Special Report 200

The Trolley Bus: Where It Is and Where It's Going

Based on the Workshop on Trolley Bus Applications
August 29-September 1, 1982, Seattle, Washington

conducted by the Transportation Research Board
and
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Foreword

Interest in an electrically powered vehicle that operates quietly, accelerates quickly, gives off no exhaust, runs on non-petroleum energy sources, and performs easily up and down hills is on the rise--and, what is more significant, such a vehicle already exists in the form of the trolley bus. The primary question, though, is how to incorporate the trolley bus into the transit planning scene for today and in the future.

The application of trolley bus systems to modern-day transportation needs was the principal focus of a four-day exploration of current technology and uses around the world. Conducted by the Transportation Research Board (TRB) at the request of the Urban Mass Transportation Administration (UMTA), U.S. Department of Transportation, the meeting in Seattle, Washington, August 29-September 1, 1982, highlighted not only those transit systems that use trolley buses but also specific developments in areas such as vehicle types, infrastructure, and propulsion systems.

The workshop was comprised of five sessions that centered on presentations about selected topics. At the end of each session a question-and-answer period ensued. There were no formal group discussions and no conference recommendations were made because the meeting was intended solely as an opportunity for people in the field to exchange information on the state of the art and the state of the practice regarding the reemergence of the trolley bus. Thus, this report is arranged accordingly. Chapter 1 provides a brief history of the trolley bus and its place in transportation. Chapter 2 offers some perspectives on the trolley bus as it reemerges as a transit alternative in large metropolitan areas. Chapters 3-6 summarize each of the meeting's topical sessions and, where appropriate, selected materials are included that enhance the summaries and provide a reference framework for the reader. Chapter 7 offers some concluding comments about the trolley bus--where it is and where it's going.

More than 200 persons from the United States and abroad attended the Seattle meeting. They represented all levels of government, transit operators, planners, designers, consultants, university researchers, equipment manufacturers, citizen groups, and others interested in the trolley bus and its present and future application.

It is hoped that this report, which represents one of relatively few comprehensive looks at the trolley bus system published in recent years, will serve as a catalyst to further investigation of trolley bus technology and applications.

ACKNOWLEDGMENT

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A word of thanks is due to John P. Aurelius for permission to use some of the illustrations included in the report as well as material adapted from a brochure on "Trolley Bus Application" that was prepared for the Seattle meeting. Finally, special appreciation is directed to Adrian G. Clary of the Transportation Research Board, who served as staff liaison, for his support and encouragement throughout this project.

CHAPTER 1

A Brief History

The trolley bus is an electrically powered vehicle that first appeared on the scene in Europe at the turn of this century, but its technological development can be traced back to the drawing boards of designers and planners in the early 1880s. Unlike the motor or diesel bus, the trolley vehicle operates quietly, gives off no exhaust, accelerates quickly, performs well on hills, and runs on electrical energy that is not necessarily dependent on oil--a fact that is contributing to the renewed interest of transit system operators in the trolley bus mode.

Trolley bus systems, i.e., the power substations, overhead electrification, and vehicles, are also attracting attention because of their possible applications in areas where environmental, topographical, or fuel considerations are of primary importance and where ridership is high but not great enough to justify rail transit.

The trolley is powered by electricity delivered to the bus from a pair of wires located about 18.5 ft above the road with a 2-ft separation. Two trolley poles are mounted side by side on the bus roof. Each is topped by a grooved carbon shoe on a swivel mount. A spring at the base of the pole presses the shoe to the wire so that it remains in contact with the underside of the wire as the bus moves forward. Although it must follow the wire, the trolley bus can deviate about 13 ft from the centerline of the wire for curbside passenger stops or to bypass improperly parked vehicles or other obstacles.

The body and running gear of a trolley bus are generally very much like those of a motor bus. Because the motor buses are built to standardized designs and use components that are identical or similar to those for trucks, they benefit from the lower costs of volume production. However, the power-collection and propulsion systems are unique to the trolley bus and, therefore, more costly. But because the propulsion system is durable, the trolley bus has a long economic life (motor buses may be purchased every 5 to 10 years; trolley buses have known 20- to 30-year service lives). Sometimes propulsion components are reused when the bus body is replaced.

The electrification subsystem is an essential part of the complete trolley bus system. The two overhead wires cover the entire route in both directions, plus garage and emergency routings. They must be supported above the roadway, usually by strengthened utility poles, span wires, and specialized hardware so that the bottom surface of the wires is smooth and unobstructed. Specialized hardware is used at junctions for turnouts and crossovers--with as much as a ton of equipment supported above the streets at complex intersections. Trolley buses operate from about 600-650V direct current (DC). Thus, substations are required at intervals of approximately 1 to 5 miles to convert commercial alternating current (AC) power to the proper DC voltage with protective switching.

The deployment of trolley buses can be traced through five distinct periods. The birth of trolley bus technology and the first actual in-service use of a trolley extended from the 1880s to 1915. The first trolley bus was developed by Werner von Siemens in Germany and was put into revenue service in 1901 in Konigstein-Bad Konigsbrunn, Germany. The first commercial trolley bus operation in the United States may have been in 1910 on a short route in Hollywood, California, as a connection between the Pacific Electric Railway and a small settlement in Laurel Canyon. In 1911 trolley buses were running in Bradford and Leeds, England. One went into service in 1913 in Merrill, Wisconsin, but lasted only about 1 year.

Possibly the first trolley bus that went into revenue service anywhere was in Konigstein-Bad Konigsbrunn, Germany in 1901 (photograph courtesy of Siemens Company).

The second period in the history of the trolley bus is generally recognized as beginning in 1921, after a 7-year hiatus primarily because of World War I. It extended until about 1926.

In the early 1920s there were new efforts at establishing trolley bus services. Toronto used four Packard trolley buses for 3 years, starting in 1922 on the Mt. Pleasant Line. On New York's Staten Island, 23 vehicles built by the Atlas Truck Company were operated. The Oregon Avenue Line in Philadelphia was established at that time and is unique in that it remained in continuous operation for nearly 40 years. None of the other U.S. trolley bus lines of this period lasted for more than a few years.

Some of these early vehicles were primitive by today's standards, but they were functional. Some designs were taken from the gasoline buses of the day; others resembled small streetcars on high wheels. Solid, rather than pneumatic, tires were the rule. By the late 1920s, larger and better motor buses were being developed. Manual gear shifts were not satisfactory in city buses, and gasoline-electrics became available. The gasoline engine turned a compact generator, and the electric power was used by electric motors that drove the rear wheels. In a technical sense, it was a simple matter to replace the engine and generator with trolley poles and a control system.

The third period, from about 1927 through the early 1950s, saw the trolley bus gain its maximum deployment in North America. In 1927, 12 vehicles were running in Rochester, New York. In 1928, 10 began service in Salt Lake City, Utah, and 16 more a year later. Trolley buses came of age with a large Chicago installation in 1930-1931. Six routes were set in the northwest section of the city, a residential district that had been built in the 1920s. Trolley buses required less investment than extending the tracks of neighboring streetcar lines. The Central Avenue Line, a 15-mile crosstown route, handled 50,000 passengers/day. Although the ridership was sufficiently high to justify street railway operation under normal circumstances, the route included a long bridge over railroad tracks that was not strong enough to carry streetcars. The trolley buses operated on a headway as short as 45 seconds in rush hour. This showed that the mode had real possibilities in city transportation service.

In 1939, the Twin Coach Company built this semi-articulated trolley bus, which bent in the vertical direction only (photograph courtesy of Flxible).

At the beginning of this third period, the trolley bus was used largely to feed existing street railway lines or was placed on routes that did not warrant the investment in street railway facilities. However, this was quickly followed by using trolley bus technology to replace street railways. The trolley bus soon became the predominant mode on many of the country's major transit systems. With the exception of the war years, 1941 to 1945, the number of trolley buses used grew steadily.

The largest installations before World War II were in Seattle, Washington, and in New Jersey. Seattle completely converted its electric and cable-drawn streetcar lines to trolley buses in 1939-1940. The system had approximately 100 route-miles and 300 trolley buses, some of which ran continuously until 1978 when the remaining system was shut down for a complete rebuilding. Today some 109 vehicles operate over 55 route-miles.

In New Jersey, Public Service Coordinated Transport (now NJ Transit) operated an extensive route system with streetcars and some motor buses that served several cities and many smaller towns. In the early 1930s, the company experimented with trolley operation of gasoline-electric buses, retaining the engine and generator for a dual-service vehicle. After a successful trial, about 400 new All-Service Vehicles were bought in the mid-1930s, most of them from Yellow Coach and a few from Mack. Approximately 200 more were converted to gasoline-electric in the company's own shop. Some routes were only partly wired, i.e., operated electrically to the end of the wire where the driver retracted the poles and started the gasoline engine. But Public Service Coordinated Transport was one of the first transit companies to buy diesel buses with automatic transmissions. It moved quickly after World War II to convert its streetcar and trolley bus lines to this mode; the last of the All-Service Vehicles was retired in 1948.

A new trolley bus crests the 18 percent "counterbalance" hill on Queen Anne Avenue North in Seattle; the famed Space Needle is in the background (photograph by J.P. Aurelius).

Trolley buses had their heyday in the years following World War II. The fourth period in their history stretched from the 1950s through the early 1970s. During this time, the trolley bus--although still in competition with streetcars--was recognized as an attractive alternative on the public transit scene. But many problems were beginning to develop. These problems contributed to the almost total disappearance of the trolley bus with a speed that practically paralleled the trolley's success before the 1950s. The availability of larger, high-performance diesel buses, the overall decline of the transit industry, and the changing economics of trolley bus operations combined to retire this mode from all but a handful of North American cities. By the end of this fourth period only 10 systems in North America still retained trolley bus operation. In the United States these included Boston, Philadelphia, Dayton, Seattle, and San Francisco. In Canada systems that survived could be found in Toronto, Hamilton, Edmonton, and Vancouver. One system operated in Mexico City.

The fifth period in the history of the trolley bus started in the early 1970s and continues to the present. It is marked by rekindled interest in trolley bus technology not only from the perspective of new designs of totally new vehicles but also from the perspective of building on the best parts of the past technological development and making new appli-

Toronto began the modern trolley bus era in North America in the late 1960s by buying unpowered Flyer buses and installing rehabilitated electrical gear in its own shops (photograph by J.P. Aurelius).

With its poles locked down and the gasoline engine turning its generator, an All-Service Vehicle drives away from the overhead wires (photograph courtesy of NJ Transit).

cations to meet current and future transit requirements. During the last several years, every trolley bus operator in the United States and Canada has purchased new vehicles. Interest has been renewed as a result of changes in the relative cost of diesel fuel. Increased concern about the environment has also prompted transit companies to look at the trolley bus as an alternative and/or supplement to the existing transportation system.

A new Brown Boveri/GM Diesel Division trolley bus is shown in Edmonton (photography courtesy of Brown Boveri/TRM Industries, Inc.).

Both in North America and in other parts of the world where trolley bus operations have been an integral part of the transportation system, this period has also witnessed the introduction of new technology that relates to propulsion system hardware; the complete rebuilding and expansion of an existing system; and the installation of an entirely new system in Guadalajara, Jalisco, Mexico.

In the chapters that follow in this report, a variety of factors pertinent to trolley bus technology and application are presented. Selected materials are included, where appropriate, to enhance the summaries provided on (a) updates on current operating trolley bus systems, (b) vehicles and propulsion systems, (c) system infrastructure, and (d) applications of the trolley bus.

BIBLIOGRAPHY

1. Sebree, M., and P. Ward. Transit's Stepchild: The Trolley Coach. Interurbans Special 58, Vol. 30, No. 1, 1973.
2. Sebree, M., and P. Ward. The Trolley Coach in North America. Interurbans Special 58, Vol. 31, No. 1, 1974.
3. Wilcox, L.L. The Metro Trolley Overhead Program, 1973-1981. Metro Technical Services Department, Seattle, Wash., June 1981. NTIS: PB82 143769.
4. Wilkins, J.D., A. Schwartz, and T.E. Parkinson. The Trolley Coach: Development and State of the Art. UMTA, Rept. DOT-UT-80037, 1979. NTIS: PB80-104870
5. Wilkins, J.D., A. Schwartz, and T.E. Parkinson. The Trolley Coach: Potential Market, Capital and Operating Costs, Impacts and Barriers. UMTA, Rept. UMTA-IT-06-0193-79-2, 1980.

CHAPTER 2

Perspectives on the Trolley Bus

In an age of high technology, supersonic transports, high-speed rail, and the natural urge to get from point A to point B in the fastest time possible, the trolley bus may at first glance appear to be an anachronism whose time has come and gone. Such is not the case, according to a number of prominent individuals in the transportation community who addressed participants at the Workshop on Trolley Bus Applications in Seattle, August 29-September 1, 1982.

Robert A. Makofski, conference chairman, noted: "In 1962, or even in 1972, the idea of a workshop on trolley buses would have been greeted with genuine indifference, if not disdain. Yet today in 1982 many of us are here because of a belief that we are about to see the second coming of the trolley bus.

"The trolley bus has a continuing and perhaps expanding role to play in public transportation. That role will depend on the city, the route, and the environment. Most people recognize that such advantages that accrue to the trolley bus such as more rapid acceleration, its hill-climbing ability, the improved impact on the environment, and the potential conservation of oil must be balanced against the higher initial investment cost, the visual intrusion of overhead wires, and the decreased flexibility associated with being tied to a wire."

Makofski stressed: "The purpose of this conference is to aid in identifying the applications and the technology that can affect the balance in favor of the trolley bus." He explained that participants would be made aware of the current status of operating systems in the United States and abroad, as well as considerations of many factors related to trolley bus development and system technology.

Neil Peterson, representing Seattle Metro, emphasized one significant factor that has contributed to the success of the trolley bus operation in Seattle--the cooperation and involvement of both the general public and the area's elected officials. Such cooperation, generated by public information efforts, helped stave off the movement to eliminate the trolley bus altogether. Peterson noted that the topography of Seattle with its many inclines was a natural for the trolley in addition to other advantages such as its relatively quiet operation and lack of pollution.

He observed that by 1990 Seattle will have some 125 miles of trolley line compared with about 55 today. Future plans call for increased use of dual-mode vehicles.

Duane Berentson, Secretary of the Washington State Department of Transportation, observed: "Trolley buses are only a part of the total public transportation system--a very important part." The state "looks at all forms of public transportation to provide the best alternative for the area served. Thus, the overall goal is a balanced system serving our diverse population with its varied settlement patterns."

"The application for the use of trolley buses in the dense urban areas is desirable and appropriate. If the present testing of trolleys that have the capability to operate on either electricity or diesel fuel proves successful, it would make trolleys, at least the rubber-tired versions, much more flexible and usable on routes exhibiting both high and low densities."

The Washington State transportation official emphasized: "Public transportation is not static, but a modal concept that needs constant attention in a changing technological and social situation. The trolley bus concept is both old and new, socially rejected and accepted, fixed rail and rubber tired. These diversities and the practical and clean operation of the vehicle put trolleys in an appropriate and dynamic place, and we must continue in our efforts to improve this viable public transportation mode."

Aubrey Davis, UMTA's Region 10 Administrator, represented UMTA Administrator Arthur E. Teele, Jr., at the conference and stated the agency's "strong interest in and support for the trolley bus as a viable and effective transit alternative. [Recognizing that] it may be unrealistic to expect that trolley buses will again be a dominant urban transit mode in this country, there is considerable renewed interest in the capacity of this mode to meet certain modern transit needs.

"Clearly, trolley bus systems have numerous advantages that make them particularly attractive in light of the current economic and political realities. Like all electric transit, this mode offers independence from diesel fuel and the uncertainties in its price and availability that will undoubtedly persist through this century. Less than 16 percent of U.S. electric power is obtained from petroleum and the percentage is expected to decline. This means that the trolley buses will be increasingly independent from petroleum of any kind. This factor, in and of itself, is a tremendous advantage."

Trolley systems are "environmentally attractive in that they offer an option for meaningful air quality improvements in areas of concentrated pollution such as the central business districts of many of the nation's cities....There are also economic factors that are equally attractive."

Davis also explained: "Actual experience with trolley bus systems here in the United States and abroad, as well as UMTA-sponsored research efforts, will result in more flexible deployment of trolley buses that could lead to further operating cost savings....Since 1975, UMTA has contributed some $100 million to the revitalization of trolley bus operations in Boston, Dayton, Philadelphia, San Francisco, and Seattle. A total of 673 new trolley buses have been put into service in recent years so that all existing fleets have been renewed....We are currently providing $660,000 for a research project that will provide a comparative evaluation of trolley coach propulsion systems.

"UMTA is also funding research to develop a flywheel energy storage system for urban transit vehicles. The use of this flywheel technology can result in dramatic reductions in the amount of overhead wire needed for trolley buses."

Davis concluded by noting that the trolley bus is not "a panacea that will be the ultimate solution to this nation's urban transit needs, but it is an affordable, environmentally attractive mode that certainly should be considered as communities seek the appropriate mix of technologies that will best serve the needs of their citizens."

George Krambles of Terence J. Collins Associates, Inc., Schaumburg, Illinois, cautioned that "in addition to the purely technological problems, there are operational, institutional, and economic concerns to be overcome if the penetration of the trolley bus into the whole public transit market is to become significant." Krambles used the rise and fall of the trolley bus in Chicago to illustrate his remarks.

"The cost of operating trolley buses in Chicago was becoming significantly greater than that of motor buses in the same service. Trolley buses were burdening the system with service regularity and control problems over and above those caused by the fast-slipping reliability of the existing 20-year-old hardware....Although trolleys comprised less than 9 percent of the fleet, they resulted in 44 percent of the tow-ins. Delays and hazards due to the exposed overhead wires, a problem accentuated by Chicago's hundreds of low-clearance underpasses, were worsening....Delivered to the vehicle, electric power was costing 60 percent more per bus-mile than diesel."

"The replacement of Chicago's last 200 trolley buses with motor buses in early 1973 provided immediate cost relief, minimized capital investment at a critical time in the transit system's rehabilitation program and resulted in improved service performance for the nearly 30 million riders per year using the affected routes."

Economic constraints, Krambles went on to observe, "have always weighed heavily against new trolley bus starts or conversions because of the relatively high portion of investment needed for fixed facilities--mainly poles, wires, and substations. Under moderate passenger traffic, investment in fixed facilities is likely to exceed the investment in vehicles. And while the fixed facilities have to be able to serve the maximum load, they cannot easily be partly relocated or stretched to reach new territory if traffic on the original alignment goes into a slump. During the period between 1948 (order) and 1951 (delivery) of a single order of 349 trolley buses for Chicago, ridership declined so rapidly that unanticipated investment had to be made immediately in 27 route-miles of fixed facilities in order to usefully employ all the new buses."

On the other hand, Krambles stressed: "Only in those cities where transit gets a price break in buying electricity from a municipal utility does there appear to be a significant advantage in the cost of delivered power compared with diesel fuel--despite OPEC.

"In the United States, for trolley bus application to emerge further as a public policy preference, there needs to be found a way for private power companies to provide electricity for public transit use at a lower rate than commercial customers pay."

Furthermore, new support technologies for communication and service control have made it easier to live with the special constraints of "being bound to wire.

