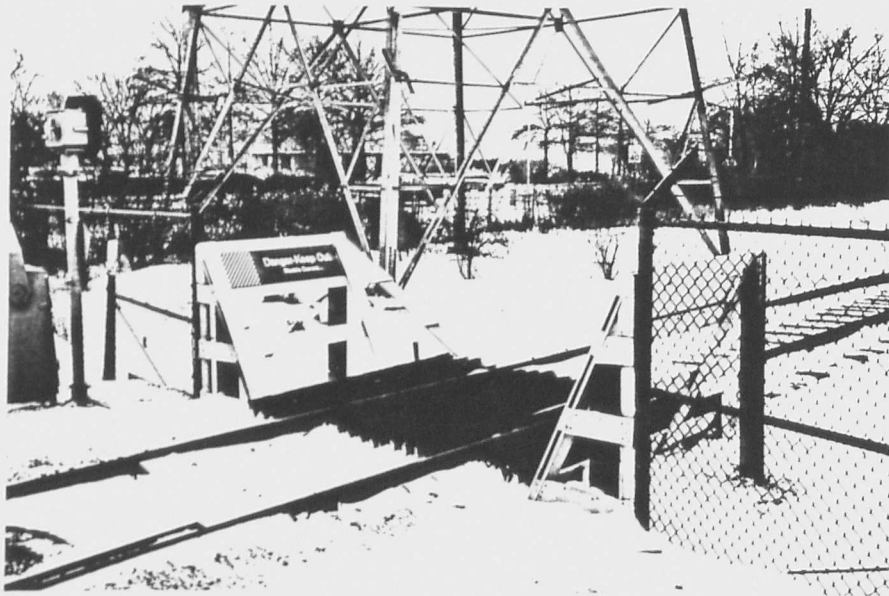
Evanston Line - two

Ravenswood Line - six

Douglas Line - ten

The location of the at-grade segments of the system are shown in Figure 59. All of the lines have 2 tracks.

All the crossings are at midblock on exclusive right-of-way, there being no median or street running with at-grade crossings on the CTA system. All of the street crossings are protected by automatic drop gates of conventional Association of American Railroad (AAR) design. Where there are sidewalks, additional gates are provided across the sidewalk. On the third rail lines, there is a break in the power rail at crossings and a device similar to a cattle guard is positioned across the tracks to prevent pedestrian access to the right-of-way (Figure 60). The two crossings on the Evanston Line are additionally protected by swinging gates which were installed, at the request of the community, at the time of conversion from overhead power to third rail. These gates block the tracks when no train is coming, and swing back away from the highway when a train is approaching. Their only function is to prevent trespassing on the railway right-of-way. The main crossing protection function is provided by the conventional drop gates.



**Figure 60. Device Similar to a Cattle Guard to Prevent Pedestrian Access to CTA ROW**

## **METHOD OF OPERATION**

To understand the context of the grade crossings on the CTA, a brief explanation of the signaling system is in order. Prior to 1947, almost the entire CTA system, some 77 route-miles, was operated virtually without signal protection and with only limited interlocking protection at switches. The only exception was the North-South Subway route, where trains were controlled by wayside signals and train stops. To enable this system to be operated without fully automatic train protection, the cars were equipped with track brakes. Typical rail rapid transit vehicles operating with automatic train protection do not have track brakes, while modern LRVs do. The