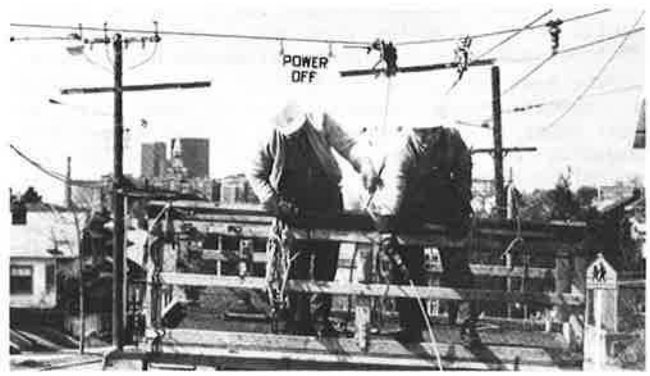
"The trolley bus is vulnerable to delay and resulting service irregularity resulting from having to progress pretty much in a fixed sequence along the fixed route of the overhead wires...but what a boon it would be for the operating department if a trolley dual-mode bus could work any route whether or not it was wire-equipped....Limited dual-mode bus propulsion already exists, using battery, internal combustion motor, or flywheel as the second source....Through expanded and improved technology, we can and must reduce the operational, institutional, and even the economic problems that have so far held the trolley bus to a minor role in public transit and technology."

In the chapters that follow the common themes expressed by the individuals quoted here are dealt with in detail. These themes serve as catalysts for an examination of the trolley bus system's advantages and disadvantages, technological advancements, and applications in urban areas both in the United States and abroad.

CHAPTER 3

Updates on Trolley Bus Systems in Operation

Ridership, difficult terrain, air and noise pollution, the presence of subways, and the availability of feeders to rail lines are some of the factors that need to be considered in the development of new trolley bus systems or in the enhancement and expansion of systems already in place. How these factors, as well as others, have influenced existing systems in four North American cities and in Europe overall and how they can be viewed by those metropolitan areas considering the start-up of new systems were the focus of five presentations, which are summarized below. The edited texts of these presentations, as well as a paper describing developments in Brazil, are included in the Selected Materials section of Chapter 3.



In 1976 Seattle Metro line crews put some size 0000 copper trolley wire up in place of the traditional size 00 bronze formerly used. The trial was a success, and most of Seattle's new trolley wire is 0000 copper (photograph courtesy of Joe Hawkins).

IN SEATTLE . . .

George Benson, a member of the Seattle City Council and of the Council of the Municipality of Metropolitan Seattle (Seattle Metro), examined the public endorsement of trolley coaches that was responsible for the initial installation of the mode in Seattle during the late 1930s and again for its rehabilitation and expansion in the late 1970s. During the earlier period the then City Municipal Railway was faced with the need to modernize an antiquated rail system. To improve the condition of transit services in Seattle, replacement of the entire rail system with gasoline-powered buses was proposed. This plan was met with disfavor and abandoned. In 1939 a new proposal was advanced that included the development of a fleet of 235 trackless trolleys and 130 gasoline-diesel coaches. The public approved this plan, and some 18 months later the new system was in operation.

For about 20 years, the trolley bus operated successfully and then all but disappeared during the 1960s. At that time it was further proposed that the entire system be replaced with buses, and the size of the system gradually decreased. The original 100 route-miles dwindled to about 26 route-miles.

The decline in the mode, however, prompted the formation of numerous citizen action groups who lobbied for support to retain electrified transit services. Through the efforts of such groups an initiative appeared on the 1964 municipal ballot to modernize the trolley system. Momentum continued for the retention of an electrified trolley bus system and, as a result, many public officials increased their support to make such a system a viable and integral part of the public transit operation in Seattle.

After the transfer of the transit system from the City of Seattle to Seattle Metro, the City Council requested a plan that called for replacing the entire system, doubling the route-miles to 55, and acquiring 109 new trolley buses. From that point Seattle Metro began the planning activity that has resulted in the city's expansive and widely used system--one that uses current state-of-the-art technology. The principal reasons for the system's success in attracting riders and in overall operations are related to (a) the public support for expansion and retention of the mode; (b) the involvement of community and professional organizations; (c) the support of the political infrastructure obtained through education and information dissemination efforts; and (d) the public relations campaign promoting the advantages of the trolley bus.

IN DAYTON . . .

Fred C. Dyer, General Manager of the Miami Valley (Ohio) Regional Transit Authority, discussed three aspects of the trolley bus operation in the Dayton area--the system's history, its recent expansion to a regional system and the impact on the trolley operation, and the need for new technology.

The first trolley bus application in Dayton occurred in 1933 when one of the five local companies providing transit services decided to convert one of its streetcar routes. Numerous additional routes were subsequently electrified, and in 1941 the five separate companies merged to form City Transit. After conversion of the last streetcar routes in 1947, Dayton operated approximately 200 trolley buses. The system continued to expand throughout the 1950s and into the early 1960s, while trolley bus systems in other parts of the country were shrinking or disappearing. During this period Dayton purchased used vehicles and equipment from other operators, and was able to put in place a modern system at low cost.

In 1972 the present authority assumed control over all services provided by City Transit. Although the Miami Valley Regional Transit Authority has the term regional in its title, it essentially represented a city system. So in 1979 the authority began the necessary action toward a referendum that would enable it to become a truly regional operation. This was effected, and shortly thereafter the system developed as one that arbitrarily terminated at the boundaries of the city or immediately adjacent suburban communities. This situation necessitated the extension of routes from their existing terminals into the suburban areas that had been annexed.

System expansion had to be accomplished quickly and, out of necessity, new diesel routes were initiated. Dayton is now considering the merits of trolley bus expansion versus the application of new off-wire technology to overcome the existing operating inefficiencies that have resulted.

Dayton is experimenting now with battery off-wire propulsion. Initial tests have indicated that such an arrangement does provide an effective emergency off-wire capability. Dayton will also be experimenting with a Renault battery trolley, which has improved operational characteristics and can be used in sustained off-wire service. If such tests are successful, this type of vehicle could possibly be used to expand existing trolley services into the new service territory. The authority is also evaluating the replacement of all existing substation equipment with modern, solid-state conversion apparatus.

Two significant factors in the Dayton experience were stressed. First, as in the Seattle experience, public opinion is a primary ingredient in the preservation and/or expansion of trolley service. Second, the enhancement of the flexibility of trolley buses requires the development of off-wire capabilities.

IN VANCOUVER . . .

Tom E. Parkinson, President of Tom Parkinson Transport Consulting, Ltd., Vancouver, undertook an extensive analysis of the Vancouver trolley bus system operation in 1978. The results of this analysis strongly favored retention of the trolley bus mode, which had been relatively stable with the exception of minor extensions made since the late 1940s. At that time, the former streetcar system had been abandoned. During the late 1960s and early 1970s, however, there was some doubt as to the system's future. In the absence of plans to convert the system to diesels, it was decided to update the trolley bus operation so that it could continue on a stronger and more efficient base.

The study, undertaken in 1978, indicated that the trolley bus operation in Vancouver enjoyed two distinct advantages when cost comparisons were made with diesel service. First, the cost of electricity was far less than that of diesel fuel. (Furthermore, the leverage exerted by fuel prices in today's economy is becoming much greater due to the rapid increases in energy costs.) Second, the cost of maintenance associated with trolley bus vehicles was far less than that related to diesel vehicles. The cost efficiencies realized in this area are more than sufficient to overcome the additional cost of overhead wire maintenance, which is not incurred with a complete diesel operation.

The cost efficiencies are further improved with the application of new technology. The advent of the chopper, for example, coupled with the use of regenerative braking, has the capability of reducing total power consumption in the range of 19 to 25 percent.

The Granville Mall in Vancouver is a pleasant shopping street. Private cars and trucks are banned; most traffic is electric trolley buses (photograph by J.P. Aurelius).

As part of the process to modernize the Vancouver system, it was decided to purchase 200 new vehicles. BC Transit, responsible for the Vancouver transit system, decided that a two-step procurement process was necessary. First, numerous vendors were invited to review and comment on the proposed specifications that the authority sought to incorporate in its new vehicle. After receipt of this information, necessary modifications were made to the specifications. Second, bids were solicited from interested manufacturers.

One of the features that will be provided by the new trolley buses is limited off-wire battery operation. Vancouver was able to purchase this option at a cost of approximately $2,000/vehicle. This system is simple and does not require a sophisticated propulsion control system. It will further provide an off-wire capability in at least 95 percent of the cases in which it is required. Such capability is oriented toward emergency situations.

The problem of vehicle weight was also considered. With the advent of new technology, the weight of trolley buses has increased; this siphons off some of the cost savings that could have been realized from reduced power consumption. Improved design and the choice of vehicle and equipment construction materials need the attention of manufacturers.

IN TORONTO . . .

Paul A. Wenning, Operations Planning Engineer for the Toronto Transit Commission (TTC), explained that the Toronto trolley bus system, operated by TTC, was introduced in the late 1940s and early 1950s. It was designed to replace streetcar operation. At present, eight routes are operating and the trolley bus is responsible for 3.7 percent of the total transit system mileage.

Toronto was the first North American city to consider the rehabilitation of its trolley bus system. In the late 1960s, when most cities were contemplating the removal of trolley bus systems, TTC decided to replace its trolley bus fleet. This decision was based on an in-house study that indicated that the trolley bus was more cost-efficient than diesels.

The province of Ontario, it was observed, has effected renewed interest in the trolley bus by offering a program that will reimburse transit commissions for 90 percent of the cost of installing trolley bus systems. TTC was also interested in trolley bus operations because (a) a surplus of trolley buses exists; (b) operating costs are lower than those for diesel service and such costs are likely to improve in the future; and (c) continued provincial support is likely.

The provincial program, coupled with some of the factors noted above, led TTC to examine its route structure for possible conversion to trolley bus operations. The criteria were proximity to existing trolley bus garage locations, proximity to the existing trolley bus network, and proximity to the existing electrical power network. As a result of this evaluation, 10 candidate routes were identified. Subsequently, these were reduced to two.

The TTC study also required consideration of the environmental effects of the trolley bus. Positively, the trolley bus contributes to reduced levels of noise and air pollution. It does, however, add to "visual" pollution because of the need for overhead contact and feeder lines. Although visual pollution can be reduced by undergrounding the feeder cables, it results in a significant capital cost penalty. Public concern about visual pollution was also expressed when specific routes were identified.

TTC investigated the energy intensity associated with trolley bus and other modes used in the Toronto metropolitan area. It found that the trolley bus had the lowest energy intensity from a consumption standpoint. In terms of megajoule per seat-kilometer, the trolley bus enjoyed an intensity of 0.026 compared with 0.042 for the subway, 0.043 for the streetcar, 0.54 for the diesel bus, and 0.66 for the commuter train.

Considering the total cost, i.e., operating and capital costs, TTC concluded that the trolley bus represents a marginal investment under present economic circumstances. Although the trolley bus results in operating cost efficiency when compared with the diesel, at present the savings on an annual basis are barely sufficient to amortize the capital cost of the system over its 30-year life.

IN EUROPE . . .

John D. Wilkins, Director of Operations Planning, NJ Transit Bus Operations, Inc., Maplewood, New Jersey, reviewed various aspects of the history, development, and operation of trolley bus systems in several European countries. It was observed that, with the exception of Eastern European nations, European trolley bus experiences paralleled those in North America. Numerous new systems were installed during the 1920s and 1930s and in the period following World War II. With the advent of the mass-produced diesel, however, the number of systems declined in the late 1960s and throughout the early part of the 1970s. In Eastern Europe, and Russia especially, the mode never was in disfavor and has prospered throughout the entire period since World War II.

The renaissance of the trolley bus first occurred in Switzerland in the late 1960s. VST, the Swiss public transit association, realized the need to replace the existing trolley bus fleets. The association approached Swiss industry with a request to design a new-generation trolley bus. Specifications required state-of-the-art technology in the areas, for example, of the application of chopper propulsion systems and improved off-wire capabilities.

A similar trolley bus renaissance occurred at approximately the same time in France. Cities such as Leon, Grenoble, St. Etienne, and Marseilles decided to rehabilitate and improve their systems following the energy crisis of the 1970s. Working with Renault, the French bus and truck manufacturer, a new standard trolley bus was designed that used the standard PR100 diesel coach body. The French design also included automatic retrievers to allow for unassisted raising and lowering of trolley poles and improved propulsion systems.

Europe's biggest contributions were advancements in trolley bus technology. For example, propulsion systems were developed. Chopper propulsion systems, originally developed by Brown-Boveri in the 1960s, can reduce power consumption in the range of 15 to 21 percent. With the application of regenerative braking, power savings can be increased. AC propulsion systems, although not new, have the capability of using commercially produced AC motors. These motors are available at lower cost and can be sealed to reduce maintenance costs.

Europeans have also routinely used overhead systems that are flexible and allow for faster travel speeds. Constant carbon contact (i.e., fittings designed so that the carbon is always in contact with the underrun) reduces wear and maintenance costs. High-speed switches allow speeds of up to 40 km/h on a straight through movement and 25 km/h on a divergent route.

In the area of current collection, Dornier has developed a system that will automatically raise and lower the trolley poles without requiring the exact positioning of the vehicle. Although this system is more sophisticated than that of the above mentioned Renault design, it is more expensive. Most European systems also use a trolley harp that is hinged, which allows for the absorption of lateral forces and decreases the potential for dewirements.

The Europeans also have available off-wire systems that, unlike their North American counterparts, have been found to be advantageous. Several European systems make use of such off-wire technology as Volkswagen engine-generators that provide for short-duration emergency capabilities and allow a speed of 30 km/h for operation on inclines that do not exceed 8 percent. This type of generator, however, is not generally applied where sustained operation is required. On the other hand, the Kirsch diesel, which has performance capabilities similar to those of the Volkswagen unit, is designed for sustained operation. In addition, the new PER180 bus, designed by Renault, provides full capabilities in either the electric or diesel mode.

At present, several projects being conducted in Europe could significantly alter the state-of-the-art technology for trolley buses. The Duo-Bus project, under way in Esslingen, West Germany, is being funded by Mercedes-Benz, Robert Bosch, and Dornier with support from the government of the Federal Republic of Germany. The project aims at developing a fully operational dual-mode system. Tests are being conducted with battery trolley buses and diesel trolley buses.

One feature of the diesel trolley bus is the use of a common drive train. Both the diesel and the electric motor supply power through a common transmission to the rear axle. When operating in the straight electric mode, this arrangement allows for the constant rotation of the electric motor, which greatly simplifies the type of propulsion control system that must be used.

Cost Project 303, being conducted under the auspices of the European Economic Community, has as its objective the technical and economic evaluation of the duo-mode trolley bus. This project will act as a focal point for the exchange of the pertinent research and studies that various country participants in the project generate. Of primary importance to the study are systems that have already developed duo-mode trolley buses (i.e., Switzerland, Germany, France, Finland, and Italy).

SELECTED MATERIALS

Seattle's Love Affair With Trolleys

George E. Benson

Public transportation is more than just a matter of getting from point A to point B. What happens in between is just as important as getting to the destination. It is a question of style, and the mode of public transportation a community prefers can reveal more about its character than dry statistics about passengers per mile or peak-hour capacity.

The people of Seattle love trolley coaches. Trolleys have been a major, if not dominant, component of Seattle's transportation system for more than 40 years. What does that say about the people of Seattle? It speaks to this community's fascination with science and technology and to its sophistication in weighing technological alternatives. Trolleys are just one element in a city history dominated by science and engineering: the regrading of Denny Hill, creation of a modern port, a visionary public electric utility, Boeing Aircraft, and the 1962 World's Fair.

In its early history, Seattle's public transportation system evolved in much the same way as did those in other cities. Privately owned streetcar companies sprang up to meet the public's needs and produced a patchwork of routes and modes of travel. We had horse-drawn trams, counterbalance cable cars, electric interurbans, and gasoline buses.

In the late 1930s this was no longer adequate. The population and area of the city had doubled and redoubled through immigration and annexation.

In 1936 the city's Municipal Railway recommended a system of gasoline-powered buses to the public, which was vetoed by the public. Three years later a new proposal, based on recommendations of the Beeler Organization of New York, was developed for a fleet of 235 trackless trolleys operated under 100 miles of wire, plus 130 gasoline and diesel coaches. This was approved by the mayor and the City Council in August 1939.

Eighteen months later, the system was in operation. It had been built and the debt of the old system retired for $10,200,000. Obviously it did not figure in the calculations of the new Transit Commission, but the inauguration of the new system in April 1941 gave Seattle one of the country's best public transportation systems--just in time for the war effort.

During World War II, 72 additional trolleys and 10 miles of wire were added to the system. It operated in this form until 1963 without interruption.

The end, however, had almost come in 1962. That year the Transit Commission proposed cutting back the trolleys and replacing them with new diesel coaches. There was even talk of completely eliminating the trolleys. Economics had changed, and the trolley critics argued that diesels were more efficient. The press complained about the "visual pollution" of trolley wires, and the 1940s-vintage trolleys were showing their age.

Many citizens, however, fought to save the trolleys. The Committee for Modern Electric Trolleys (COMET) was organized. COMET collected enough signatures to place an initiative on the 1964 ballot to modernize the trolley system. The group lost the vote but demonstrated enough political support to dissuade the Transit Commission from dismantling the trolley system. About 27 miles of the system were saved. This nucleus became the seed for an all-new system when the voters of King County authorized Metro to establish a regional transit system in 1972.

Metro is a consortium of Seattle, King County, and suburban city governments. It was created in the 1950s to establish a regional sewer and water quality utility to clean up Lake Washington and other area waters. Starting on January 1, 1973, Metro faced a new challenge: How to create a rational public transportation system out of the crazy quilt of city and private suburban bus systems it inherited. Trolleys were assigned a major role from the outset. The economics of public transit had changed again, and there was no question that trolleys were a wise investment.

In response to a request by the City Council, Metro provided a plan that called for replacing the entire system, doubling the lineage to 55 miles, and acquiring 109 new trolleys. It proved to be a more ambitious scheme than anyone anticipated.

I took my seat on the Seattle City Council and the Metro Council in 1974, so I got to wrestle with the problems of trolley modernization firsthand. No one had tackled an installation of the size we planned for a quarter of a century. The literature was scant, and it turned out that the maintenance crews on the old system knew as much, if not more, than the experts.

We eventually succeeded, and in the process much new technology was introduced, such as the neighborhood rectifier system, new wiring systems, the Fahslabend switch activators, and new chopper control systems on the trolleys.

Of course, new technology creates new problems, and we had our share. Lightning wreaked havoc in the first year, and the rectifiers turned the overhead wires into the world's largest radio antenna.

We have solved the lightning problem and we are working on the radio interference. One thing we had no problem with, however, was community acceptance. When my office polled 45,000 citizens along proposed trolley routes, more than 87 percent said that they wanted the service.

When the system is complete, the price tag will be about $41 million--four times the cost for a system half the size of the original.

We unveiled our Waterfront Trolleys on Memorial Day 1982. These are vintage tracked trolleys that link Pioneer Square on the south end of the central waterfront with Pier 70 on the north.

Getting these going proved to be almost as difficult as were the trackless trolleys, but again there was no shortage of support. When, in 1981, it looked like the Waterfront Trolleys might have to be abandoned, area businesspeople volunteered to tax themselves to finish the project.