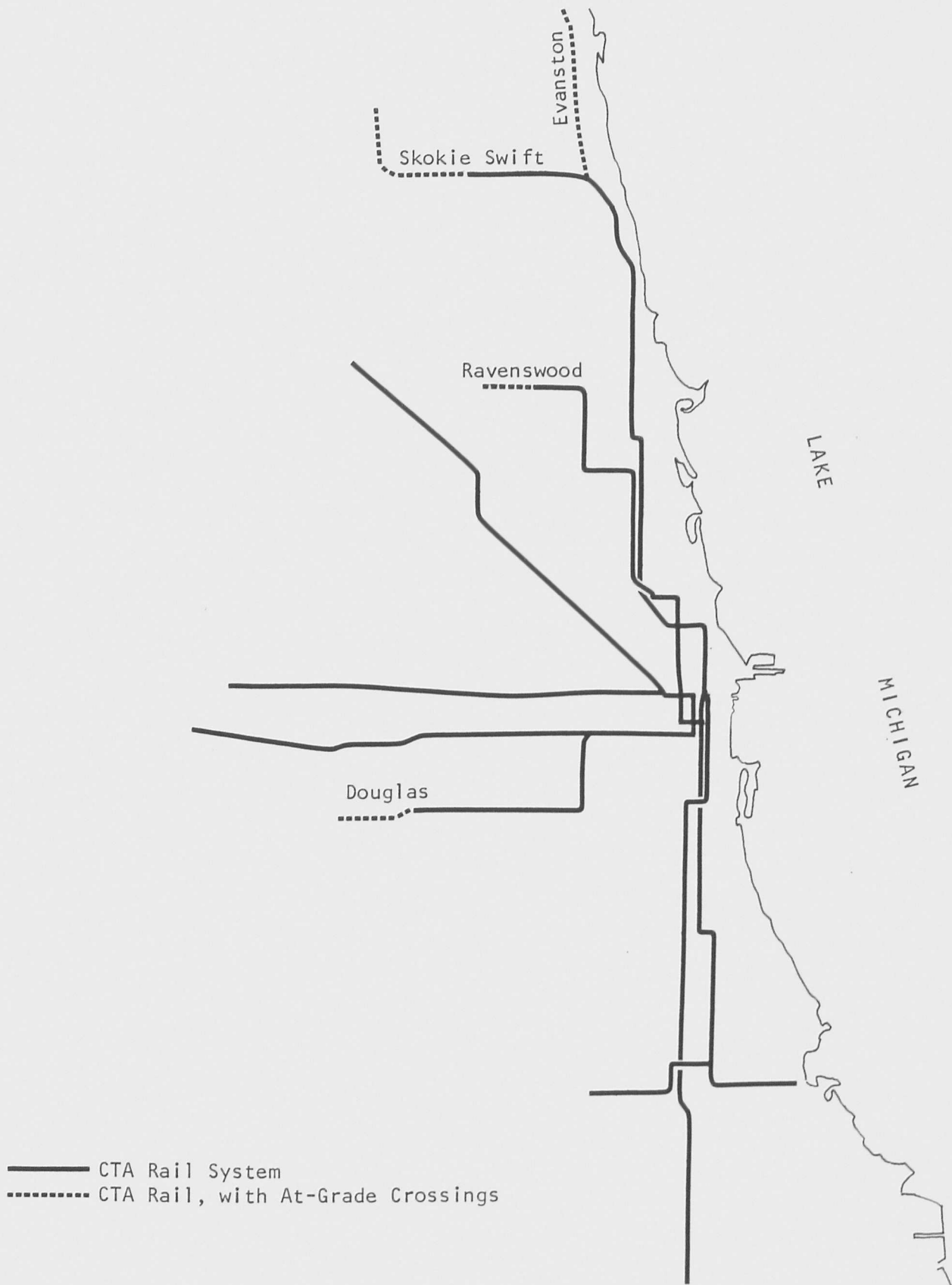


Figure 59. Location of At-Grade Segments, CTA

need for high braking capabilities, mandated by unsignalized operation and short radius curves typical of the early elevated lines, resulted in the use of vehicles on the CTA system which are almost identical to modern LRT equipment, and illustrates the continuum that exists in the family of rail transit modes between fully grade separated, automated systems and less costly nongrade separated systems typical of LRT.

Since the Second World War, signal protection has been gradually extended over the whole of the CTA system, initially by extending the wayside signals, and more recently through the introduction of cab signals. The installation of systemwide signal protection is scheduled for completion in 1977.

On the 4 lines with at-grade crossings, the gate controls will be operated by the cab signaling circuits. Prior to the installation of these circuits, the gates will continue to be operated according to standard AAR procedures. When a train enters the approach zone to a gate, the bells and flashing red lights commence operation. After 10 seconds, the gate begins to descend and in approximately 20 to 22 seconds, the gates are fully down. After 30 seconds, the train arrives at the crossing. Between 2 and 5 seconds after the train clears the crossing, the gates begin to rise and are fully clear 10 seconds later. The gate protection facing the train motormen consists of a single aspect green light. When the train enters the crossing approach zone, the green light, which is normally off, begins to flash indicating that the gate operating cycle has commenced. The green light continues to flash until the gates are fully down, at which point a continuous green aspect is shown and remains on until the train has cleared the crossing. The more conventional red/green wayside signal light is not used at crossings to avoid confusion with the wayside block signals used elsewhere on the system. The CTA rule book requires that the train stop if the green light fails to light up or continues to flash as the train approaches the crossing. There is no automatic train stop at crossings.

The legal speed for street traffic through the crossings is the same as for the adjoining streets, generally 30 mph. In many cases, vehicles slow down slightly because of the irregular pavement at crossings. Train speeds are generally 35 mph, except at Kedzie Avenue where there is a mandatory stop in one direction, or where the location of stations results in lower train speeds. The Skokie Line is an exception, and here the maximum train speed is 55 mph.