Metro's plans for the end of this decade call for adding half again as many trolley routes to the city. Even as the regional power situation darkens, trolleys that today require less than 0.1 of 1 percent of the city's total electrical load are still a wise investment for the future.

Seattle's trolleys are going to be around for a long time to come. But it is not just a matter of efficiency or economics. In Seattle, people love their trolleys. They would no more part with them than they would with the Pike Place Market or Mt. Rainier. Trolleys are not just a part of Seattle's public transit system, trolleys are part of the soul of the city.

The Dayton Experience

Fred C. Dyer

Dayton's first trolley coach route was placed in operation in 1933 as a replacement for streetcar service. During the period before World War II, several additional routes were converted to trolley. Unlike most cities the trolley routes were operated not by just one company but by five. This situation continued until 1941 when a 15-year process of merging all companies into a single unit was begun. In 1947 the last two streetcar lines were converted and Dayton was completely served by trolleys. Approximately 200 trolley coaches were operating on 10 routes after the last conversion was made. The system's route structure became stable at this point and did not decline as was the case in other cities. In fact, during the 1960s the reverse was true and extensions were made to keep pace with the city's outward growth.

Between 1962 and 1970, seven additions were placed in operation. Some of these additions required extensive lobbying on the company's behalf to overcome the objections that outlying communities had with overhead lines. Only one major withdrawal of service occurred and that was necessitated by freeway construction.

The rehabilitation and growth of Dayton's trolley coach system can be directly attributed to two situations.

First, City Transit, the system operator, had firmly embraced the trolley, and through the efforts of its president, W.W. Owen, resisted various pressures to abandon it. For example, when the city put in a one-way grid system there was pressure to take down the wire rather than put it up on additional streets. Second, City Transit was able to turn the trolley's national decline to its benefit. Vehicles and hardware systems were purchased for a fraction of the original cost from systems that were phasing out. City Transit was able to replace its older coaches and extend service for much less than the cost of a new diesel fleet.

The general decline in transit use in the late 1960s forced City Transit into the familiar pattern of raising fares and cutting service. In spite of financial problems, and to prove that trolleys could still be made, the company ordered one Flyer E700 and had the Toronto Transit Commission install electrical equipment from a retired coach. It arrived in 1971 and was dubbed the "1971 Trolley Bus."

As the decline continued, the inevitable public takeover occurred with the formation of the Miami Valley Regional Transit Authority (RTA), which assumed control in November 1972. Before the takeover there was a controversy over the new RTA's position on the future of trolley coaches. Newspaper articles stated that a decision for diesel had been made but the authority refused to either confirm or deny this. Whether the articles were correct or simply a maneuver to lower the cost of purchasing the system is not known. Clearly, if diesels were to be used, the trolleys would be worth little more than scrap value.

Regardless of the reasons for the controversy, several citizen groups came out in favor of retention. RTA moved quickly to resolve the trolley versus motorcoach question.

A public hearing was held during March 1973 with overwhelming support in favor of trolleys. In April, RTA decided to purchase 25 new trolleys. The energy crisis intervened and the number was increased to 64.

However, the dilemma was not over; when the single bid from Flyer Industries was opened in late 1974, the asking price was 75 percent higher than RTA's estimate: $104,961 versus $60,000. The Authority then attempted to order only 40, but UMTA insisted that would require new bids and offered to increase the federal grant to cover 80 percent of Flyer's quote for the 64 vehicles. Resoliciting the bids would have delayed the arrival of new buses for several years. Wishing to avoid any further delay, Flyer's bid was accepted and two years later the new buses began arriving in Dayton.

In 1979 the Board of Trustees determined that the RTA should truly live up to its name and start on an ambitious expansion program. The scope included doubling the miles operated, fleet size, employees, and new riders. Most of the expansion was to be accomplished within 3 months after the election and the remainder 6 months later.

The acquisition of equipment, hiring and training new employees, and hundreds of attendant tasks placed a tremendous burden on our staff. Obviously, in order to meet the time limits, the expansion was totally motor coach.

Clearly, just the hardware requirements precluded any use of trolleys within the expansion time limits. There are significant implications in that. Before expansion the proportion of vehicles was 65 percent trolley; after expansion it reversed to 65 percent diesel. The nature of the system changed dramatically as well--from a predominantly urban to a 50 percent suburban and rural system.

I believe that going regional has given us a unique opportunity to make major and long-lasting trolley system improvements. We are currently studying substation improvements, power distribution, line extension, and rolling stock in a new environment that has removed the boundary limits and minimized the financial constraints that had previously hampered significant improvements.

From the standpoint of trolley system capital improvement, it is evident that going regional is having a positive impact. From a ridership standpoint, again there has been a positive effect. The previous urban riders have found additional job, shopping, and educational opportunities in suburbs, whereas the new suburban riders use the urban trolley system for trip completion as well as for some ancillary trips.

On the negative side, there have been and will continue to be productivity inefficiencies until the two distinctly separate requirements of the motor coach suburban and trolley coach urban systems unite in a balanced, integrated transit system. Again, knowledgeable transit people recognize that it takes more than just 2 years for that to occur.

What happens when the power goes off has been the most significant effectiveness problem for our industry. In cooperation with UMTA and the Garrett Corporation, we recently completed a test of off-wire propulsion through the use of batteries. The test results are promising.

RTA is also looking forward to a demonstration project in cooperation with UMTA and Renault/Mack Truck to test the feasibility of dual-mode battery trolley.

As I mentioned earlier, we are looking to an expansion of our trolley system as well as some efficiency modifications that require costly overhead work.

If the off-wire capability can approximate standard operating speeds at reasonable operating costs, the technology can allow the trolley to better emulate the flexibility that motor buses enjoy.

Another technological change we are investigating is solid-state substations.

RTA is in the process of acquiring about 14 miles of railroad right-of-way from Penn Central and Conrail. It extends from the southeast corner of the county to the Dayton central business district through the most traveled traffic corridor in the region. It may become an exclusive right-of-way for a trolley rapid transit system--if not on a permanent basis, at least as an interim step toward light rail.

I also envision that technological advances will soon give us off-wire flexibility at full operating level, which can significantly reduce construction and maintenance costs on the catenary system while increasing on-street schedule dependability.

Vancouver and the Trolley Bus

Tom E. Parkinson

Transit in British Columbia and Vancouver is unusual in that the city and other municipalities have never been involved. It started out with B.C. Electric Railway Company running streetcars and generating power. Power became the bigger part of the operation and this private company elected to convert from streetcars to a trolley bus system in the late 1940s. The company did this with no public funds partly because the streetcar system had few new vehicles and needed major capital improvements. Vancouver has a large trolley bus system and has never had any route cutbacks. The province purchased B.C. Electric in 1964, and transit and the then freight rail operation came with it into the transportation division of B.C. Hydro and Power Authority. B.C Hydro never wanted transit, but it was 15 years before it was able to hand it over to a newly created provincewide transit authority. Transit never extended into the suburbs under B.C. Hydro. Only in 1972 did a new agency, the Bureau of Transit, instruct B.C. Hydro to start serving the neighboring municipalities, leading to the present system.

The Bureau of Transit initiated serious thoughts on the retention and expansion of the trolley bus system by purchasing 50 new Flyers in 1976 using reconditioned electrical equipment. The Bureau of Transit became the Urban Transit Authority in 1979, with a subsequent name change in 1982 to BC Transit (BCT). BCT is a provincial crown corporation. It owns and purchases all transit assets in the Province of British Columbia and contracts out for the operation of service in a tripartite agreement between the regional district or the municipality and an operator. BCT has 27 transit systems under its jurisdiction. In Vancouver the system is too big to put out to public tender; another crown corporation, Metro Transit Operating Company, was created solely to operate transit in Vancouver and Victoria.

Under the auspices of the Urban Transit Authority, economic studies were done with B.C. Hydro Transportation Division in 1978 and 1979 to determine the future of trolley buses in Vancouver.

There are three main indices that affect a decision to retain trolley buses or to introduce trolley buses and all of them have significant hazards. There have been enough recent bids to know the price of vehicles, substations, and overheads. Five years ago this was not the case. The price of diesel fuel and electricity throughout the future life of the coach is difficult to project. The most significant factor and important advantage of the trolley bus is the maintenance cost. The trolley is (and in Vancouver has proven to have much lower maintenance cost than diesels) fully offsetting any differentials in fuel and cost of maintaining and renewing the overhead and the substations. There have been much conflicting data on the relatively different maintenance cost of electric vehicles versus diesel vehicles. In Vancouver we were fortunate in having diesel and trolley buses of the same make, model, and vintage running out of the same garage to allow a reasonably accurate comparison.

The BCT analysis demonstrated that with modern electrical equipment on a trolley bus, a maintenance savings of 30 to 40 percent below that of a diesel coach could be achieved. When the decision was made to renew the trolley bus fleet in 1980, procurement of a new fleet was started using a two-stage process. Vancouver was at a turning point between old but reliable electrical equipment being retrofitted in diesel coaches and the new generation of trolley buses using 1980 electronics.

BCT tried to take a fresh look at the need of drivers and passengers to evolve an urban transit vehicle for heavy-duty service, not for use on suburban routes. BCT wanted to retain the double front doors not available on buses in North America since 1955. This was the biggest battle. It is regrettable that manufacturers have resisted the desires of transit authorities (and authorities with much higher density routes than Vancouver) by insisting that a double front door bus was not necessary or possible. BCT fought hard and now has the first two-axle North American double front door bus in 15 years. This is an urban bus; it has two-one seating with stanchions on every seat, double exit doors, and windows that open.

In the two-stage procurement BCT was prepared, given the resistance of the North American suppliers to provide double front doors, to go to a European vehicle. A technical specification was widely circulated to solicit the world for responses and opinions. BCT was prepared to change specifications in order to open the bidding process. There was extensive feedback with visits to 11 electrical manufacturers, indicating a view that the trolley coach or the dual-mode coach is here to stay and may even increase in numbers.

BCT had 19 bids, probably the largest and most extensive bid for any trolley bus procurement in North America. Some of these were permutations of different electrical manufacturers with the same body builder, making evaluation difficult.

One distressing aspect was that all the vehicles offered were heavier than the buses being replaced. The low bid with Japanese electrical equipment had to be disqualified because, with a passenger load, it exceeded the rear-axle highway loading limit. Some of the vehicles offered had a power-to-weight ratio inferior to the buses being replaced because of their weight. There was some difficulty in evaluating technical risk. On the premise that complexity is the enemy of reliablility, there was a desire for simple proven equipment, which was in conflict with energy efficiency and lower bids. Given an opportunity to move into the future, BCT selected the bid from Flyer Industries and Westinghouse Electric Corporation for a propulsion system that previously had never been used on a trolley bus. It uses a fourth-generation chopper, which was working well on the light rail vehicles in Philadelphia.

BCT also looked closely at off-wire operation. Records were sketchy on the number of delays and incidents that occurred on the extensive trolley bus system in Vancouver, but it appeared clear the 90 plus percent of all incidents were minor. They involved a coach being stuck on an insulator, a defective switch, a span wire or an intersection down--the sort of things that do not need a lot of stored energy to correct. For a small incremental cost in the procurement, battery capability of about a kilometer at low speed was provided. This is limited by how much air for braking can be stored and permits somewhere between six and eight stops. It is enough to get over almost all these minor problems. In some cases--for example, stuck on an insulator--the driver does not have to touch the poles, he just presses the button and moves away. It adds weight to an already heavy coach, but new battery developments should reduce this.

BCT was aware that there would be problems in introducing a bus with so much complexity. The first prototype was due in 1981 and was delayed for manufacturer's reasons. It came in April and had, with three counterparts, undergone about 400 vehicle-days of testing. There have been many problems; most have been corrected but a few are still outstanding. Transients are a big problem on trolley coaches and some of the transient problems on this bus were solved by the simple expedient of reprogramming the microprocessor (putting in different timing constants). There are additional problems with transients that appear to internally generated, and debugging is continuing. Initial "hot coach" problems were resolved by increasing insulating grommets on the resistors.

BCT is proud of having pioneered a new-generation trolley bus with microprocessor control, full regenerative brake, off-wire battery operation, and double front doors, and is looking forward to having the full fleet in service over an expanded network.

Trolley Coach Applications in the 1980s: Toronto Update

Paul A. Wenning

The eight existing Toronto Transit Commission (TTC) trolley coach routes are centrally located in metropolitan Toronto, contained for the most part in the city of Toronto. These trolley coaches were introduced in the late 1940s to the early 1950s and replaced streetcars that formerly operated on these routes. Figure 1 shows the geographic location of these trolley coach routes within the TTC system.

The trolley coach has a rather limited, albeit important, share in the public transit make-up in Toronto. In 1981, trolley coaches constituted 3.7 percent of the total annual TTC system mileage (3,938,374 miles). This compares with 48.1 percent for diesel buses, 39.6 percent for subways, and 8.6 percent for streetcars. In terms of passenger use, 4.9 percent of system ridership--representing 19,204,000 revenue passengers--traveled on trolley coach routes.

As the TTC system has expanded over the years since its official formation in 1955, the relative role of the trolley coach has diminished. This trend reflects the general stability of the central-core trolley coach and streetcar routes in relation to steady suburban growth and resulting bus and subway system expansion.

HISTORICAL PROFILE

The presence of trolley coaches on Toronto streets dates back to the 1920s, when "trackless trolleys" replaced gasoline buses on the Mt. Pleasant route on June 18, 1922. Mt. Pleasant trolley coach service was later replaced by streetcars on September 1, 1925. This first type of trolley coach is shown in Figure 2.

A fleet of second-generation trolley coaches was acquired by the then Toronto Transportation Commission over the period 1947-1951. Engaged in a post-war system modernization program, the Commission decided to purchase new and used trolley coaches on economic grounds. These trolley coaches were used to replace certain sections of streetcar lines that would otherwise have required extensive track rehabilitation and replacement work.

The spring of 1967 marked a major milestone in Toronto trolley coach history, when the TTC decided to study the feasibility of refurbishing its aging trolley coach fleet. Coach No. 9020 was rebuilt as a prototype and underwent 1 year of successful operational testing in revenue service. By mid-1972, the remainder of the 151-vehicle fleet had been overhauled, resulting in a third-generation trolley coach fleet. The catalyst behind the rebuild program was economics.

In March 1981, the TTC considered a staff report (1) recommending greater use of existing trolley coaches through a two-phase route electrification program. The TTC granted approval in principle to this undertaking and to date has authorized its staff to proceed with initial design work for a phase 1 conversion only. However, TTC staff are re-evaluating the conversion program in light of public concern over visual pollution from overhead lines and the more recent diesel-electricity cost scenario.

TROLLEY COACH EXPANSION REVIEW

The March 1981 staff report to the TTC advocated a two-step trolley coach expansion program for the 1980s. The two-step process recognized the economic limitations of conversion at that time, and was recommended as a means of staging electrification of routes to be compatible with the present and future economic circumstances. Essentially, the phase 1 conversion of three proposed routes (Wellesley-Parliament-Sherbourne) would take immediate advantage of capital deferment of 20 peak-period buses, and

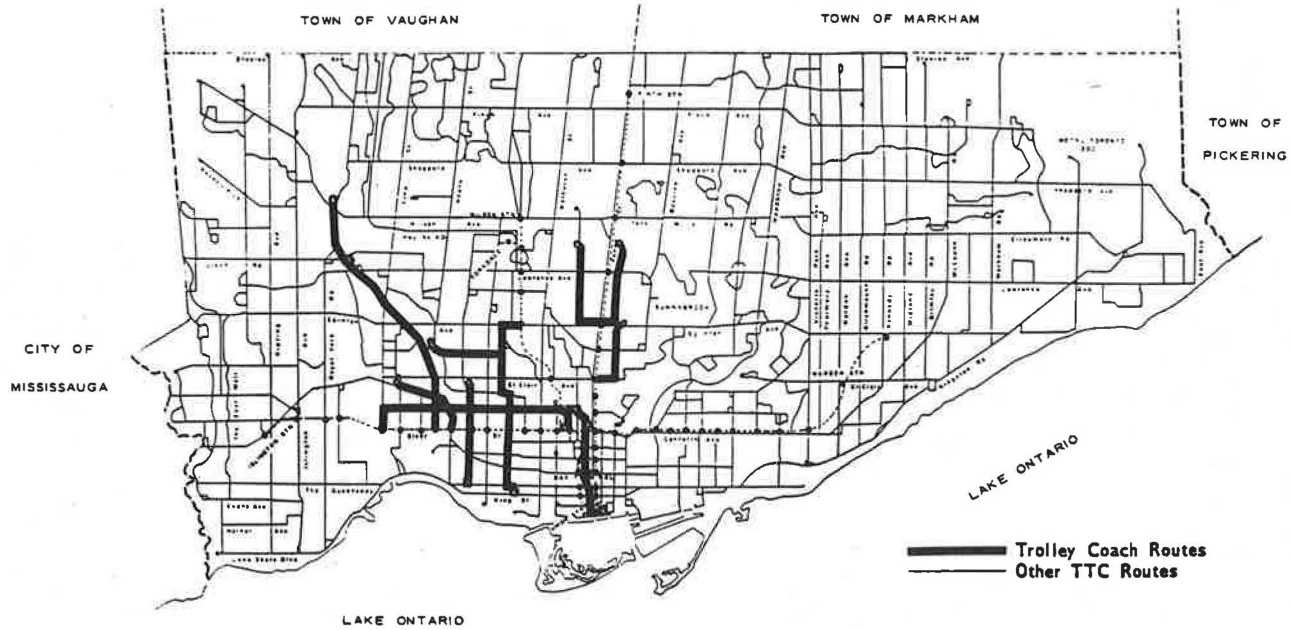
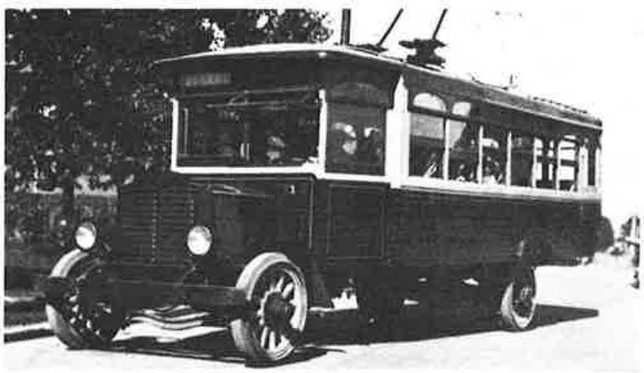


Figure 1. Metropolitan Toronto TTC system, August 1982.



THE ORIGINAL TRACKLESS TROLLEY USED IN TORONTO ON THE MT. PLEASANT ROUTE FROM 1922-1925

CLASS T-1 TROLLEY COACH BUILT BY C.C.F. IN 1947

REBUILT FLYER COACH—APRIL 1971

Figure 2. Evolution of trolley coaches in Toronto.

the phase 2 conversion later in the decade would exploit the predicted energy cost advantage.

A brief summary of some of the background considerations in the 1981 TTC staff report is presented here.

Rationale

Interest by the TTC in expanding its trolley coach route network is predicated on three primary factors:

1. There are surplus (unscheduled) trolley coaches available in rush-hour periods. By using the spare trolley coaches on converted diesel routes, it would be possible to free a corresponding number of diesel buses to use elsewhere in the TTC system. This strategy could hold considerable short-term financial advantage, because it would ob-

viate the need to purchase a number of new diesel buses to meet current growth needs. The current surplus exists because replacement of streetcar lines with trolley coach operation never materialized, due to the renaissance of streetcars in Toronto.

2. In terms of motive power costs, there is an operating cost differential on a cents-per-mile basis favoring trolley coach operation. The 1982 TTC operating budget used 18.42 cents/mile for trolley coach operation, and 33.20 cents/mile for diesel bus operation. It is expected that this gap will widen in the future, given the favorable situation with respect to non-petroleum-based electricity in the Province of Ontario.

3. There is an increased awareness of the role that public transit can play in achieving an energy-efficient urban transportation system. With the current emphasis on energy conservation, and with a recent provincial government commitment to provide 90 percent capital subsidization for diesel route electrification, the TTC has resolved to explore the feasibility of trolley coach conversion. Normally, transit capital works projects qualify for 75 percent provincial funding. Canada's National Energy Program supports electrification efforts as a means of achieving Canadian energy security through independence from the world oil market by 1990. New and converted electrical generating plants powered by coal, hydro, and nuclear energy are being established across Canada.

Candidate Route Selection

In a pure diesel bus system, the ideal setting for a route electrification program would be a confined network of high-density routes that could be served by a common electric feeder system. However, in the present context of the TTC, a network of overhead and feeder supply facilities already exists, as do divisional garage locations with trolley coach storage facilities. As a result, the TTC has followed a slightly different approach in its route selection process, with a view to maximum use of the existing trolley coach capital infrastructure.

In brief, the following general guidelines were used in identifying candidate routes: proximity to the two existing trolley coach garage locations; proximity to existing trolley coach routes; and proximity to the city of Toronto, which is centrally located in the metropolitan area, where most transit service is already electrically powered.

A long list of routes satisfying the above criteria was developed. It was recognized, however, that the efficient use of additional trolley coaches to achieve energy conservation goals would be a direct function of the potential off-peak electric mileage. With this maxim in mind, a short list of candidate routes was subsequently prepared, categorized according to the ratio--route mileage: average normal-hour scheduled vehicles. This ratio served as a general cost-effectiveness indicator.

Preliminary conversion cost estimates were then prepared for the short list of 19 routes falling in the range of 0 to 3 route miles/off-peak vehicle. A priority ranking based on capital conversion cost per off-peak vehicle was thereby achieved. These 19 routes were ranked from a low of $124,500/off-peak vehicle to a high of $870,000/off-peak vehicle (1980 $ Canadian). As a final step, the top 10 routes were chosen for further detailed study.

Operating Considerations

If the top 10 priority routes were converted to trolley coach operation, it would not be possible to operate a full rush-hour complement of trolley coaches on new and existing routes, given the 151-trolley-coach fleet. Consequently, some blend of diesel/trolley coach service would be necessary on the subject routes during peak periods. Past experience has shown that a mix of diesel buses and trolley coaches on the same route is acceptable from an operating point of view.

It was recognized that under a mixed operation, the appropriate number of trolley coaches would have to be assigned to the base service on each route to fully meet off-peak requirements. Diesel buses would therefore supplement this base trolley coach fleet in the peak periods. This manner of vehicle assignment would avoid the need to change trolley coaches between routes between peak and off-peak periods. This approach would also mean replacing some trolley coaches with diesel buses on the existing trolley coach routes in rush hours.

During daily rush hours, there are some 21 surplus trolley coaches available for service. This compares with 83 to 105 unscheduled trolley coaches during the various off-peak time periods. Conversion of all 10 candidate routes would fully use the trolley coach fleet 12 hr/day, six days/week. During certain light periods, namely evenings and Sundays, the trolley coach fleet would not be used to its full extent. Full conversion of all 10 routes would increase trolley coach mileage by 4 million miles annually--a 100 percent increase.

With respect to operating flexibility, trolley coach service is more susceptible to disruption in the event of temporary emergency detours or traffic congestion. This operating constraint exists with current trolley coach routes and would apply equally to any new route conversions. Furthermore, trolley coach operation imposes a long-term limitation on potential routing modifications. For example, it could be difficult to implement a route extension or rerouting at some future time, in view of the capital cost involved.

One other operating effect of converting 10 candidate routes would be the resulting redistribution of diesel buses among divisional garage locations. It would be desirable to reallocate rush-hour diesel buses to the two trolley coach garage locations, in order that each route would be self-contained at the appropriate trolley coach garage.

Environmental Considerations

There are off-setting environmental effects stemming from conversion from diesel to trolley coach mode.

On the positive side, trolley coaches are quiet and do not emit air pollutants. On the other hand, the overhead trolley coach lines can be regarded as introducing visual pollution to a streetscape. The latter may be particularly objectionable from aesthetic and political points of view, particularly if monies have already been spent on programs to bury hydro wires in underground duct banks along a proposed routing. Strong concerns in this regard have been expressed by local municipal authorities in Toronto.

If for aesthetic reasons, decorative-type support poles and an underground feeder system are deemed necessary, then capital installation costs could increase dramatically (perhaps 300 to 500 percent) to the detriment of the overall project feasibility.

The province of Ontario Ministry of the Environment requires preparation of an Environmental Assessment Class Document for transit undertakings such as trolley coach conversions. This category of environmental assessment is intended for projects that have minor environmental impact. This Class Environment Assessment sets out the planning procedures that will be used in undertaking the project. A description of the environmental effects and possible mitigative treatments is required in the document.

Energy-Saving Considerations

The province of Ontario has an abundance of electric power from nuclear and hydraulic generation, but must import almost all of its supply of natural gas, petroleum, and coal. The majority of these fossil fuels comes from Canada's western provinces, but some quantities are imported from the United States. Despite the current domestic supply situation, metropolitan Toronto would face serious hardships in the public transportation sector should moderate or serious shortfalls occur in imported oil supplies.

A recent energy study (2) undertaken for the metropolitan Toronto area recognizes the operating efficiency of trolley coaches relative to other urban transportation modes. It noted that trolley coaches are the least intensive mode from an energy consumption standpoint. In megajoule per seat-kilometers, the energy intensity of individual modes was trolley coach, 0.26; subway, 0.42; streetcar, 0.43; diesel bus, 0.54; commuter train, 0.66; and automobile, 1.55.

Assuming that the 10 priority diesel routes were converted, it was estimated that there would be a net annual change of some 4 million revenue miles from diesel mode to trolley coach mode, based on 1981 service schedules. This represents a potential saving of approximately 750,000 gal of diesel fuel/year, or 8 percent of total diesel fuel consumption.

Timing of Route Electrification

It was estimated that a 5-year installation period might be required to convert the 10 priority routes, using TTC manpower. That estimate was based on all design being done in-house, with overhead construction work staged in concert with design progress and material orders.

Based on past experience, trolley coach overhead line material has a delivery time of up to 1 year, whereas trolley wire and feeder cable deliveries typically take 6 months. A 15- to 18-month delivery time for additional overhead maintenance trucks is required.

Two of the 10 routes would require a new substation. Property acquisition and substation construction would naturally increase the conversion period for these routes.

Any trolley coach conversion would require a Class Environmental Assessment involving about 6 to 12 months for preparation, review, and approval by the Province of Ontario Ministry of the Environment. If significant public concern is registered in this review process, then a full 1- to 2-year environmental assessment could be required. This environmental assessment process would obviously have to be completed before material orders could be placed. Hence, even for a single route conversion, a minimum 3-year lead time is involved.

BENEFIT/COST ANALYSIS

The original TTC phase 1 conversion program proposed the electrification of the Wellesley, Parliament, and Sherbourne bus routes. However, some concern was registered by municipal authorities regarding these candidate routes. Concerns centered around visual pollution from overhead lines and the loss of future routing flexibility.

Further benefit/cost analysis has now been directed by TTC staff toward the conversion of the Wellesley route only. The Wellesley route offers the greatest potential for near-term savings (highest vehicle per mile density) and is considered to be relatively stable vis-á-vis long-term route alignment. However, aesthetic concerns persist.

Analysis Technique

There are different methods of approaching an economic analysis of trolley coach conversion. The most recent analysis undertaken by TTC staff is based on a "constant worth dollar" technique, which accounts for uncertainties surrounding the absolute values of future long-term inflation and interest rates. The constant worth dollar method assumes a stable differential between interest and inflation rates regardless of their actual values, thereby isolating the real cost of capital financing. In terms of cash flow, equivalent 1982 dollar capital costs have been annualized by means of the capital recovery cost technique. A 30-year life-cycle planning horizon (commencing in 1986) corresponding to the longest-lived asset has been used. It is assumed that the same future rates of inflation, whatever their value, will apply uniformly to all cost parameters.

Capital/Operating Cost Items

Some of the major assumptions about the various capital and operating costs are briefly summarized below:

1. The purchase of 15 diesel buses could be postponed and 15 available spare trolley coaches could be used during peak periods.
2. Two additional overhead trucks and temporary overhead crews would be required to facilitate installation work by TTC forces.
3. The 15 available spare trolley coaches to be used in the conversion program would be eligible for retirement and hence replacement by new trolley coaches shortly after conversion.
4. Diesel fuel costs will escalate 5 to 10 percent above electricity costs over 30 years.
5. Electricity costs will escalate in line with future inflation rates.
6. A constant 4 percent differential between interest and inflation rates has been assumed.
7. Future rates of inflation, whatever their absolute values, will affect all cost parameters uniformly.

Capital expenditures contribute the highest conversion costs. Depreciation and interest charges on new trolley coaches and overhead line material are estimated at $8.5 million and $2.2 million, respectively. It is significant to note that new trolley coaches are currently twice the initial cost of new diesel buses. The additional trolley coach maintenance costs contribute another $4.0 million. Labor and material charges for overhead line upkeep produce these higher maintenance costs.

The primary financial advantage of conversion is the reduction in diesel fuel consumption. Depending on the future costs of diesel fuel and electricity, this energy saving could more than offset capital and operating expenses.

Figure 3 reflects the sensitivity of the economic analysis to future diesel/electricity cost relationships. In the context of this analysis, the breakeven point corresponding to a 4 percent real interest rate occurs at a 6.5 percent differential between diesel and electricity annual escalation

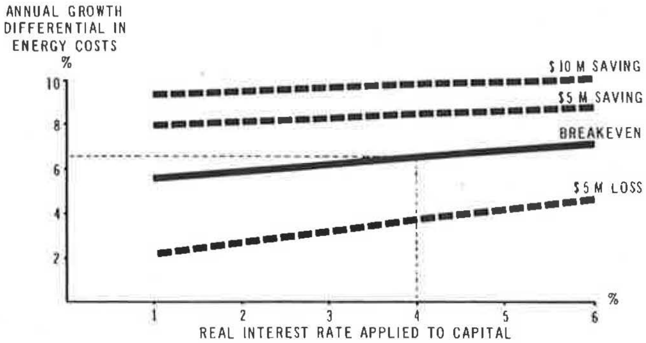


Figure 3. Economic analysis, Wellesley route.

rates. The effect of even a 2 percent variance from the 6.5 percent energy differential is apparent.

The preceding analysis does not allow for capital residual value at year 30, or for the installation of decorative poles. These factors would increase potential savings by an additional $2.0 million. Also, the application of provincial subsidy to capital items improves the cost effectiveness of conversion from a TTC perspective.

SUMMARY

From a transit management point of view, there are definite advantages associated with undertaking a trolley coach conversion program: fuller use of existing trolley coaches, less reliance on diesel fuel, energy conservation, and so forth. However, these factors must be considered in relation to other key criteria such as cost effectiveness and public acceptance.

From a cost/benefit perspective, trolley coach conversion represents a marginal investment under present economic circumstances in Toronto. The real cost or saving associated with converting is quite sensitive to the future cost differentials between diesel fuel and electricity, which will evolve over the remainder of the century. This observation is made independently of financial incentives such as special capital or operating subsidies favoring trolley coach conversion.

The issue of public acceptance of new trolley coach routes continues to be a major concern. Public opposition to obtrusive overhead wires frequently arises, particularly in residential areas. Furthermore, new overhead wires and fixtures may contradict municipal programs to bury utility lines in underground ducts. TTC management is weighing and evaluating these opposing factors.

This paper has reviewed the socioeconomic aspects of trolley coach conversion within the present context of the TTC. In keeping with this overall theme and the contents of the preceding summary, the following areas of future research are suggested: (a) develop an accepted economic analysis methodology for use by transit properties in considering new/expanded trolley coach routes and (b) evaluate public attitudes toward new trolley coach overhead lines relative to overhead visual pollution versus lower noise and air pollution.

REFERENCES

1. TTC Planning Department. Possible Conversion of Diesel Bus Routes to Trolley Coach Operation. TTC, Toronto, Commission Rept. 3, March 4, 1981.
2. W. Smith and Associates, Limited. Metropolitan Toronto Area Transportation Energy Study. Municipality of Metropolitan Toronto; Toronto Transit Commission; and Ontario Ministry of Transportation and Communications, Toronto, Dec. 1980.

The Trolley Coach in Europe and Other Parts of the World

John D. Wilkins

The European experience with trolley coaches paralleled that in North America. The earliest installations occurred shortly after the turn of the century. Numerous new systems were installed during the 1920s and 1930s and in the period following World War II. Many of these new installations replaced tram operations that were being abandoned.

The availability of mass-produced diesel buses led to a gradual decline and in some cases total abandonment of trolley coach operation. In England, for example, where there were numerous trolley coach operations, all systems had been abandoned with the closing of the Bradford system in 1972. In both East Germany and West Germany, which at one time had an excess of 50 systems operating trolley coaches, only six remained by 1977. Switzerland was the only country that continued with its trolley coach systems and few closures were experienced during the period when other systems were being withdrawn.

Generally, Eastern Bloc countries continued with their trolley coach operations. This is particularly true in the Soviet Union where the trolley coach has been the major mode in many systems. Although trolley coaches were being withdrawn elsewhere in the world, new system starts were being installed in Russia. Because there has been a level of activity similar to that for light rail, one must assume that national policy favors the use of electric propulsion wherever possible.

This paper briefly states the European experience in the recent past and indicates some of the directions being taken that will influence the trolley coach in the future.

SWITZERLAND

The trolley coach renaissance in Europe started in Switzerland, which had never really abandoned the trolley as a primary transit mode. In the late 1960s, VST, a public transit association, realized the need to replace the then existing trolley coach fleets operating on numerous systems throughout the country. VST approached Swiss industry to design a new-generation trolley coach vehicle. It did not seek to have the existing fleet replaced in kind but desired that state-of-the-art technology be incorporated in the new vehicles. The end result was the standard Swiss trolley coach.

It should be noted that in Switzerland three firms typically are required to furnish a completed trolley coach. One firm constructs the chassis, one firm constructs the coach body, and a third firm supplies the propulsion system. The end product supplied by the consortium incorporated numerous new features:

1. Chopper control--a system designed to produce power savings in the range between 15 and 21 percent;
2. The standard design, which included a VW petrol engine to provide off-wire capabilites for

greater distances than had previously been provided by battery off-wire propulsion; and

3. Articulated and two-axle versions.

Since these vehicles were introduced, they have been purchased by practically every trolley bus system operating in Switzerland. In this same period only two small systems have decided to convert their operations to diesel bus.

It should be indicated that the Swiss government has always had a policy of encouraging electric propulsion. Approximately 99 percent of all railway mileage in the country is electrified. This policy has carried over into urban transportation through encouragement of trolley coach systems and light rail systems. The Swiss have an abundant supply of hydroelectric power but must import 100 percent of all petroleum needs.

FRANCE

While the Swiss were energetically laying plans to rejuvenate and extend trolley bus operations, the French trolley coach also underwent a similar rebirth. In the mid-1970s five systems still retained trolley coach operation: Lyon, Grenoble, St. Etienne, Marseilles, and Nice. These systems decided to retain trolley bus operations primarily on the basis of projected shortages of petroleum products. The location of the five properties was also in close proximity to hydroelectric power, which lent credibility to the trolley coach. The French bus and truck firm of Berliet, a subsidiary of the Renault Corporation, proceeded to design a standard trolley coach that was made available to all operators. Similar to the Swiss experience, numerous additional features were incorporated in these buses at the time of manufacture or shortly after their delivery to the various properties. These improvements included sustained off-wire capability, automatic retriever, and propulsion control.

Based on French national policy, additional new trolley coach systems are beginning to appear in France. It is estimated that approximately five new systems will be put on line in future years. The first new system will be in the city of Nancy. As part of this new installation, the system will incorporate several additional features, which include (a) articulated vehicles and (b) bi-mode vehicles. Operation in Nancy will commence in the near future. All overhead lines have been installed and driver training has begun. To date seven of the articulated trolley buses have been delivered. A portion of the fleet will be equipped with the Alsthom freon-cooled chopper system. In addition to the application of state-of-the-art hardware technology, the Nancy system will include such features as reserved busways, reserved lanes, and a traffic preemption system that will speed the movement of trolley coaches.

IMPROVEMENT IN STATE-OF-THE-ART TECHNOLOGY

Some of the significant contributions made to the new era of trolley coaches are discussed below.

Propulsion Systems

The prior generation of trolley coaches relied almost entirely on resistance-type control. The new era of trolley coaches in Europe has ushered in a number of new propulsion systems.

Chopper Propulsion Systems

Brown-Boveri, as part of its effort in contributing to the new Swiss standard trolley coach, developed a chopper propulsion system that has the capability of reducing power consumption up to 15 to 21 percent. Such systems have now been made available by competing firms, including Ansaldo of Italy, Siemens and AEG Telefunken of Germany, and TCO of France. The French firms of TCO and Alsthom are also offering chopper equipment that uses freon as the cooling agent. The Japanese firm of Toshiba and a Brazilian firm are also offering chopper propulsion systems to the trolley bus market.

AC Propulsion Systems

The Finnish firm of Stromberg has how made available an AC propulsion system that was first experimented with in Helsinki and in Winterthur, Switzerland. This system converts DC current to a pulsed current that can then be used in conjunction with an AC motor. The principal attributes of this system are its ability to use commercially produced AC motors, which are available at a lesser cost, and reduced need for maintenance efforts because the system can be sealed.

Overhead Line Systems

The new and existing systems in Europe are making extensive use of flexible overhead systems. This system has been in existence since the late 1930s when it was developed by Kummler and Matter. Two significant advances have been made in recent years: (a) all overhead fittings are designed so that the carbon is always in contact with the underrun thus reducing wear and maintenance cost, and (b) high-speed switches have been developed that eliminate the need to slow down whenever a special work is encountered. The flexible features of this overhead also allow for high-speed operation on tangent wire or wire that is subject to a slight curvature. The wire and the current collector are interwoven in such a manner that slight skips, which can cause dewirements, are avoided and the collector remains in constant contact with the overhead.

Current Collection Equipment

The current collector used in most European systems has typically been much different than that used in North America. The greater desire in Europe for off-wire capabilities provided the impetus to perfect a system that can raise and lower poles automatically with a minimum of effort. A brief description of European practices and innovations in these areas follows.