**Table 10. Train Data, CTA At-Grade Operations**

Line	Peak Headway (min)	Peak Train Length (feet)	Maximum Speed
Skokie	4.4	70	55
Evanston	4.3	300	35
Ravenswood	4.3	300	35
Douglas	4.8	300	35

At two locations on the system, the gates are interconnected with nearby signalized intersections. One is at Oakton on the Skokie Line and one is at Cicero Avenue, where there is also a station. The station has a single-island platform rather than the conventional offset platforms more commonly found on LRT. A train entering the crossing approach zone requests the crossing gate phase of the intersection signal control. After the appropriate clearance times, the intersection is set for the parallel traffic flow, and the gates then come down and the train may proceed. The problem with this arrangement is that on occasions, trains approaching the station from the far side of the intersection may have to stop twice, once for traffic and then again at the station.

At Kedzie, on the Ravenswood Line, where the station is on the west side of the intersection, there is a mandatory stop for westbound trains. Westbound trains, in this case, always stop twice while eastbound trains only stop once at the station.

Lighting at crossings is provided by the cities having jurisdiction over adjacent streets. No special lighting standards are applied. In most instances, the crossings have two vehicular gates protecting the approach sides and four pedestrian gates covering both directions of travel on the sidewalks. At least one location has two vehicular gates on each approach side (Oakton/Skokie). Some pedestrian gates have hangers beneath them to prevent pedestrians from ducking underneath. At a number of crossings there are stations consisting of a single-island platform with at-grade exits to the street. To provide protection for the pedestrians to and from the station platform, the pathway from the station island platform to the street is also protected by a drop gate and light.

The CTA experiences a certain amount of vandalism of crossing equipment. All train motormen have radio communication with central control, and are required to report such incidents. This enables a quick response. The gates are balanced to be lowered the first 45 degrees by a motor and the last 45 degrees by gravity. If a gate is damaged or broken and will not close, the motorman will not receive the steady green light that he requires in order to proceed through the crossing. Failures of this type will delay, but not stop service since the rule book permits a train to proceed after making a stop and giving audible warning if the operator is satisfied that it is safe to do so.

The method of crossing operation used by the CTA does not work well with skip-stop service. Skip-stop service is used extensively on the CTA system, but on only one segment (Ravenswood) having at-grade crossings. The principal problem is that some trains stop at a given station, and some do not, so the approach time to the crossing varies. Since the train detection equipment is not speed sensitive, unnecessary delay to street traffic results and may tempt drivers to evade the crossing gates. The Ravenswood Line does have a higher incidence of accidents. The problem might be alleviated by use of modern grade crossing predictor equipment such as that marketed by the Safetran Corporation.

## SAFETY

During the past 5 years, there have been 32 vehicular accidents with one fatality, and 16 pedestrian accidents with seven fatalities at the CTA at-grade crossings. There have been no serious injuries either to operators or to passengers at these crossings during this same period. Review of the cause of these accidents suggests two significant contributing factors. First, the layout of the crossing has a major influence on the probability of accidents. Over half of the vehicular accidents occurred on the Ravenswood Line, which has only 6 out of the 25 at-grade crossings. The Ravenswood Line runs through an area of dense development, with the rapid transit alignment passing through the blocks on a narrow right-of-way wedged between multistory structures. The auto driver's view of the tracks is therefore obscured. Pedestrian accidents, which are less influenced by sight distance, do not occur in a disproportionately high number on this line. The second observation is that the vast majority of both pedestrian and vehicular accidents are caused by persons who do not see or who deliberately evade the crossing protection. Thus, in 24 of the 32 vehicular accidents, cars drove around or through the crossing gates.

In vehicular accidents involving rail transit, the relatively low floor height of the transit vehicles and the large amount of underfloor equipment generally prevent the automobile from ending up beneath the train. The resulting accident is potentially less severe than similar accidents which occur at railroad crossings. Autos driven into the side of freight trains, are sometimes crushed beneath the freight cars, a common source of fatalities at railroad crossings. It may also be

observed that a transit car is illuminated at night, and therefore conspicuous at grade crossings. A freight train is not illuminated, is dark in color, and car floors are high enough to allow auto headlight beams to pass beneath. Auto collisions with the sides of trains at night, a problem with railroad crossings, are therefore not thought to be a major problem with transit.

Significantly, only 3 out of the 32 vehicular accidents were caused by a vehicle stopped on the tracks at a crossing. These were most likely at locations where the view of the tracks was obstructed by curves. Two accidents were caused by vehicles reversing under the gates (from a parking place), one accident involved a wrong-way vehicle on a one-way street, and one was due to vandals raising the crossing gate in front of a train.

Pedestrian accidents follow a somewhat similar pattern. Ten out of the 16 accidents arose from pedestrians crossing a closed gate in front of a train. A further 4 were caused by suicides, and the remaining two were apparently the result of persons being trapped between gates.

## CASE STUDIES

Two at-grade crossings on the Skokie Line of the CTA were studied in detail. Both crossings, at Crawford Avenue and at Oakton Avenue, are located in the Village of Skokie.

Crawford Avenue, a 2-lane arterial street with parking on both sides, crosses the tracks in a residential area. All cross streets along Crawford Avenue have stop signs. There is no major intersection for approximately 1/4 mile in either direction from the transit crossing. Crawford Avenue carries approximately 20,000 ADT, and has a speed limit of 35 mph. There have been no accidents at this location during the past 5 years. During the peak hour when train headways are just under 5 minutes, minor delays are sometimes experienced. However, the street has adequate traffic storage space and this is not considered a problem.

The Oakton Street crossing has more problems, primarily arising from its location. Figure 61 illustrates the layout of this crossing. Approximately 50 feet to the east of the crossing is a major signalized intersection and 200 feet to the west is a minor railroad crossing. The site has experienced 2 accidents involving the CTA during the past 5 years. It is also the site of frequent traffic congestion.

Since the trains operate at 55 mph on the Skokie Line, a major design objective of the Oakton Street crossing is to clear the crossing of any traffic backed up at the intersection with Skokie Boulevard on the approach of a train. Figure 62 illustrates the signal phases for the intersection of Oakton Street and Skokie Boulevard, immediately adjacent to the grade crossing. As soon as a train enters the crossing approach zone, the signal goes to Phase 2 for approximately 10 seconds to clear the crossing. At the end of this time the crossing gates are to be closed. The intersection signal then goes to Phase 4 and stays with this phase until the train clears the crossing. During Phase 4 when the crossing is closed, signs prohibiting turns onto the crossing are illuminated in the appropriate lanes. These signs prohibit the northbound left turn and the southbound right turn when illuminated. As soon as the train clears the crossing, the intersection returns to Phase 1 to clear out accumulated traffic, followed by Phase 2, 3, and 2 again, etc., until another train approaches.

A review of the accident diagrams for the intersection and CTA crossing for the period 1968-76 showed an accident pattern fairly typical of a heavily traveled signalized intersection. The major type of accident which occurred at the intersection was rear end collisions on the intersection approaches. Rear end collisions at the crossing approaches and left turn collisions at the intersection both occurred in equal numbers.