Automatic Retrievers

As part of the Duo-Bus project, Dornier, a German firm, has developed a system that will automatically raise and lower the trolley poles. The system is so designed that the coach can be in one of three preselected positions. For example, the coach may be immediately below the wire, to the left of the wire, or to the right of the wire. In those instances when it is necessary to use a non-programmed position for raising or lowering the trolley poles, the driver can manually perform this function from a console at the driver's station. Wire height is critical in this system. In most instances short spans must be provided at those locations where trolley poles will be routinely raised. Both raising and lowering procedures must be accomplished while the vehicle is at a standstill.

The French trolley bus system in Lyon also required the capability of raising and lowering poles automatically. Lyon opted for a much simpler system than that devised by the Germans. It is really a modification of a system used by Public Service Coordinated Transport, now New Jersey Transit, when it was experimenting with the D900 All-Service Vehicle in the early 1950s. This system requires that vehicles be precisely positioned and uses a pneumatic cylinder to raise and lower the trolley poles. A V-shaped pan on the wire guides the trolley shoe to the wire.

Trolley Harps

Most European systems use a trolley harp that is hinged. It is the function of this hinge to absorb lateral forces, thereby decreasing the number of dewirements associated with quick turns or abrupt changes in the path of the overhead.

Off-Wire Systems

Many European trolley bus operators have always felt the need to have some degree of off-wire capability. In earlier-generation coaches this capability was provided by a battery propulsion system that provided low performance for short distances to overcome blockages and other situations requiring movement away from the wire. The new-generation trolley coaches have generally incorporated improved off-wire capabilities. These capabilities fall into several categories.

1. Volkswagen engine-generator--The majority of new trolley coaches in Switzerland incorporates this type of off-wire capability. This unit allows for low-performance operation over far greater distances and provides the operator with additional time in which to react to situations that might require temporary dieselization. This system will allow for a speed of 30-35 km/h and for operation up inclines of 8 percent.
2. Kirsch diesel--This unit has been used in France, particularly in Lyon. In a normal urban street environment where there are insignificant grades, this unit will provide sufficient operating performance. The unit is not capable of providing for high-speed operation or operation on significant grades but can operate for sustained periods of time. At full load this unit will move at speeds in excess of 35 km/h and climb a grade of 8 percent.
3. All-service capability--This capability is currently being provided by Renault.

Vehicles

Unlike the experience in North America, many firms in Europe are offering trolley coaches that include state-of-the-art automotive improvements. Some of these manufacturers are noted here.

1. Switzerland--There are generally two firms involved with the actual coach construction: the Swiss firm of FBW, now a subsidiary of Mercedes Benz; and Saurer, a chassis manufacturer. Hess provides the coach body for practically all of the Swiss standard vehicles.
2. Austria--The firm of Graf and Stift has made available numerous coaches to systems in Austria and has also exported vehicles to Bergen, Norway. Graf and Stift is an affiliate of M-A-N.
3. France--Renault Industries offers a variety of trolley coaches to the French and world market. A PER180 is currently on loan to Seattle for demonstration purposes.
4. Hungary--The Hungarian firm of Ikarus (Mogert Trading Company) has been a major supplier of articulated coaches in the Eastern Bloc countries.
5. Czechoslovakia--The firm of Skoda is currently making available two types of coaches to the Eastern European market. These coaches include the 9TR, the older model, and the more recently designed model, 14TR.
6. Russia--The foreign trading arm of the U.S.S.R., Energonach Export, is making available the ZIU-9 model to the export market. Although this coach is crude in comparison with the other European buses, it has been exported to such places as Colombia and Greece.
7. Brazil--Marcopolo is the principal firm offering trolley coaches in this region.

TROLLEY BUS DEMONSTRATION PROJECTS

At present there are several projects taking place in Europe, which could contribute significantly to the state-of-the-art technology for trolley coaches. Some of these projects are described below.

Duo-Bus

The Duo-Bus project, currently under way in Esslingen, West Germany, is being undertaken by the firms of Mercedes Benz, Robert Bosch, and Dornier in cooperation with the Federal Republic of Germany. The first phase of this project produced a battery trolley coach vehicle. Based on the performance and data collected from this phase, a second phase was initiated, which involves two battery trolley buses, two diesel trolley buses, and one articulated vehicle propelled by both diesel and electricity.

When this vehicle is operating in the electric mode, the electric motor is rotating at all times, even when the coach is idling. This greatly simplifies the propulsion control apparatus that must be provided when the vehicle is operating in a straight electric mode. The disadvantages of this scheme appear to be that while operating in the electric mode, the vehicle does not have performance characteristics that are equivalent to that of a regular trolley bus.

Johannesburg, South Africa

Trolley coaches have operated in Johannesburg for a number of years. In the 1970s it was decided to gradually phase out all trolley coaches but to leave the overhead apparatus intact until such time as a final decision was made with regard to their disposition. In the late 1970s, partly due to a national South African policy of minimizing the import and use of petroleum-based fuels, it was decided to look at the attributes of a trolley coach renaissance in Johannesburg.

The trolley bus project involves numerous parties, including the national government, the local transport operator, and the city of Johannesburg. The decision was made to purchase seven different types of trolley buses and two diesel buses. The trolley buses would be a combination of articulated and double-decked buses and would also be equipped with both chopper and standard resistor controls. The vehicles would all be assigned to a particular route that had a variety of operating environments including busways and significant grades. The project would determine two things: (a) the costs associated with the trolley bus on a life-cycle cost basis when compared with a diesel, and (b) are the results significant enough to warrant the purchase of additional trolley coach vehicles in an expansion of the system? The demonstration will run through 1983.

Cost Project 303

Cost Project 303 is being conducted under the auspices of the European Economic Community. Its primary function is a technical and economic evaluation of the duo-mode trolley bus. This project will act as a focal point for the exchange of pertinent research and studies that have been conducted by various participants. Of primary importance are the off-wire systems currently seeing service in Switzerland, West Germany, France, Finland, and Italy.

WORLD TROLLEY BUS STATUS

During the last several years, there has been an intense amount of activity not only throughout Europe but also in the rest of the world related to improving existing trolley bus systems and implementing new starts.

Australia

New trolley bus starts are being reviewed in both Melbourne and Sydney.

Austria

At the present time, the three systems in Austria, including those in Salzburg and Lintz, have purchased new equipment and either have made or are planning extensions of trolley bus service.

Brazil

As part of a national program to reduce the dependence on petroleum-based products, there has been a renewal of interest in trolley buses in Brazil. In the city of Sao Paulo 200 new vehicles have been ordered. This system is now considering a significant expansion that could possibly see the need for more than 1,000 new vehicles in the years to come. This system is also considering the application of state-of-the-art technology for future equipment purchases. One new system is being constructed and in many others plant improvements are being made, new equipment is being purchased, and extensions are being considered.

Britain

The West Yorkshire PTE has conducted an extensive analysis of the feasibility of restoring trolley bus operations in Bradford, England. The study reviewed comparisons of trolley bus to diesel and comparisons of duo-mode to both trolley bus and diesel. It concluded that trolley buses are the most economical mode for the environment considered, followed by duo-mode buses and regular diesel buses. At present, construction funds are being sought from Parliament. It should be noted that Bradford was the last English system to operate trolley coaches.

Colombia

The existing system in Bogota appears to be purchasing a few new vehicles periodically from Russia. Other cities are said to be actively considering the purchase of new equipment.

Germany

Although the number of systems in Germany has greatly declined, those remaining are in the process of upgrading their fiscal plan. Kaiserslautern has purchased new equipment for its system and has made several route extensions. Solingen has made numerous extensions and has also experimented with differing types of overhead special work to determine which best suits its needs. Currently, an M-A-N demonstrator is helping to direct the city's efforts toward new vehicle procurement.

Greece

Athens has in recent years purchased a number of new vehicles from Russia. New routes are being considered.

Holland

Arnhem is in the process of reequipping its fleet.

Italy

There are numerous trolley coach systems throughout Italy. At present 5 to 6 smaller systems are in the process of reequipping their fleet and modernizing their systems. Some of the larger operators, such as in Milan and Torino, have not made definite decisions regarding the future status of trolley coach operation.

Mexico

For many years the STE system in Mexico City has relied on second-hand equipment from North America as its primary source of buses. New equipment is being purchased with Toshiba choppers, and it is expected that this system may be greatly expanded in the years to come.

New Zealand

The city of Wellington is in the process of reequipping its existing trolley fleet. Although there have been some problems with the consortium approach to procuring new vehicles, it appears that the problems are near solution and the vehicles in service will be replaced shortly. However, the problems experienced in Wellington were substantive enough to cause the city of Auckland to drop its proposed plan for system modernization.

Norway

Bergen, the one system remaining in Norway, is completely reequipping its fleet with new buses and is looking at possible extensions. New Graft and Stift buses are currently being delivered.

Eastern Bloc

The Eastern Bloc countries are also upgrading and expanding the use of the trolley coaches. Although complete documentation is not available, the trolley coach appears to be a major component of the surface urban transportation network in many major Russian cities. The demand for trolley coaches in Eastern Bloc countries is about 1,200 vehicles/year.

CONCLUSION

This has been a brief presentation of the status of the trolley bus in Europe and to a certain extent the remainder of the world outside of North America. Nevertheless, it shows that the trolley coach mode is receiving serious consideration throughout the world.

The general conclusion derived from this activity is that although trolley coaches will not become the predominant transit mode, they are being seriously considered for specific applications where economic and environmental considerations dictate that it is the superior mode. Clearly, the trolley coach renaissance is not a passing phase; rather it will firmly establish the role for trolley coaches for the remainder of this century and a good portion of the next.

Trolley Bus Development in Brazil

Francisco A.N. Christovam and
Jaime Waisman

The first Brazilian trolley bus experience dates back to 1949 in the city of Sao Paulo. A 7.2-km one-way overhead wire line was built and operated with 16 vehicles. After its introductory phase and its acceptance as a convenient mode of transport, Sao Paulo experienced a rapid expansion of the system through the introduction of new lines. The principal objective was the replacement of tramway services.

Between 1953 and 1967, another 10 cities introduced trolley bus systems: Belo Horizonte, Recife, Rio de Janeiro, Salvador, Niteroi, Santos, Porto Alegre, Campos, Araraquara, and Fortaleza. In recent years, all these cities and Sao Paulo have been under common pressures that discouraged system expansion and upkeep. These pressures included the lack of spare parts for imported equipment, absence of a real program for local manufacture of components, and hesitation in the application of resources, plus the false impression that individual transport would be substituted for transit systems. Thus, in 1973, only Sao Paulo, Recife, Araraquara, and Santos continued operating trolley bus systems.

The 1974 oil crisis, as well as the concern about environmental pollution, increased the demand for public transport in the large and medium-sized cities. These were the main reasons for resuming feasibility studies to reintroduce trolley bus systems. In 1977 an Interministerial Labour Group, formed by technicians of the Planning, Transport, Power, and Mining Ministries, finished a report that gave top priority to the expansion of existing trolley bus systems as well as to the short-term introduction of new systems.

The technical specifications for vehicles, overhead hardware, and rectifying substations were developed in 1978. The aim was to use advanced technology comparable to the most modern systems in Europe and North America.

All the cities in Brazil where the trolley bus survived have devoted their efforts to rehabilitation and expansion. Ribeirao Preto started operating its new system in March 1982, and several cities have already concluded or are making technical feasibility, economical, and financial studies.

SAO PAULO UPDATE

The Sao Paulo trolley bus operation started in 1949. From 1949 to 1958, the Companhia Municipal de Transportes Coletivos (CMTC) increased its fleet from 16 to 155 vehicles--an increase totally supported by imports. In 1958 Brazil started manufacturing trolley buses. Initially this activity was carried out by private companies and thereafter by CMTC. Around 1964, CMTC had difficulties in importing vehicles and component parts required for fleet maintenance. CMTC was forced to manufacture trolley buses in its own service workshop. By 1969, 139 new vehicles were built and an additional 38 were remanufactured from the existing fleet. At the end of the 1960s, CMTC owned 233 trolley buses, 129 km of one-way overhead electric line, and 13 rectifying substations (10,500 kW), which were required to operate 12 lines.

To a large extent, these lines were projected with the idea of reaching residential quarters, without consideration for the global needs of a transit system. The routing of the trolley bus lines was the same as that used for the creation of new omnibus lines. Vehicles circulated through narrow streets in search of passengers without concern for an increase in the commercial speed or better exploitation of the trolley bus transporting capacity.

The Sistran Plan, concluded at the beginning of 1976, addressed the technical, economical, and financial feasibility of a new trolley bus system for Sao Paulo. The new system called for 280 km of two-way overhead line to be used on 400 km of individual route miles. Some 1,280 vehicles will be circulating. The installed power capacity will be 198,000 kW and the approximate transport capacity will reach 600 million passengers/year. The budget for this project, including engineering, installation, and acquisition of equipment, has been estimated at (U.S.)$830 million.

The federal government authorized CMTC to implement the plan, which is divided into five stages. CMTC is responsible for the development of technical specifications and the establishment of an operation pattern that characterizes the trolley bus as a system of high transport capacity. The first stage, which consists of 200 new biaxial trolley buses, 15 rectifying substations, almost 50 km of two-way overhead line, and 1 garage, was completed by the end of 1981. The second phase is now being built and includes 210 biaxial vehicles, 14 rectifying substations, and 59 km of wire network. The location of the corresponding garage is still under study.

CMTC is now involved in the planning for subsequent phases and in determining the equipment, installation, and necessary investments to complete the Sistran Plan, as well as the construction of a new type of articulated trolley bus. At the same time, a project for rehabilitating the vehicles, networks, substations, and garage corresponding to the old system is also being developed.

For Sao Paulo, which today has almost 9 million inhabitants and an area of 150 km², the trolley bus represents not only an option for transportation services but also provides a way of attending to transport necessities by offering an improvement in the quality of living.

RECIFE UPDATE

Recife is the capital of the Pernambuco State and is the main population center in the Brazilian Northeast. It is also the center of a metropolitan region with 2.5 million inhabitants. The trolley bus system first instituted in 1959 has 8000 kW of installed power, 100 km of wire network, and 140 vehicles. The system uses Brazilian, American, and French equipment. During the 1970s, Recife's trolley bus system started to decline, as did the remaining trolley bus systems in Brazil.

Several rationalization and public transport improvement programs are under study in the metropolitan area of Recife. The recuperation and expansion program of the trolley bus system is the subject of one study. In accordance with studies made in 1980, six urban corridors were reserved for a trolley bus operation that would be installed in three consecutive phases. These corridors when installed and operating will result in a 2000-kW, 77-km electric network; 230 trolley buses (115 rehabilitated and 115 new); and a new garage.

In 1982 two corridors (12 km and 11.5 km) were operating. Some 23 vehicles were built in a workshop especially designed for that purpose, and 12 new trolley buses with chopper command were purchased. This system transports 66,500 passengers daily and each corridor has its own interconnection terminal with diesel bus feeder lines. The trolley bus system fare is 25 percent lower than the diesel one.

SANTOS UPDATE

The city of Santos is the most important port in Brazil and is in an important metropolitan region with more than 1 million inhabitants. The Santos Mass Transit Company started operating at the beginning of this century with an efficient tramway system. Diesel buses were introduced in the 1950s, and the trolley buses came in 1963 with the aim of replacing the tramway system.

The Santos trolley bus system is of Italian origin, obtained through a turnkey installation operation. The system made use of two old substations (2600 kW), which belonged to the tramway station. The initial system owned 50 vehicles, 7 substations (one of which was mobile) with a capacity of 4600 kW, 60 km of electric network, and 5 operating lines. Difficulties with the supply of spare parts and maintenance problems, together with the lack of new investments, resulted in a fast deterioration of the system. In 1979, at the beginning of the recuperation and expansion program, the system had only two lines operating with 15 vehicles. The system was in poor condition.

During the period 1979-1982, a workshop was set up to reconstruct trolley buses, and 25 vehicles were rebuilt. Simultaneously, five new trolley buses were bought with electronically activated contactors. Seven substations were built, and the oldest equipment was replaced with state-of-the-art equipment. Some parts of the electrical network were rebuilt in order to allow a more reliable operation of the system, which is transporting 30,000 passengers/day.

ARARAQUARA UPDATE

In 1958 Araraquara, located in Sao Paulo State, decided to reorganize its transport system and to reintroduce trolley buses as a means of public transport.

At the time several steps allowed for the continuous development of an efficient and cheap system for public transport. It should be emphasized that although the system (vehicles, electrical network, substations, and garage) belongs to the city, its administration and operation have been entrusted to a private concern. The Araraquara Trolley Bus Company (ATC) owns a 50-year concession for the exclusive running of the public transport of the city.

From 1959 to 1976, ATC experienced a period of continuous expansion--from 7 vehicles, 1 substation, 18 km of electrical network, 2 operating lines, and 3.1 million passengers/year to 28 vehicles, 3 substations, 84 km of electrical network, 6 operating lines, and 15 million passengers/year. This expansion was made possible from the resources generated by the operation of the system, without any outside financial aid. With a competent administration, ATC was able to purchase equipment from trolley bus companies that were being deactivated all over the country, thus enabling ATC to expand its system with reduced investments.

The expansion of the system had been restricted by the investment capability of the company. When an expansion program was started within the context of the National Trolley Bus Program, 80 percent of the project costs were available from the federal government. The goals of the expansion program during the period 1979-1982 were the purchase of 11 vehicles, installation of 3 substations (1200 kW), 14 km of electrical network, and the rebuilding and expansion of the garage. New technologies were introduced (vehicles that had a traction system based on electronically actuated contactors and choppers) as part of the expansion program.

Today, Araraquara is the only city in Brazil with a public transport system that is totally electrified. It operates 8 lines and transports 55,000 passengers/day.

RIBEIRAO PRETO UPDATE

The city of Ribeirao Preto is an important commercial and education area in the northcentral portion of the state of Sao Paulo. Due to its sociological and economical characteristics, it was selected by the federal government as a representative medium-sized city for the installation of a pilot trolley bus program. This program, the first to be implemented in the last 15 years, employs all available technology.

In 1979 the pilot program started with the organization of TRANSERP (Ribeirao Preto Mass Transit Company) owned by the municipality. This agency is responsible for the development, installation, and operation of the trolley bus system. Until that time, public transport services had been operated by a company whose service level was very low.

Initially a planning study of the transport system was made with the purpose of nationalizing and integrating the diesel and electrical systems. As a result of this study, the corridors with high density were selected for trolley bus operation.

The trolley bus system started its commercial operation in July 1982 with one line operating 8 vehicles and transporting 11,000 passengers/day. This system is the first one in Brazil to use only one operator (driver). Passengers purchase their tickets at designated places and the trolley buses are equipped with two automatic turnstiles close to the driver. The fare price is 25 percent lower than that in the diesel bus.

The funds for the installation of this system were provided by the federal government (50 percent) and the municipality (50 percent).

FUTURE PROSPECTS

The rehabilitation and expansion programs of the trolley bus system for Sao Paulo, Recife, Santos, and Araraquara and the installation of the new system in Ribeirao Preto allowed the development and consolidation of new and modern technology in Brazil. The level of technological development reached by the Brazilian industry, specifically in the manufacture of vehicles, can be compared with that in the United States and Western Europe.