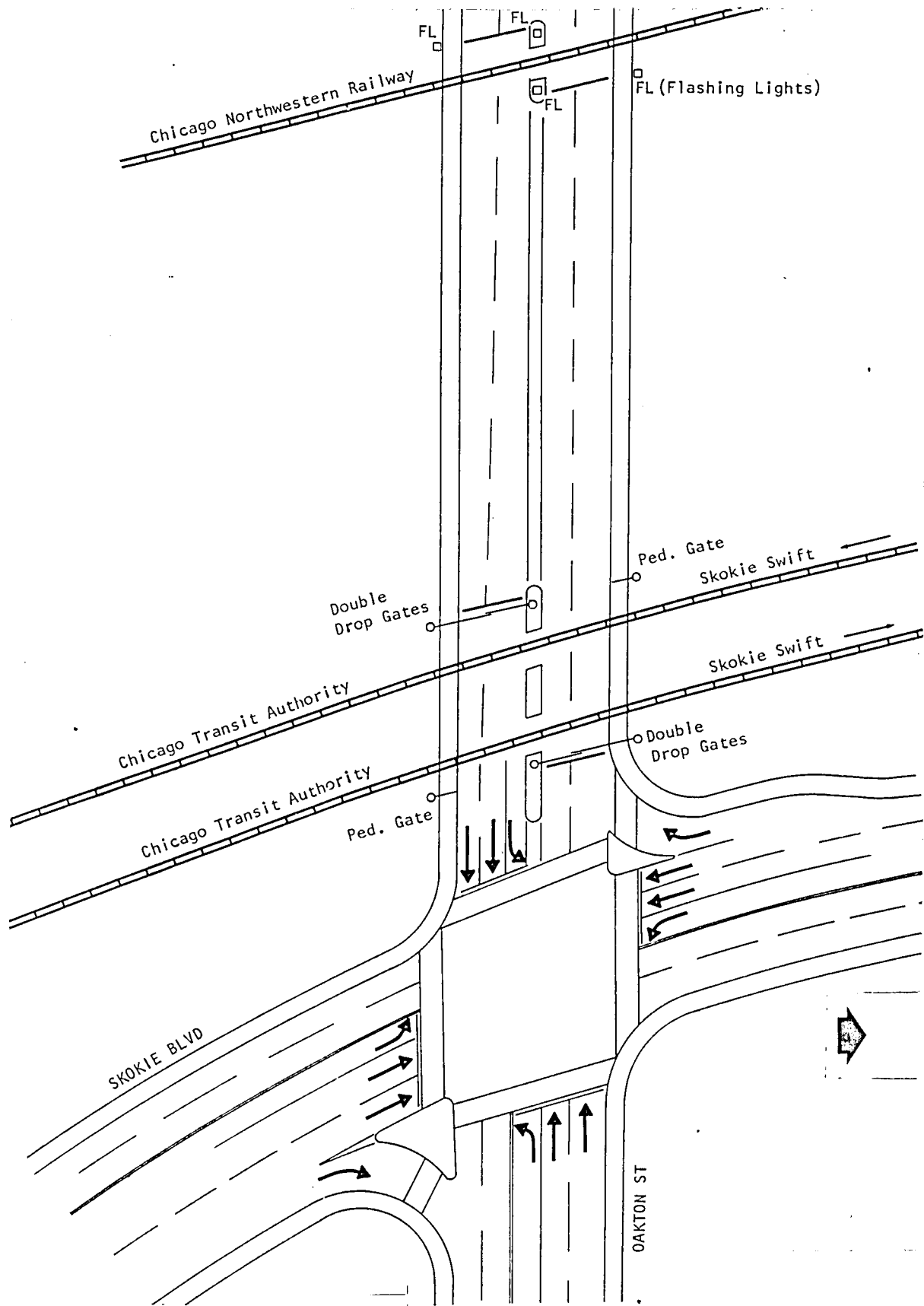
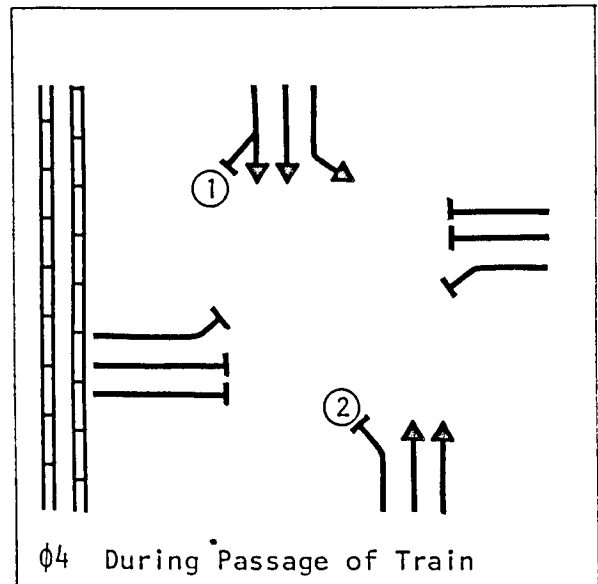
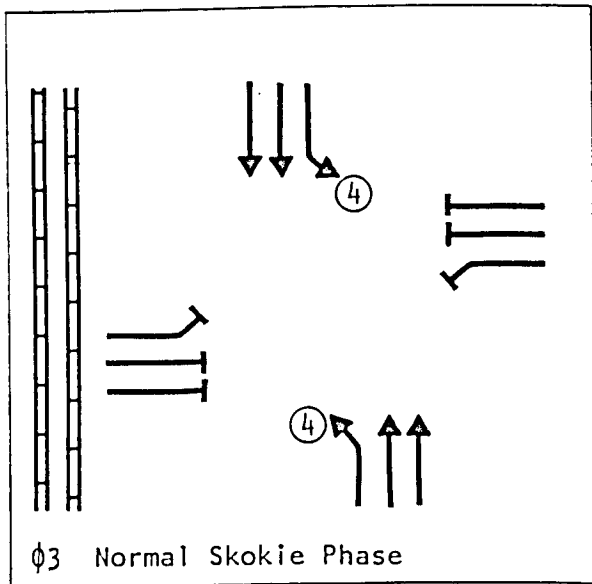
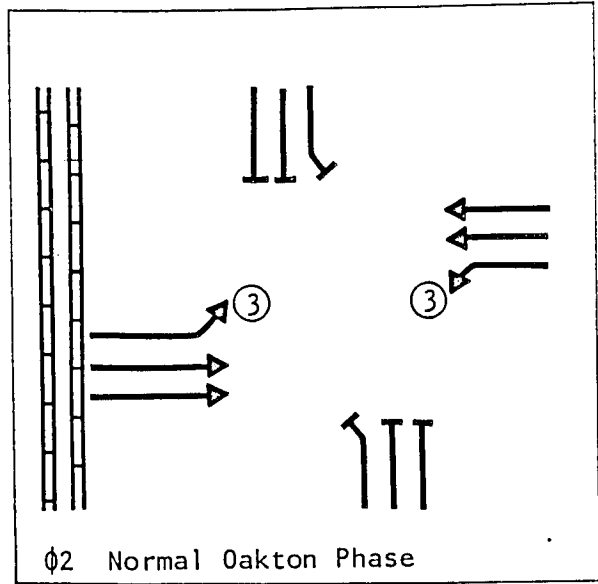
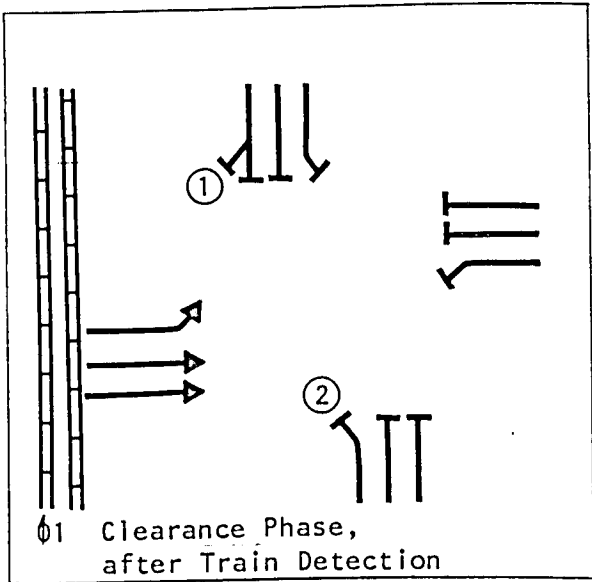


Figure 61. Oakton Street Crossing Layout, Skokie Line



- ① Illuminated Sign - No Right Turn
- ② Illuminated Sign - No Left Turn
- ③ Uncontrolled Left Turn
- ④ Uncontrolled Left Turn

Figure 62. Signal Phases at the Skokie Boulevard/Oakton Street Intersection

Over the 9-year period reviewed, less than 25 percent of the vehicle accidents in the vicinity of the intersection occurred near the crossing. Between 1974 and 1976 the majority of the accidents at the crossing were rear end collisions between westbound vehicles. The number of rear end collisions could probably be reduced by lengthening the crossing clearance phase, but some intersection capacity would be sacrificed.

The Oakton crossing is geometrically similar to several crossings built in The Hague in recent years. These latter are all controlled by traffic signals and operated with considerably lower train speeds.

## FUTURE PLANS

In general, neither the City of Chicago nor the Village of Skokie expressed any great concern over the CTA crossings, and it is unlikely that any changes will be made. On the other hand, the CTA perceives the crossings as a nuisance which it would prefer to be without, and does not plan to build any of its proposed new lines with at-grade crossings.

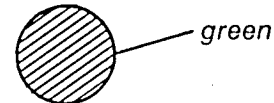
A significant difference between the CTA system and an LRT system is that the CTA's crossings do not confer on it the advantages of using otherwise unusable rights-of-way, such as street medians or shared traffic or pedestrian facilities, that are typical of LRT and account for some of its lower cost potential.

## RULES OF OPERATION

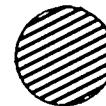
The CTA rule book provides procedures for operating through at-grade crossings as follows:

*Rule No. 148: ASPECTS AND INDICATIONS OF AUTOMATIC GATE AND CROSSING SIGNALS. Aspects and indications of automatic gate and crossing signals are as follows:*

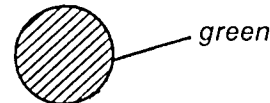
*Proceed, provided it is safe to do so.*



*Dark or Flashing  
Stop; operate Gate Wayside Push Button  
if one is provided.*



*If gate fails to lower, sound proper  
whistle or horn signal and proceed  
with caution if it is safe to do so.*



*RULE No. 170: MOTORMEN MUST OBSERVE ASPECTS OF GATE POSITION INDICATOR SIGNALS.*

- (a) Motormen, when approaching street crossings protected by Gates and Gate Position Indicator Signals, must observe the aspects of these signals, and comply with the indication.*
- (b) Gate Position Indicator Signals are not automatic block signals and therefore do not indicate track occupancy.*
- (c) Defective Crossing Gates or Gate Position Indicator Signals must be reported to the Radio Dispatcher at the first opportunity.*

*Rule No. 219: OPERATION AT STREET CROSSINGS.*

- (a) *Motormen must not operate over a street crossing protected by crossing gates unless the gates are fully lowered.*
- (b) *Motormen, when approaching street crossings protected by Gates and Gate Position Indicator Signals, must observe the aspects of these signals and comply with the indications.*
- (c) *If the crossing gates are out of order, or are not fully lowered, the Motorman must bring his train to a full stop. After the train is stopped, the Crossing Gateman, if one is on duty, must signal the Motorman when it is safe to proceed. Then the Motorman may proceed "on sight," with caution. If no Crossing Gateman is on duty, the Motorman, after stopping and sounding the "grade crossing" horn or whistle signal, may proceed "on sight," with caution.*
- (d) *Motormen, when approaching street crossings must be in a standing position and have their train under control, prepared to stop their train in emergency.*