Substitution of petroleum-derived combustibles by alternative energy sources such as electric traction, alcohol, vegetable oils, and solar energy has gained ground. Petroleum represents 40 percent of total Brazilian imports, whereas hydroelectric power is cheap and abundant. There are sufficient reserves to last until the end of the 21st century.

In the major metropolitan areas and medium-sized cities, public transport accounts for more than 50 percent of the daily trips. Brazil has a population of 120 million inhabitants, 70 percent of whom live in urban areas, creating a large number of trips for urban transport systems. The short-term tendency is, therefore, the continuation of trolley bus programs and the installation of new systems in other cities where the technical-economical viability of the undertaking is justified.

Simultaneously the operating companies are trying to modernize and rationalize their services, and industries are trying to procure new technology and modernize subsystems. In 1983 trolley buses with alternate current propulsion systems and an electrical network with polyester supports will be tested.

CHAPTER 4

Implications of Trolley Bus Installations

Issues of economics, the environment, system design, and operations that relate to applications of the trolley bus mode were dealt with in four papers prepared especially for the Seattle workshop. Trolley bus systems were shown to be attractive for applications in which fuel considerations, environmental concerns, topographical factors, and ridership are of primary importance. These elements, coupled with technological developments, have prompted renewed interest by urban planning and transit officials in the trolley bus mode.

ECONOMICS

Carl Natvig of the San Francisco Municipal Railway not only explored the economics of the trolley bus state of the art but also summarized the economic history of the trolley. Several major themes were detailed. Probably the most important is that the economic justification for trolley electrification does exist today. This conclusion matches that of the Urban Mass Transportation Administration's Task II report on electrification feasibility--a report that deals with the potential market, capital, operating costs, impacts, and barriers related to trolley expansion. The economic justification is particularly important if, for a variety of reasons, transit installations of a major type are viewed as long-term investments.

Trolley systems have a relatively long life. The overhead wire and power supply equipment are by nature long-lived; support poles and underground feeder cable conduits can last almost indefinitely with proper maintenance. The trolleys themselves last longer than comparable motor buses, and other components such as overhead switches and rectifiers can last from 35 to 70 years depending on the density of operation and the degree of maintenance.

There is a high initial cost, it is true, but early returns on the capital investment that are initially low give way to increases in subsequent years. These increases can be substantial. By taking the long-range view, the benefit is maximized.

A second major assertion is that there was probably never a real economic reason to discontinue the nation's electrified bus systems. There was in fact no economic necessity for major trolley abandonments as occurred in the 1950s, 1960s, and 1970s in the United States. Long-term profitability and long-term service to the public were not the primary concerns of the privately owned systems in the 1950s and 1960s. However, when faced with economic collapse, they opted for abandonment whatever the long-term consequences might be. Where systems were maintained, economic collapse did not occur any earlier.

Finally, some of the major economic advantages of the trolley bus were identified: the lower maintenance cost of the vehicle, the longer life of the bus, the longer life of the electrical system, and the lower power cost for the trolley compared to that for the motor bus.

Two issues were raised that bear on the future directions of the trolley bus. The first is that trolley system operation may attract additional patrons. Cited were reports of increased patronage when the streetcar systems were converted to trolley bus operations in the 1930s, as well as data from San Francisco. Second was the issue as to whether platform savings can be realized from electrification. It has been asserted that superior acceleration of the trolley bus enables it to operate a given route, particularly one over hilly terrain, with a faster schedule and hence a lower cost.

ENVIRONMENT

Bo Persson of the National Swedish Environmental Protection Agency summarized the current status of environmental knowledge concerning trolley bus operations in urban areas. (Persson's paper was presented by Alonzo Wertz of the Tri-Met Transit Development Department, Portland, Oregon.)

The trolley, as a system, is a strategy that can help in the control of air and noise pollution in urban areas. Although diesel buses are only a minor source of air pollutants, the electrification of bus routes tends to be particularly effective in reducing further air and noise pollution on congested downtown streets where there are concentrations of people and vehicles in what are, in effect, canyons formed by narrow streets and tall buildings.

Some important new findings based on recent research in the United States, Japan, and Sweden showed that the use of the Ames test, which involved the exposure of salmonella virus to active substances, indicates that there is a high comparative mutagenic potential from diesel engine exhaust emissions. It was also noted that the high concentration of oxides of nitrogen in the exhausts of heavy-duty diesel engines contributes to possible carcinogenicity of diesel exhaust. The active nitro-aromatic compounds present in diesel exhaust are more likely to be formed by modern turbo-charged diesel engines than by older engines.

Visual pollution of intrusion is probably the trolley bus system's biggest disadvantage. However, careful planning and environmental design can alleviate much of the problem. Overhead wires can be toned down by landscaping techniques, for example.

Three areas are identified in which there is a need for more information on the environmental impacts of trolley buses: first, the content of toxic agents in diesel exhaust, especially the emissions of mutagenic substances as well as the emissions of such substances that could form mutagens in the urban area; second, activities on the dilution of diesel exhausts in the street environment and measurements of diesel exhaust components in areas affected by diesel buses (e.g., bus-only streets or near bus terminals); and, third, how individual doses of exposures to diesel engines could be used as a method to quantitatively evaluate various policies relative to the introduction of trolley bus operations.

From the environmental point of view, the introduction of trolley systems in large cities could have important positive effects. The trolley represents an attractive alternative to the conventional diesel bus without the noise and diesel exhaust disadvantages.

OPERATIONS

Llew Lawrence, Director of Operations for the Edmonton Transit System, stressed the importance of putting the passenger first in the design and operation of transit systems. From this basic principle were derived the desirability and importance of a trolley operation as part of a comprehensive transit system. A status report on trolley bus operations in Edmonton identified in particular the return to full operation of the trolley system after a lapse of some years due to a lack of rolling stock. With the recent introduction of the new BBC fleet of trolleys--basically a modern electrical plant in the standard GM "new look" bus body--complete electric operation has returned.

The importance of using the trolley bus for heavily serviced areas such as city trunk-routes was stressed. The relationship of trolley bus operation to the development of timed transfer focal points in Edmonton was also examined. In particular, reference was made to the Jasper Place timed transfer focal point--truly a development that broke new ground in North American transit operations. Edmonton also plans in the future some minor system extensions, the upgrading of overhead lines, and the retraining of bus operators to refresh their trolley driving skills. Possible major electrification of certain routes is being considered.

The notion of inflexibility was raised as a positive attribute that can be used by the transit system to stave off requests for special off-route deviations and requests for other than the fixed-route services that transit systems ought to be providing for the benefit of all of their passengers.

The concept of teamwork as a requirement of trolley operation was identified. A parallel was drawn between railway operations, which require considerable teamwork and coordination among the operating staff, and the trolley bus system, which, unlike the diesel bus system, requires a lesser degree of coordination and teamwork in order to operate effectively for the benefit of the passengers. The primary question here was whether or not the introduction of trolley bus operations can be of some assistance in restoration of morale and a sense of shared purpose among the operating staff.

SYSTEM DESIGN

Thomas G. Matoff, Director of Transit Development for the Tri-County Metropolitan Transportation District of Oregon (Tri-Met), Portland, pointed out that the trolley bus, once a major transportation mode in the United States, is now undergoing a renaissance; however, it is still not significant on an industrywide basis. Only 1 percent of the U.S. transit passengers is carried by trolley buses, and less than 1 percent of the systems is actually operating trolleys. Despite its environmental advantages, economy of operation is the key to making the trolley bus mode more viable. If the economic stage is not set, electrification will not occur on a large scale, and the trolley bus will never become dominant on a nationwide basis.

Related to this conclusion is the fact that the economical operation of a trolley bus system is only possible with dense operational levels. There are two multidestinational design strategies that can lead to these dense operating levels--the timed transfer focal point system, such as is used in Edmonton, suburban Vancouver, and, to some degree, in Portland, and the grid system for urban levels of service. These two kinds of networks actually serve public needs better than the traditional radial route system and, at the same time, by concentrating downtown service on relatively few routes they can lead to dense operation levels and set the stage for an economical electrification of routes.

It was concluded that electrification should not be looked at as an individual route-by-route determination, but that trolley buses are best considered as part of an overall strategy to redesign the transit system to work better for more people. Current analyses under way in Portland were briefly cited, as well as the position that the articulated trolley bus with multiple wide doors, chopper control, and self-service fare collection in use on a multidestinational network could well be the most efficient and effective type of transit bus.

SELECTED MATERIALS

Trolley Bus Economics

Carl Natvig

Quiet, no air pollution on city streets, 100 percent more energy efficient, one-third less maintenance, 25-year life with no major overhauls--these are the virtues of the trolley coach. This sounds amazing considering that the trolley coach, replete with all of these advantages, has been around in a fairly well-developed form since the early 1930s. The question, then, is: Why has not the trolley coach, with all of the concern about petroleum shortages and air or noise pollution, enjoyed a resurgence in use along with the turnaround of the transit industry? The basic answer, of course, is because it is a trolley and requires a substantial investment in overhead trolley wire and power supply equipment to be put into operation.

ECONOMIC HISTORY OF THE TROLLEY COACH

If the main obstacle to using trolley coaches is the cost of the wire, then why did the many systems that operated trolley buses and obviously already had overhead wire scrap the wire in favor of motor buses? A brief review of the history of the trolley coach in this country can shed some light on this question and give some indication as to why we can approach new electrification today with confidence.

When the trolley coach first came on the scene in significant numbers in the 1930s, city streets had improved, automotive technology had advanced, and the street railway saw the trolley coach as a means of obtaining modern but cheap vehicles while retaining the same electric propulsion technology with its attendant power conversion/distribution infrastructure with which everyone was familiar and that had proved so reliable. Also, most important, the street railways could in many situations avoid the necessity of rebuilding worn out or substandard track at great expense and, in nearly every case, avoid the expense of maintaining the roadway adjacent to the track--an almost universal local franchise requirement. Avoiding large capital expenditures was particularly crucial during the Depression for the transit industry, which was not often in particularly good financial condition even in the best of times.

At that time, the capital cost for converting to trolley coach was not too great. It generally required only the addition of a second trolley wire and some feeder reorganization, special work, and turnback loops. Existing line crews could do the work. Trolley coaches, themselves, were cheaper than streetcars and at that time only slightly more expensive than motor coaches.

There were immediate payoffs on the small capital investment. Then, as now, trolley coach maintenance was considerably less than for motor coaches. The cost differential was considerably marked because the motor coaches in use then were powered by gasoline engines, which are more expensive to fuel and maintain than are diesel engines. For example, the Municipal Railway reported equipment maintenance costs of \$0.48/hr for trolley coaches and \$0.69/hr for gasoline motor coaches in 1949. By 1960 maintenance costs were \$0.64/hr for the same trolleys, \$0.87 for the new Mack diesels, and \$1.31 for the worn-out gasoline Whites. Fuel or power costs were \$0.51/hr for the trolleys, \$0.46 for the diesels, but \$0.91 for the gasoline buses. It should be noted that the \$0.51 for electricity costs included 18 percent for manning the old-fashioned rotating equipment and another 10 to 15 percent for power lost in the conversion equipment itself; both are expenses that are avoided today with modern silicone rectifiers.

The trolley coach boom peaked in 1954 with 9 percent of vehicle mileage in the transit industry operated by trolley coaches. By 1952 conversion had virtually stopped. By that time all but 8 percent of total service had been converted to either motor bus or trolley coach. The remainder was either solidly, at least for the time being, streetcar or in the hands of the motor interests or their converts.

By the late 1950s trolley coach systems began to disappear. Factors other than purely economic ones appear clearly to have been at work as evidenced by the fact that the average life of trolley coaches was only about 15 years--well below the 25 to 30 years possible. Two basic underlying problems appear to have been at work--the financial weakness of a declining transit industry and the dominance of the motor industry.

In a declining, financially strapped industry, there was naturally little interest in long-term investment in new wires to serve new, expanding low-density suburbs or in new and now more expensive vehicles, however long lived, regardless of the long-term economies. It was said that in many cases it was more profitable to sell the copper in the trolley system, buy new diesel buses, and, then, sell out a fully depreciated diesel bus system to a municipality.

As evidenced by the virtually universal collapse of privately operated transit in this country, it is probably fair to conclude that long-term profitability and long-term service to the public were not primary concerns in transit investment or disinvestment decisions in the 1950s and 1960s. Those in local government who were supposed to be regulating the transit systems and who might have objected to trolley coach abandonments were always presented at the time with a brand-new fleet of modern diesel buses to replace the trolleys and with the fact that this was the industry trend.

The best evidence that trolley coach abandonment was not an economic necessity can be found in the Dayton system. This was a 70 percent trolley bus transit system that remained profitable in a medium-sized city long after most other such systems had gone out of business and sold out to municipalities. This contention is also supported by our experience at MUNI in San Francisco. Except for brief periods when diesel fleets were new, at no time over the past 43 years has it been cheaper to operate motor buses than trolleys.

TROLLEY COACH INVESTMENT AND PAYBACK

Enough said for the past. The question before us today is: Can we justify the substantial first cost of installing a completely new trolley coach overhead wire system? I believe we can--if we are willing to look at a trolley coach system as a long-term investment. I believe such an approach can prove fruitful for several reasons.

1. Trolley coach overhead wire and attendant power supply equipment are long lived. Trolley support poles with regular painting and underground feeder cable conduits can last indefinitely. Other components such as wire, overhead switches, and rectifiers can last 35 to 70 years on moderate-density lines with peak headways on the order of 5 to 10 min.
2. Although trolley coaches are less expensive to maintain and power in equivalent service than motor coaches, the initial capital cost for installing a trolley line is high and the initial rate of return is low except for the heaviest lines, which would be in the 1 to 2 min peak headway range.
3. The return on the trolley coach investment increases primarily with the increase in labor wage rates, which, except during depressed economic times, have increased more rapidly than the rate of inflation.
4. Because public transit is now, in every locality, a public enterprise and presumably operated for the benefit of society, we can look to long-term returns rather than immediate profit and quick paybacks on quickly depreciated and short-lived assets. In a public enterprise, I believe it is perfectly legitimate to look at returns on a current investment that will accrue to future generations as being important and valuable.

I would like to enumerate the basic capital costs and returns on investment or savings that can be expected with a trolley coach investment. Although these amounts are based on recent and historic MUNI experience, there are many variables that can enter the picture. For example, overhead line costs can vary greatly depending on whether aerial, underground, or no feeder cable is used; on how much higher overhead utilities, such as power and telephone lines, must be moved; or on how many switches and turnback loops are needed. For a given service headway, vehicles per mile and hence savings per mile will vary directly with average speed, which in turn is dependent on the number of stops per mile for passengers and traffic controls. Other variables are local electricity rates, labor rates, hills, and so forth.

The methodology presented here, I hope, will prove to be a useful guideline for performing economic feasibility studies for trolley coach conversions in other systems.

There are two areas of initial capital costs with a new trolley coach investment--the overhead trolley and the net additional cost of trolley coaches over motor coaches. The overhead system includes the overhead wire and hardware, the rectifiers and power feeder cables, and the maintenance trucks (a relatively small item). The extra cost of trolleys is about 50 percent at the present low rate of demand for trolley coaches. (That is only 44 percent if one assumes 5 percent fewer spares.) We can assume that new trolleys will most likely be replacing life-expired diesels in the fleet; hence, we need only look at the net increase in vehicle capital costs.

The savings from trolley coach operation are primarily in the areas of energy, vehicle maintenance, and vehicle replacement.

In the past, when most motor coaches were propelled by underpowered six-cylinder engines rather than the recent eight-cylinder or current enlarged six-cylinder engines, significant savings in driver labor have been reported. However, on level ground, current diesels perform about the same as trolleys. On hilly terrain, the trolley is a little better, and a case can probably be made for including some driver time savings. In San Francisco, such savings have been negated by the large number of slow-speed switches and crossings on each line. When these are all replaced with the newer full-speed models, the full advantages of electric propulsion in hilly terrain will materialize.

There are other benefits that are too difficult to quantify or are relatively small. For example, a trolley coach system requires less in the way of vehicle maintenance facilities because less maintenance is required. Trolley coaches are more reliable and, therefore, can provide more reliable service, which certainly has a definite though difficult-to-quantify economic value. Trolley coaches require little in the way of major overhauls; hence, the problem of all engines or transmissions in a fleet of coaches bought at the same time needing a major overhaul at the same time is not a maintenance or even a vehicle purchase planning issue with trolley coaches. Open storage in cold climates is much less of a problem with trolley coaches, and scheduling of fueling is not a problem at all. Although there is only scant evidence that trolley coaches attract more patrons, they should attract more riders and hence more revenue than motor coaches. There are numerous reports of increased patronage due to conversion from old delapidated streetcars in the 1930s to the faster, more comfortable trolley coaches--as well as for conversions to PCCs, I might add. There are far fewer reports of increased patronage from conversion to motor bus. In San Francisco, when the Sutter Street trolley coach lines were temporarily converted to motor coach to facilitate a one-way street scheme, our revenue records indicate a 10 percent drop in patronage on these lines with little change on parallel motor coach routes.

MUNI has recently converted two motor coach routes to trolley: the famous 55-SACRAMENTO and the 45-GREENWICH. Patronage counts are scanty, however, and it is difficult to draw firm conclusions. Also, the routes were changed in length at the same time, which further complicates analysis. It appears, though, that there has been some patronage increase.

The problem in including increased patronage and revenue in an analysis such as this is further complicated by the fact that most transit systems operate at a deficit. Hence, more business actually means more losses, because added revenues will not usually cover added operating costs.

The usual method of increasing patronage in the transit industry in recent years has been either to expand route mileage into low-density areas with accompanying large operating subsidies or to lower fares, which is a variation of the same idea. In the transit industry, it usually takes a 10 percent reduction in fares to increase patronage just 2 percent. A 10 percent increase in patrons would require, then, on the order of a 50 percent reduction in fares. Assuming a 35 percent farebox recovery, an additional subsidy equal to 17 percent of existing operating costs, which are about $100,000/year/coach, would be required to increase patronage 10 percent. If, in fact, patronage can be increased 10 percent by conversion to trolley coach, then as much will be achieved by conversion as is usually accomplished by lowering fares 50 percent. We might then look at trolley coach conversion as another type of expenditure that can increase transit use.

It is worth noting that in the era of streetcar and trolley coach abandonments, lower cost per mile was often touted as a clear advantage of conversion to motor bus--completely ignoring such things as vehicle size, frequency of stops, or acceleration capabilities. It should have been obvious that the vehicle assigned to the heavier lines would have the lower average speed and the higher number of labor hours per mile.

The average scheduled speed of trolley coaches in San Francisco is 7.89 mph versus 9.77 mph for motor coaches, reflecting the greater number of stops and heavier loadings on the trolley coach routes. Calculations indicate that trolley coaches in San Francisco service in fact deliver 44 percent more energy to the rear wheels per mile on the average than do motor coaches. [This assumes 4.45 kWh/mile, 83 percent motor and gears efficiency, 75.4 percent rheostatic controller efficiency, and 3413 Btu/kWh for trolleys, and 3.33 miles/gal for new diesels. Current vehicles obtain 2.83 mpg, 15.7 percent overall engine and transmission efficiency as determined from actual tests in local service, and 140,000 Btu/gal. The calculations are $4.45 \times 0.83 \times 0.754 \times 3413$ = Btu/mile for trolleys; $(1/3.33) \times 0.157 \times 140{,}000 = 660$ Btu/mile for diesels, and $9504/660 = 1.44$.] On a vehicle-hour basis, power output tends to be more equal, with trolleys producing 16 percent more effort per hour.