## **CLEVELAND**

The Cleveland, Ohio, Regional Transit Authority operates one light rail and two heavy rail lines. The light rail line was formerly known as the Shaker Heights Rapid Transit. It consists of a 6-mile grade separated express LRT line from downtown Cleveland to Shaker Square, at which point it forks into 2 branches, one 3-1/3 miles in length, the other 3-3/4 miles in length. These two branches operate in wide street medians. The system is presently operated with 55 PCC cars which are scheduled to be replaced by vehicles to be ordered during 1977. The system is double tracked throughout. The first 2-1/2 miles of ROW from downtown are shared with the heavy rail system. On this section only, the LRT system runs on the left track in order to utilize island platforms adjacent to the heavy rail platforms.

## **CROSSING CONTROL STRATEGIES**

On the 2-1/2 miles between the CBD and a junction point, the light rail and heavy rail lines operate in a fully integrated maner along common tracks. This section of the system is equipped with automatic block signaling and with automatic train stop, and no distinction is made between heavy and light rail trains.

On the 2 branches, the LRT line operates in a median, intersecting numerous cross streets at signalized intersections. Most of the segment is surrounded by a grassed landscaped area, and is unfenced. Pedestrians are therefore free to cross at any point, but the excellent visibility afforded by this open type of construction has avoided problems.

## **CONTROL SYSTEMS**

The traffic signals governing all at-grade street crossings operate independently of the LRT system. Because these crossings are fairly widely spaced and most occur at station stops, system travel time is not unduly impacted.

## **FUTURE PLANS**

The former independent LRT line was absorbed by the Regional Transit Authority in 1976. As part of the new Authority's plan to improve transit in the region, the LRT line will be upgraded and



provided with new equipment. Minor extensions are also anticipated. As part of the overall upgrading process, it is likely that operation of the at-grade crossings will be studied and that measures to reduce delays to trains at traffic signals and insure observance of crossing signals by street vehicles will be examined.

## SAFETY

The experience on the light rail system has been approximately one auto "incident" approximately every 50,000 car-miles, most of them minor. The bulk of these arise from vehicles turning left at intersections across the tracks and sometimes from automobiles stopped on the tracks. Both of these accident types would appear to be amenable to design improvement solutions, including improved crossing geometrics, left turn signal phases interlocked with the LRT signals, and platform relocation. During the whole life of the system there has been only one fatal accident at an intersection.

## RULES OF OPERATION

The Cleveland LRT line is essentially self regulated, and is specifically exempted from the Federal Railroad Administration's reporting requirements and from the jurisdiction of State agencies. There is no requirement for any specific form of crossing protection, and indeed for many years prior to the introduction of the traffic signals, most of the crossings were uncontrolled.

Operation of the Cleveland LRT line is governed by a rule book containing both general instructions and instructions relating to particular locations or situations. These rules include specific speed restrictions at certain at-grade crossings, curves and switches. Most crossings are limited to 20 mph although certain crossings are restricted to lower speeds. Because most of the crossings are situated at stations, this is not a significant delay factor on the system. The cars themselves are governed for 45 mph which is, therefore, the maximum operating speed on the system. Other rules require observance of all traffic signals, which form the method of control at all at-grade crossings. A minimum headway of 1000 feet is required between cars. Audible warnings are specified in certain situations such as passing a car in the opposite direction at a station, or at the Shaker Square street crossings.

## PITTSBURGH

The Pittsburgh, Pennsylvania, LRT system consists of a single corridor running south from the CBD which splits into two long branches. The total length of the system is approximately 20 miles, much of it on private right-of-way. The CBD system operates entirely on city streets. There are a number of other short segments that use city streets or street medians. Wherever the system operates on city streets or on the medians of streets, train movement is controlled by conventional traffic signals and operation of the system is governed by the appropriate sections of the Traffic Code. However, along segments in private right-of-way, a wide variety of crossing protection is employed.