Despite the greater amount of work done per mile by the propulsion systems on trolley coach routes, the historic average cost per mile for maintenance has still been 29 percent higher for motor coaches. Similar results have been reported in Zurich, Toronto, and Vancouver--systems that maintain separate records for the two modes. A little more than 50 percent of motor coach maintenance costs is related to the propulsion system. On a cost-per-hour basis diesel vehicle maintenance costs are 60 percent higher than for trolleys because placing energy and maintenance on an hourly basis tends to equalize actual work done; this ratio (1.60) should tend to apply over a wide range of service situations or average service speeds.

Vehicle purchase costs have tended to range from 33 percent to 50 percent higher for trolley coaches. However, they last at least twice as long. Because a third less maintenance is required for trolleys, it should be possible to perform maintenance with a third fewer spares.

The total average annual savings per vehicle for vehicle-related costs is $13,550.

The cost estimates for installing trolley coach overhead wire given in the table below are for a light line and are based on recent experience with the 24-DIVISADERO crosstown line now being built in San Francisco:

Item	Cost per Double Track Route Mile ($000s)
Straight wire	405
Switches (2 per mile)	85
90° turns (1 per mile)	40
Crossings (2 per mile)	6
Substations (0.66 per mile, no feeder)	425
Utility relocation (0.75 mile per route mile)	300
Construction cost	1265
Engineering and miscellaneous at 26 percent	328
Project cost	1593

Heavier lines, especially those with steep grades, may require parallel feeder cable. It is assumed here that coaches will be equipped with auxiliary power supplies such as batteries or generators obviating the need for most emergency switches and turn back loops.

It should be noted that costs can go much higher with extras. For example, the 1.6-mile Sacramento line electrification cost $7.9 million or $3 million/mile. This, however, included all new street lighting on the trolley support poles, an average of 11 switches/mile, three turnback loops, and underground feeder cable along the entire route with some expensive underground work in the financial district. Where there are no low aerial utilities, there will be utility relocation costs--a substantial savings.

As noted earlier, the most expensive item listed--support poles--can last indefinitely. Utility relocation, a high-cost item, is a one-time cost. Rectifiers have essentially no moving parts and can be expected to last at least 35 years. Wear components--wire, switches, and crossings--constitute only 12 percent of the total and can be expected to last in the 15- to 75-year range on a light line with about 140 trips/weekday and a 10-min headway at the peak.

The total project cost per mile for overhead is on the order of $1.6 million. To demonstrate the relationship of construction cost to vehicle-related savings of $13,550/year/vehicle, a line with a 5-min peak headway would pay for itself in 45 years. A light trolley line with a peak headway of 10 min and about 140 trips/day would still pay for itself within the life of the overhead in 90 years. If we were to assume a patronage increase of 10 percent and add in an amount of $17,000/vehicle/year, which is equal to the fare reduction required to accomplish the same patronage increase, a line with a 5-min peak headway would pay for itself twice over in 80 years.

These conclusions are based on the following assumptions. A 10-min headway will result in an average of 1.33 vehicles/mile at an average speed of 9 mph. The payback figures above assume that savings will inflate annually at a rate equal to the prime interest rate resulting in a net discount rate for future savings of zero. The present value of future savings can then be calculated simply by multiplying annual savings by the expected life of the investment. These inflation and discount rate assumptions seem reasonable, because over the past decade wage rate increases have usually been about equal to the prime interest rate whereas bus price escalation has exceeded the prime rate. It is safe to assume that energy price increases will also probably continue to equal or exceed the prime rate in the future.

The Electric Trolley Bus Feasibility Study by UMTA estimated that there are 26 cities that can justify trolley bus systems of 75 or more vehicles on routes with headways of 10 min or better and 140 or more trips/day per route. The study estimated the total potential trolley coach fleet for these routes at more than 10,000 vehicles nationwide. Our experience at MUNI indicates that not only can the trolley coach pay its way but also is well worthwhile in terms of noise and pollution reduction as well as improved reliability.

MUNI, which operates 16 trolley coach routes, is considering converting 13 of its motor coach routes to trolley. One route, the 24-DIVISADERO, is now under construction. Two of the 13 are also being studied as possible light rail routes. Vehicle densities on these routes range from 5.3/mile to 2.5/mile. Total route mileage is 55. If these lines, which would require 170 coaches, are converted, more than 70 percent of MUNI service would be then electrically propelled.

The Trolley Bus and the Environment

Bo Persson

The increased use of fossil fuels for transportation, heating, and energy production has aggravated the problem of air pollution in most densely populated areas around the world. Exhaust from motor vehicles is the dominating source of air pollution in almost every urbanized area. Furthermore, it must be noted that exhausts from motor vehicles are emitted directly at breathing level, which make their contribution to the pollutant content of the air inhaled even more significant.

In addition to the local air pollution problem created by high numbers of motor vehicles on narrow city streets, motor vehicle emissions may also make a significant contribution to areawide environmental problems, such as the formation of photochemical smog and the acidification of rainfall.

Several strategies exist that aim at the control of air pollution. The development of alternative transportation solutions, such as public transportation, is a strategy that tends to be increasingly important due to increasing energy costs.

The trolley bus is a public transportation system that has the advantage of making only a small impact on urban environment when compared with automobiles or diesel-powered buses. This is true not only in relation to the air pollution problem, but also in relation to the noise problem. Those advantages are most important when the trolley bus is to be used in downtown areas or in heavily traveled corridors of major cities.

The current discussion concerning health effects from diesel exhaust is an issue that may be an important argument favoring the introduction of trolley buses. This is a recently recognized problem, partly because new research methods have indicated high levels of mutagenic and possible carcinogenic substances in diesel exhaust, and partly because modern and more fuel-efficient diesel engines appear to produce more of these substances.

AIR POLLUTION IN URBAN AREAS

There are several reasons for the dominating role of transportation as a source of urban air pollution. First, the transportation system is primarily based on large numbers of motor vehicles with polluting combustion engines. Individual transportation has led to urban land planning policies that have increased substantially the number of vehicle miles traveled per inhabitant during the past 50 years. During the same time, other sources of air pollution, such as industrial sources and power stations, have reduced their share of air pollution problems in most countries.

The fact that in the transportation sector the pollutants are emitted directly from tailpipes at street level, whereas pollutants from industry or power utilities are emitted from high smokestacks, makes the pollution contribution from transportation to individual exposure far greater. A recent Swedish study indicates that the same amount of pollutants emitted from an automobile in an urban area makes a 30 times greater contribution to the exposure of the average citizen to such emissions than emissions from industry or power utilities.

In the transportation sector, the main interest so far has concentrated on the control of emissions from gasoline-powered automobiles. In some countries, such as the United States and Japan, fairly stringent regulations of exhaust emissions have been introduced. Those have led to substantial reductions in the amount of air pollutants emitted from gasoline-powered automobiles. In Europe only minor reductions of the emission level have so far been achieved because of less stringent emission regulations.

As for the emissions from diesel-powered vehicles, only limited legislation concerning the control of some of the components of diesel exhaust exists in some countries. The increasing number of diesel vehicles, both heavy-duty vehicles such as trucks and buses and diesel passenger cars, together with the less stringent control of diesel emissions, is the reason why the contribution from diesel vehicles to urban air pollution problems is rapidly increasing around the world.

The automotive air pollution problem is widespread. Not only in the great cities but also in downtown areas of smaller cities high levels of air pollution may occur during unfavorable weather conditions. Swedish studies indicate that violations of air quality standards recommended by the World Health Organization and of standards adopted in the United States may be expected along busy streets in almost any city with more than 25,000 inhabitants.

During the past few years the possible content of mutagenic and carcinogenic substances in urban air has been the subject of intensive discussion. New methods of biological testing have made it possible to detect mutagenic effects of urban air pollution and of exhaust from combustion engines used in automobiles and buses.

EXHAUSTS FROM MOTOR VEHICLES

Two principal differences between the exhausts from gasoline and from diesel engines exist: (a) the uncontrolled gasoline engine emits more components like carbon monoxide and low-molecular hydrocarbons whereas the direct-injected heavy-duty diesel engine emits more nitrogen oxides; and (b) the diesel combustion process generates more soot and particles in the exhaust (5 to 10 times more than an uncontrolled gasoline engine and 30 to 100 times more than a gasoline engine equipped with a catalytic converter).

The low particle rate produced by a gasoline engine that runs on lead-free gasoline makes it possible to use advanced exhaust control devices like the catalytic converter, which significantly reduces the emission levels of almost all exhaust components. This technique has made possible the strict regulations on exhaust emissions from gasoline-powered automobiles in the United States and Japan.

The introduction of such effective exhaust control measures for gasoline-powered automobiles and the trend of rapid increase in the number of diesel-powered vehicles are two reasons why diesel vehicles may play a much greater role as precursors of urban air pollution in the future.

No effective technique exists for control of diesel exhaust. In the future, catalytic converters may be developed, which may help reduce some of the emissions from the diesel engine, i.e., particles. This may make it possible for engine manufacturers to meet the stringent regulations on diesel particulate proposed in the United States. However, it will be difficult to reduce the emission of nitrogen oxides while ensuring proper function of the devices for longer periods of time.

MUTAGENICITY OF EXHAUSTS

The most widely used method to measure mutagenicity is the Ames test, where salmonella virus is exposed to active substances and the mutagenic effect is observed within 24 to 48 hr. The Ames test has, when used in recent research projects in the United States, Japan, and Sweden, indicated a high mutagenic potential for diesel exhaust emissions compared with other known emissions. A recently concluded research program with the aim of testing biologically various combustion emissions in Sweden gave the following average mutagenic potentials:

Item	Revertants/kg of Fuel Consumed
Gasoline engines	190,000
Diesel engines	2,700,000
Coal combustion in power utilities	800

In this study, the gasoline engines were not equipped with catalytic converters. If they were and if the automobiles were run on lead-free gasoline, the mutagenic potential would drop to the same low level as for a well-controlled coal combustion process.

These values are also based on biological testing of the particulate fraction of the exhausts. It is generally assumed that most of the carcinogenic and mutagenic potency of combustion emissions is associated with the particulate fraction. However, some contribution is also made by the gaseous phase. This is especially true for emissions from gasoline engines. It has not been possible to consider the gaseous phase due to the complexity of the sampling procedure until recently, when a few results have been obtained. Combined consideration of the gaseous phase and the particulate phase appears to indicate that the ratio of mutagenicity gasoline/diesel changes from 1:15 to about 1:6 compared with investigations made separately on the particulate phase.

The reason for the high mutagenicity of diesel exhaust as indicated by the Ames test in comparison with other combustion emissions appears to be the formation of highly mutagenic and possibly carcinogenic nitro-aromatic compounds during the combustion process. The high concentration of nitrogen oxides in the exhausts from especially heavy-duty diesel engines is an important factor for the formation of these compounds. Among the mutagenic and carcinogenic nitro-aromatics now identified in diesel exhaust is 1-nitropyrene, which may be one of the most important of these substances. Partly oxidized organic compounds may also be an important contributor to the mutagenicity of diesel exhaust.

It also appears likely that a high proportion of the nitro-aromatic compounds present in diesel exhaust is attracted to the surface of diesel particles, and that this makes the particulate fraction interesting.

It appears that more of these compounds, especially nitro-aromatic compounds, are formed in the exhausts from a modern turbo-charged diesel engine, compared with older, smoky diesel engines. This has to do with the increased formation of nitrogen oxides in newer, more energy-efficient, diesel engines. The few comparable test results available confirm this hypothesis.

Diesel-powered trucks are the most important contributors to diesel emissions in most areas. Other contributions of importance in urban areas are light-duty diesel vehicles, diesel passenger cars, and diesel buses. It has been estimated that the buses contribute about one-eighth of total diesel emissions in a typical major city in Sweden, and the figures appear to be similar for cities in other parts of Europe and in North America.

However, if one takes into account the contribution of diesel buses to the exposure of urban citizens, the role of the diesel buses may be significant because of the concentration of bus traffic in central areas of cities, where many people will be exposed to high concentrations of diesel exhaust along streets with several bus lines, along combined pedestrian/bus streets, at nearby bus terminals, and at major bus stops. The concentration of diesel exhaust inside buses may in some cases also be high, especially inside articulated buses.

It should be noted that the observed mutagenicity in ambient urban air is not necessarily the direct result of the emission of mutagenic compounds. Some mutagenicity may be the result of atmospheric reactions in the urban air mainly involving nitrogen oxides and polyaromatic hydrocarbons. Diesel emissions are, however, important contributions of these precursors of mutagenic substances.

Another matter of controversy is the interpretation of the presence of mutagenic air pollutants in terms of a real cancer risk. It is generally agreed that there exists an increased risk of cancer in urban areas due to the presence of mutagenic substances in urban air. But the level of risk as well as the possible interaction with exposure to cigarette smoke are areas of intense debate among researchers.

So far, the issue of most concern has been lung cancer. It is generally believed that about one-tenth of lung cancer cases are caused by air pollution. The majority of lung cancer cases have been blamed on cigarette smoking. However, it is questionable whether the mutagenicity of cigarette smoke is high enough to explain the high share of lung cancer cases among smokers. The mutagenicity of cigarette smoke is low when compared with urban air pollution sampled at locations with high exhaust concentrations. It has been suggested that the dangers of cigarette smoking instead lay in the high amounts of certain substances that act as promoters together with carcinogens, and that this might lead to the conclusion that the higher risk of lung cancer among smokers may be caused by the combined effect of exposure to cigarette smoke and mutagenic particles from urban air or other exposures.

The fact that mutagens are carried to other parts of the body from the lung alveoli and the fact that they may be transformed into other but related chemical compounds, which may have an even higher mutagenic effect, suggest that the mutagens in urban air do not only influence the risk of lung cancer but the risk of other cancer forms as well. The conclusion might be that the contribution of emissions from the transportation sector, especially exhausts from diesel engines, to the population risk of cancer and genetic effects appears to be greater than has been anticipated previously. It is and will be an area of intense discussion among researchers for many years to come. Several research programs have been launched in the United States as well as in Europe and Japan, but due to the complexity of the matter it is probable that the definitive answer concerning the cancer risk caused by diesel emissions will not be given in the near future.

IMPACT OF TROLLEY BUSES ON AIR QUALITY

The use of trolley buses would probably be feasible on bus lines with high frequencies or where corridors with several bus lines exist. This would mean that trolley buses can substitute for diesel buses at those locations where the environmental disadvantages of diesel buses are most observed, that is, along streets with a large number of passing buses in the inner parts of major cities. In addition, it would be interesting to possibly consider the introduction of trolley buses in the case of a bus-only street in an area with high demands on environmental quality--i.e., a pedestrian mall with bus traffic in an inner city or a separate busway in a residential area.

Even if diesel buses are a minor source of diesel emissions in urban areas as a whole, significant improvements in the local situation may arise from the introduction of trolley buses. And even if the contribution of such a measure to the total improvement of urban air quality is small, it must be recognized that those streets that have high bus frequencies also often have high numbers of pedestrians, as well as passengers of the public transportation system waiting at stops, at bus terminals, or even inside buses, who are exposed to diesel exhaust. Recent Swedish research has shown that the air quality inside buses is affected by the buses' own exhausts, especially in articulated buses where diesel exhaust may leak into the passenger compartment through the articulation. The status of bus maintenance is also a factor--new and well-maintained diesel buses seldom have problems with high oxide pollution levels caused by their own exhausts.

The improvement in personal exposure (i.e., reduction of the individual dose of diesel exhaust products) from the introduction of trolley buses may be quite significant. A calculation of the effect on individual doses (population dose) may constitute a suitable method to evaluate the environmental (air pollution) effects of such a measure.

Even if the cancer risks are difficult to interpret, the fact that there exists a suspicion of such a risk is a strong argument to discuss possible methods to limit this risk. It is evident that the public would welcome all measures that decrease the amount of mutagenic substances emitted into the urban air, including the substitution of diesel buses with trolley buses. It must be noted that a public transportation system based on electric modes, such as commuter rail, metro, light rail, or trolley bus, with diesel bus lines acting as feeders, could allow a significant improvement in urban air quality, especially if the existence of this low-polluting public transportation system motivates a traffic policy with the aim of shifting from private to public transportation.

Even if the electricity used by the trolley buses is generated in a coal-fired utility, the gains relating air pollution will be considerable. The emissions of mutagenic substances from a coal-fired electricity production utility are more than 3000 times lower per kilogram of fuel consumed compared with diesel fuel combusted in a diesel engine. Also the emissions of nitrogen oxides are lower whereas the emissions of sulfur oxides might be higher for a trolley bus system compared with a diesel bus system if electricity is derived from coal-fired utilities. In addition, there is a significant difference concerning the contribution to individual exposure between emissions spread from high smokestacks and emissions spread from tailpipes in the streets.

It must also be mentioned that in many cases the electricity is not produced in the "worst-pollution-case." A large part of the electricity used in various parts in North America and Europe stem from hydroelectric or nuclear facilities, which do not generate combustion emissions.

VISUAL INTRUSION

The visual intrusion problem refers most often to the catenary of trolley buses. This is a clear disadvantage of trolley bus systems from the environmental point of view, which has to be balanced against other environmental factors such as the air pollution situation and the noise problems.

However, several possible solutions to this problem exist. One is to use a trolley bus concept with some potential of energy storage (battery or flywheel). The catenary may then be avoided at sensitive locations for short distances. Another is to design the catenary in a careful manner, e.g., to fasten the catenary in house walls instead of using poles.

NOISE

Noise is perhaps the most obvious source of environmental disturbance as observed by the public, even if the health effects from urban air pollution may be far more serious. This may be the reason why discussion of noise problems often receives the most attention.

Traffic is by far the most important noise source in urban areas. A diesel engine produces more disturbing noise than a gasoline engine. This is why local bus traffic (at streets with many passing buses) may create a noise problem. The noise problem is most obvious for buses accelerating from a stop or going uphill.

Even if the modern diesel bus is much more silent than older diesel buses because of new noise abatement techniques, the trolley bus would provide a substantial improvement for urban residents living on those streets where bus noise is a problem. It must also be noted that an increasing share of road traffic noise depends on the interaction of tire/road surface, which is a significant factor for vehicles running at constant speed or generally at higher speeds. The introduction of trolley buses has the most positive influence on noise problems in situations where the engine noise is dominating, which is most often the case at those locations where bus noise problems occur. The diesel buses running on freeways are generally not a significant factor in the noise situation, and trolley buses running the same freeways would also not create any problems.

Some noise might be generated by the friction between the overhead and the trolley shoe. This has been the source of some noise problems for older existing trolley bus systems, but may be almost totally eliminated by modern trolley bus techniques.