## CROSSING CONTROL STRATEGIES

The Pittsburgh LRT lines are remnants of an extensive system which once served the Pittsburgh area. At one time they were to be phased out in favor of the Skybus project, but with the abandonment of that concept, they are now to be completely renovated, and upgraded to modern LRT standards. A deficiency of the present system is the range of crossing protection types found along the private right-of-way segments of the system which in some cases, exhibits inconsistent treatment from one crossing to another and, in others, does not seem to conform to conventional traffic safety practices. Crossing protection along the private right-of-way includes: no\_

protection, apart from a conventional railroad crossing sign; traffic signals; flashing lights with gates; and a crossing sign with a continuously flashing yellow light. This latter device would seem to be of questionable value, and might even be construed as hazardous since regular users would quickly learn to ignore it and trust only on watching for approaching trains.

Unlike the Chicago system, the Pittsburgh lines follow conventional LRT practice and offset platforms are used at locations with at-grade crossings. Consequently, crossing protection at station stops can be integrated in a consistent manner. Stringent speed restrictions are mandated for LRVs at crossings without full protection. This may be due to safety problems arising from the ambiguous flashing yellow light protections and general auto disregard for crossings without positive right-of-way assignment. Since many crossings are also passenger stops, this restriction does not create undue delays.

### Use of Passing Tracks

An unusual feature of the Pittsburgh system is the operation of a segment of single track at close headways by means of frequent passing tracks. Many of the passing tracks are only a few hundred feet in length, protected by automated block and wayside signals. Although the single track section undoubtedly imposes an operating constraint during peak hours, it does illustrate a technique for reducing construction costs on lines which, at least initially, might operate at larger headways and on which the use of single track at a few locations (such as existing bridges or tunnels) might save a proportionately large initial investment.

As part of the original transit improvement program known as the Early Action Program, which included the now defunct Skybus project, a parallel busway is being constructed along part of the LRT route. Although this busway made sense under the original Early Action Program, its parallel use with the renovated LRT system will result in substantial unnecessary bus-miles and operating costs. Unfortunately, any reconsideration of the busway plan at this stage would require Pittsburgh to repay to UMTA the funds expended on the busway. Pittsburgh, therefore, seems locked into a future uneconomic operation as a result of the transit planning process and the political situation which envelops it.

### FUTURE PLANS

In mid 1977, design commenced on a project to renovate the Pittsburgh system. This work will involve track upgrading, car procurement, line changes, and improvements to stations and at-grade crossings.

While it is too soon to report on the standards that will be adopted, it is anticipated that some major crossings will be grade separated, and that many of the midblock crossings will be equipped with crossing gates. Where the tracks operate in median or street right-of-way, traffic signals will probably be employed for crossing control.

### TORONTO

The Toronto Transit Commission operates a multimodal system of subway, streetcars, trolley buses and buses. The streetcar system consists of approximately 40 miles of double track. Approximately 370 PCC cars are in use. The extent of the system has slowly diminished since the Second World War, the lines with heaviest ridership being converted to subway, and the lightly traveled lines to diesel or trolley buses.

## CROSSING CONTROL STRATEGIES

The Toronto LRT system operates almost entirely in mixed flow, with some short sections of median operation. Intersections are controlled by traffic signals or other traffic control devices, and no distinction is made between streetcar operation and other street vehicles. There are no gated crossings, and preemption is generally not used. System operations are governed by a rule book which requires adherence to the Canadian traffic laws by LRV operators.

## FUTURE PLANS

System length is relatively stable, and 200 new light rail vehicles are now being manufactured to replace part of the aging fleet of PCC cars. The Toronto Transit Commission has announced its intention to construct a number of semi-metro LRT extensions to the subway system, including a major circumferential line, but at the present time no firm commitments have been made.

It is possible that the arrival of the new cars, beginning in 1978, and the announced end of heavy rail subway construction will generate new interest in improving the streetcar system operation, just as it did in Europe some 10 to 15 years ago.

## BUFFALO

The City of Buffalo in New York will soon construct a 6.4-mile initial segment for a proposed regional light rail system. The project is now in the design stage, with construction scheduled to commence in 1978. The initial line will consist of a 5.4-mile semi-metro type subway, with a 1-mile transit mall in the CBD. Extensions to the initial system, which are not scheduled for construction until 1980, will be constructed in railroad right-of-way. The Buffalo system will be the first new LRT in the U.S. Although the designs are still not complete, the strategies to be used for at-grade crossings have been broadly established.

## CROSSING CONTROL STRATEGIES

The 1-mile downtown surface segment of the initial line will operate in the center of a pedestrian mall. This street presently carries mixed automobile and bus traffic. The LRT intersections on the mall segment will all be controlled by traffic signals. The method of signal actuation is still subject to further study, but will favor transit operation. This can be done with either a preemptive system or by modification of the existing CBD signal system to provide a progression suitable for LRT operation. The planned expansion of the system to railroad right-of-way will utilize conventional railroad gate crossing protection. The gates will be train actuated, but the method of integrating gate operation with traffic signals at nearby intersections on adjacent streets has yet to be developed.