RESEARCH NEEDS

It is obvious that there is a need for increased knowledge of the environmental factors related to trolley buses. Such knowledge is important to verify raw estimates of the possible environmental benefits of trolley buses, which might be essential to justify the higher costs involved when compared with diesel buses. Some of the areas, in addition to ongoing and planned research programs, that might be of special interest are

1. Increased research on the content of toxic agents in diesel exhaust, especially concerning the emissions of mutagenic substances as well as the emissions of such substances that might form mutagens in the urban air;
2. Increased research activities concerning the dilution of diesel exhausts in the street environment, measurements of diesel exhaust components in areas affected by diesel buses, such as on bus streets, close to bus stops, and bus terminals; and
3. Increased knowledge of individual doses and how calculation or measurement of individual doses may be used as a method to evaluate various traffic planning policies, i.e., the introduction of trolley buses.

DEVELOPMENT IN SWEDEN

Since the abolishment of the existing trolley bus systems in Sweden (in Stockholm and in Gothenburg) in the mid-1960s, there have been several proposals for the introduction of electric bus systems in these and in other major cities.

The most obvious result so far is that two battery-powered electric buses were to be put in service on an inner-city bus line in Stockholm during 1982. In Malmo the government is sponsoring a study on the possible introduction of trolley buses. The Swedish mass transit industry has also developed a proposal for a Swedish-built trolley bus (Scania/ASEA), which, if the result of the study is positive, eventually might be used in Malmo.

A problem in Sweden is the financing of trolley bus systems. A proposal to divert highway construction funds and thus make state grants possible for cities that wish to invest in trolley bus systems was recently rejected by the Swedish parliament.

However, the official policy of the National Swedish Environmental Protection Board is to promote development and new technology that contribute to the improvement of the environment, including the urban environment and the air pollution situation. The agency is discussing the use of some of its funds for the development of trolley bus systems in Sweden. A project has been initiated in Linkoping, which includes the conversion of three diesel bus lines to trolley bus.

CONCLUSION

From the environmental point of view, the possible introduction of trolley bus systems in larger cities would have important positive effects. Trolley buses provide an alternative to the conventional diesel bus. The use of electric traction in public transportation can contribute to policies that aim at the substitution of individual transportation with public transportation in urban areas--an important strategy for reducing air pollution in those areas. It is with this background that the transportation community has to evaluate the possible profitability of trolley bus systems.

The negative effects of trolley bus systems in the form of visual intrusion by the catenary have been debated for many years. In light of current knowledge about the environmental impact of diesel emissions, it might be expected that the significance of these negative aspects on the use of trolley buses in larger cities will be small when compared with the positive aspects of trolley buses in the eyes of a well-informed public.

Trolley Bus Operations

L.A. Lawrence

Edmonton is a city of interesting contrasts. A brief history of the city will aid in understanding how it came to be one of the select group of North American cities operating trolley coaches. As a place, Edmonton is senior to most U.S. and Canadian cities, having been founded in 1795 as a fur trading post. As a city, however, Edmonton belongs to the 20th century. In 1983 Edmonton Transit will be celebrating its 75th anniversary. The city skipped the horse-car and cable-car periods, but by the 1911 census it had a population of 30,479 who made use of 17 streetcars. The operation began under municipal ownership and has continued as a city department to this day. Although its history has included many ups and downs, the department avoided the damaging sequence of crisis after crisis that stifled long-range thinking in the privately owned public transit systems.

Edmonton's contrasts include geographical factors. Although it appears to be a typical prairie city in most respects, it has a deep river valley cutting through its center. This is at exactly the point where streetcars and the early motor buses would be most heavily loaded on lines linking residential areas with the central business district across the river. The inauguration of trolley coach service in 1939 introduced a route that tackled the big grades directly, eliminating the circuitous route used by streetcars.

Some of the cities represented at this conference also introduced trackless trolley operations in the 1930s and Edmonton's civic administration was impressed by these. A specific report on Portland influenced the decision on trolley coach service, according to Tom Schwartzkopf, who is coauthoring a book on Edmonton's trolleys. Despite the interest in U.S. systems, however, Edmonton still was a part of the British Empire and its initial trolley coaches were British.

During the war, the original trolley coaches and the American Mack and Pullmans, which supplemented them, proved to be reliable performers. Canada's own industrial strength was also growing. In the post-war period, replacement of the streetcars continued with the most successful series of trolley coaches ever built--the Canadian Car and Foundry Brill. In its post-war peak in 1964, Edmonton operated 100 trolley coaches. The last Brills ordered in 1954 were literally that, because no more trolley coaches were turned out by that firm.

During the 1950s and early 1960s, Edmontonians were preoccupied with the automobile. However because the city itself was growing, Edmonton Transit did not experience severe cutbacks. It gradually spread itself over the area with motor-bus feeder lines.

It is hard to put a label on the 1960s. Although that decade was full of crashing final curtains in the U.S. transit industry, the scene in Canada was mixed.

On the one hand, there were people who wanted to imitate the decisions being made in the United States. The new look diesel was on the streets in Edmonton, with the front that drivers loved, a back that equipment people loved, and passenger facilities tossed in as an afterthought.

But Canada was not the United States, and there was no Interstate freeway money to influence the city's decisionmaking process. Groups opposed to freeway construction carried more weight in that environment. Post-war immigration combined with Edmonton's position on the trans-polar air routes kept decisionmakers open to European influences. The development of integrated rail bus operations in Toronto and Cleveland interested transit officials. And the most important step was taken when the right men, ideas, and technology were brought together. In annexing the town of Jasper Place, Edmonton implied that it would offer that sprawling low-density suburb the same level of transit service enjoyed by city residents. How could that be done without great expense?

The timed transfer concept has been and will be discussed in other forums. I will be brief in describing what happened. An existing trolley coach route was extended to a terminal built beside the Jasper Place Town Hall. Motor-bus feeder routes were timed to meet both trolleys and each other. And in peak hours, the heaviest trips were extended to downtown as expresses. This put each bus mode into the range in which it could perform best. Trolleys covered the stop-and-go main line operation to lower the distributed capital cost of the electrical system. It fits our system's need to be a good neighbor in areas where main lines cut through residential areas and hospital grounds. Glenora, the most affluent inner-city residential neighborhood in Edmonton, is served quietly and efficiently by our main line to Jasper Place.

Diesel buses perform well in express operations, where their engines can run at a fairly constant speed. Their noise levels are not as severe a problem on routes served infrequently, or where late-night service and Sunday service are not offered. Feeder routes sometimes have the potential to use smaller buses as well, but traffic has grown on most of these lines to the point where the use of 40-ft buses is necessary.

The timed transfer concept has also allowed us to run a fairly simple system from the customer's standpoint. The traditional North American radial system often makes the outlying express route points difficult to reach from intermediate areas. This presents planners with a choice of adding stops to expresses, running expresses and locals over the same route, or just writing off the people who want to reach points in the part of the older city that falls between downtown and the suburbs. This area contains many trip generators, and in the concept employed in Edmonton, these points are accessible via transfer at the outlying transit centers. If it is necessary for an inner-city route to wander around in order to tap an industrial area, for example, it is not necessary for the residents of outlying areas to join its slow trip.

We see the trolley coach offering a part of our complete system. Its attributes give it a solid place on the main lines and in the most densely populated parts of Edmonton. We see it as a forerunner of light rail transit (LRT) service in these corridors. Trolley coaches will not be replaced by LRT lines, however, where local stopping services are necessary. In coordination with LRT, trolley coach operations will enable us to meet our 1984 goal of carrying 27 percent of our passengers with electric power.

FUTURE OF TROLLEY COACH OPERATIONS

Many people are aware of our 1973 decision to continue trolley operations. This was followed by the purchase of 37 Flyer E-800s, which used recycled electrical components from older buses. We went through a difficult period with those buses, and it took 3 years to get them all into service. At the same time, maintenance of the Brill fleet was curtailed in anticipation of their retirement. This caused us to stop and take stock of the situation.

The eventual result of this experience was our order for 100 Brown Boveri-equipped GMC trolley coaches. These buses were designed with input from all parts of Edmonton Transit, incorporating many features that were intended to overcome operator objections to the Flyers.

The feedback from operators and passengers is generally good. Chopper-controlled motors provide a smooth operation. Electric heat is great in the winter, and twin-roof vent hatches have kept interior temperatures comfortable in the summer. The appearance of a new-look bus with trolley poles did cause some double takes at first, but most Edmontonians do not realize that these vehicles are unique. They just want the service to function smoothly and with some comfort. Although it looks a bit racy, with the black bumpers, dark standee windows, and raised roof hatches, service is why they are standing out on those corners.

What are we offering the people standing on those corners? Trolley coach operation will expand to use the existing overhead again. From 1979 through 1981, the 37 Flyers turned up here and there, covering 88 runs that were scheduled as trolleys. We needed 100 to provide spares. By the end of 1982, we will have enough trolleys to cover every run. In addition, we have a backlog of minor overhead extensions that will require additional vehicles. One of these extensions is due to open in late 1982, and will extend our Route 3 through an industrial area from the apartment house district it now serves to the original Jasper Place Centre. This and the other extensions involve routes that are under trolley overhead a substantial part of the time.

We are working to upgrade the overhead. Our lines are constructed and maintained by Edmonton Power, the city-owned utility. During the period in which trolley coach operations were being curtailed, valuable skills were lost with personnel retirements, and many flaws developed in the overhead. Other problems were caused by the growth of traffic on city streets, and the growth in length of the buses themselves, with switches and some curves remaining in outdated locations. Perhaps the single step most appreciated by operating personnel and least noticed by the public was the switch to K&M elastic suspension overhead. Along with induction control switches, the new overhead system has been nicknamed speed wire by operators. Trolley coaches are controlled so that they cannot literally speed, but the time and inconvenience wasted on lost poles have been reduced.

As trolley operation becomes more common, we will also be working to upgrade the personnel operating them. We have a commercially made training film, based on the Flyer E-800, which gives beginning operators some background on the trolley coach system. We are working to develop better information on the condition of the overhead network. We are working to upgrade the service control on our system, so that disruptions are handled more easily. The overhead program includes some additional switches and short links to allow a variety of situations to be met. The best upgrading is already under way--that is, having a fleet big enough so that a run scheduled to have trolleys can be expected to have them assigned. Operators who want to drive trolley coaches will sign on those runs, and the experience level will improve.

We have examples of operators suddenly finding themselves in a trolley coach 2 or 3 years after their training period. This leads to sloppy or awkward operation and also prevents overhead problems from being promptly identified.

When the overhead extension projects are completed, we will be able to use all of our 137 trolley coaches. At that point, we expect to look at cost-comparison studies, our operating experience, and our ridership levels on other routes to determine any future expansion of the system. The system of diesel lines that we operate over the original Low Level Bridge trolley coach route is based on the criteria set in the 1973 Edmonton Transit study by Robert Clark and similar criteria developed by the San Francisco Municipal Railway's Carl Natvig in 1979. I would like to see continued extensions where traffic warrants them. In the mid-1980s, one of every six buses in Edmonton Transit's fleet will be a trolley coach. When I began work as a transit operator in the 1950s, trolleys formed the majority of our vehicles.

SOME OFT-HEARD WORDS

The trolley coach is inflexible! This is probably the number one chant. It means almost anything that the speaker cares to imply. Let us just imagine for a moment that the wires disappeared from Edmonton overnight. The next morning buses would still be making their way along the same heavily paved streets, stopping at the same shelters and concrete bus pads. Everything is running along, just slower, more noisily, and with a bit of smoke. But down the street a woman is coming. She lives in a little cul-de-sac area that faces an uphill walk to the bus. It is a quiet area, where people have been walking uphill since streetcar days. This morning is no exception, but something is different.

"The buses are flexible now!" she whispers to herself, as she skips back down the hill to call her Alderman with the suggestion that some, not all, of those frequent buses swing into her neighborhood. She is not greedy; she just wants a few trips. And how can her Alderman disagree? Out past the end of the line, a corporation is building a new office building. It is within walking distance of the former trolley line, but it would draw higher rental income if the bus went right to the door. Unfortunately, only some trips can be extended to the building because the others have had all their layovers soaked up going down into that woman's cul-de-sac.

Within a decade, bus operators will be walking out to their diesels carrying armloads of dash cards. Route brochures will be littered with fascinating footnotes. Special interest groups will be temporarily pleased, but operating costs will climb as buses roll through back lanes and driveways looking for passengers. Additional street paving will be required, and the shelters will have to be moved around.

The most important consideration is the effects on patronage. The passenger from outlying areas will find the circuitous routing past the new office building or past the woman's house unattractive. They will either quit riding or demand direct operation of their feeder routes to downtown. Either revenue will be lost or operating costs will go up. Flexibility has a price, which system after system in North America has paid without realizing it.

The routes on which trolley coaches are operated are main lines where the travel desire has remained constant over a long period. This allows the full use of the capital investment involved, and, in turn, the capital invested acts as a balancing factor to offset short-term action. If necessary, detours can be arranged for major construction projects, and in Edmonton most major projects occur during summer months when there is a surplus of diesels from university-oriented routes.

Breakdowns present a more serious case for the use of the term inflexibility. Breakdowns that affect the power supply will affect any number of buses, whereas diesel buses fail individually. The detailed study done for Edmonton Transit by Robert Clark in 1973 showed less than one power breakdown per 100,000 miles operated on a system using many recycled components.

The restoration of trolley operation in the last few months has been accompanied by several overhead problems, likely a result of long periods of inactivity. As work continues on the power system we expect those problems to recede.

We do have difficulties with overloaded trucks. Edmonton is the base for shipping into the northern territories and the economic boom brought marginal companies and marginal drivers into the trucking industry. We take action to recover costs from these firms, but as long as truckers are romanticized as bold men of action we will have to deal with the occasional irresponsible operator.

The overheight truck is a universal phenomenon, however. A colleague of mine has noticed scarred traffic lights and pedestrian overpasses in our sister city of Calgary, which has no trolley bus operations.

When we were making a study of new buses we considered battery or auxiliary gasoline-engine operation. However, examination of the weight penalty and cost that we would incur for the few occasions where this would be a factor led to the conclusion that we were better off without the auxiliary power. Dwelling on inflexibility in breakdown or detour situations stems from looking at a few specific incidents rather than at the overall picture.

The lack of short-term flexibility does require extra work in operations, but it appears also to offer higher patronage levels. Patrons have a sickening feeling when they discover they have been left standing at a bus stop that has been bypassed due to a detour, or worse yet, left standing by an operator who decided to save some time by cutting off part of the route.

Trolley coach operation requires team work to overcome the other problem that hides under the inflexibility label. There is a tendency of diesel bus operators to regard themselves as being their own little transit system. Time and time again I have heard senior men talking about the feeling of teamwork and cooperation that they experienced with fellow operators, which included working together to share a load when traffic disrupted service, courtesies to each other in traffic, and sharing information about almost anything. Railway operations demand this relationship. Without it, customers quickly turn away. Motor-bus operations should involve the same cooperation, but a feeling of anonymity appears to strike some people when they sense that diesel engine revving up. Yes, they can now pass another bus, and they will from time to time. But too often, the passing comes after the lead bus in a jam has collected all the passengers. Block traffic to let another bus out of a side street? With that diesel engine finally wound up it is awfully hard to come back down to earth. Instructors say to take it easy on curves? The slower the diesel driver takes the curves, the harder it is to get going again, so passengers better learn to hang tight. I am talking about a minority of operators here, but it can affect everyone. If anyone doubts that this is true, consider the style of small suburban lines that sprang up as all-motor-bus operations.

Does that style of operation meet customer needs? It may take care of some immediate problems at best, but it leads to a gnawing uncertainty about the dependability of transit service and the quality of people who operate it. On the other hand, the trolley system introduces a clear requirement for team work, just as rail operation does. The operator is literally wired into the system, and can drop out if necessary, but cannot operate with disregard for others.

Instead of seeing the trolley coach as an obstacle to a self-centered form of transit operation that has come to be the norm, in the process of meeting trolley system requirements we can attain and develop that sense of shared purpose recalled by the older operators. We cannot do this without also keeping in mind the reasons for operating trolley coaches--foremost among them the passenger on that corner. Imagine that it is not August but January. Imagine that it is 20°, 30°, or 40° below zero on either temperature scale. You are standing in a bus shelter and it does not matter what time it is, because it is dark most of the time in January. Within a minute or two you hear a faint laser sound twanging over the wires and then the crunching sound of braking tires on frozen roadway. Climb inside an Edmonton Transit bus that is big and warm and friendly and you are on your way directly to a thousand places, smoothly and quietly. A Hollywood director would have to shoot over and over again to achieve that effect. We are expected to do that successfully every day, and with teamwork in the operations section and cooperation from other sections and departments we can do it.

ACKNOWLEDGMENT

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The Trolley Bus and System Design

Thomas G. Matoff

After more than 20 years of neglect and decline in North America, the trolley bus has begun to enjoy a modest renaissance. The abandonment and dismemberment of existing systems in the United States and Canada have stopped. Almost a decade has now passed without serious erosion of North American trolley bus system mileage from the Chicago and Calgary abandonments of 1973 and 1975, respectively. Defying the trend to dieselization, the remaining nine U.S. and Canadian systems have replaced their post-World War II (or even pre-World War II) equipment with contemporary rolling stock. Toronto and San Francisco have seen actual extensions of their systems take place. In Seattle, much of the system abandoned in the 1960s has been replaced, augmented by the electrification of some streets that never had trolley service. Foreign manufacturers, UMTA, and TRB are showing a fresh interest in the trolley bus. This phenomenon is not restricted to North America. Renewal is occurring in countries where trolley bus systems have traditionally been widespread--Czechoslovakia and Italy in Europe, for example. System developments have occurred recently in Latin America, and, of course, an immense number operate in the U.S.S.R. and China. New rolling stock is being developed and acquired in many countries, and system extensions are being made.

A QUESTION OF SIGNIFICANCE

Gratifying though the recent surge of trolley bus activity and renewal may be to those with an interest in the subject, it is important to view the mode--and its renaissance--in perspective. When one focuses on Toronto's Bay Street, San Francisco's Sacramento Street, or Seattle's Rainier Avenue electrifications, it is easy to imagine that trolley installation is on the rise everywhere in North America. The reality is that, on an industrywide scale, the trolley bus is not at present significant. In the United States, 98 percent of the 1,000 or so transit systems counted by the American Public Transit Association (APTA) are 100 percent motor-bus operated, primarily with diesel buses. Only the well-known and celebrated five systems in the United States (Seattle, San Francisco, Dayton, Philadelphia, and Boston) operate trolleys. APTA figures indicate that only slightly more than 1 percent of all originating transit passenger trips in the United States is taken on trolley buses. Total U.S. trolley bus ridership, therefore, is somewhat less than the annual fluctuation alone in overall transit patronage (1).

It has not always been this way, of course. In the early 1950s the trolley bus could truly have been said to be on its way to real significance in North America. In 1951 trolley buses represented 11 percent of the entire North American bus fleet, having just emerged from a period of remarkable growth. From 1947 through 1951 the U.S. motor coach fleet remained static in size (increasing 1.3 percent in this period) despite the delivery of several thousand coaches per year. On the other hand, the trolley bus fleet increased by 50 percent in the same period largely at the expense of the streetcar. The trolley's particular niche appeared to be in the medium and medium-to-small range of cities. Forty percent of all trolleys ran in cities of 250,000 to 500,000 population, and these accounted for more than one-fourth of the buses operating in cities of that size. Even in cities with a population of 500,000 to 1,000,000, trolleys represented 16 percent of all buses in operation. By 1950, 15 percent of all U.S. bus transit trips was trolley trips (2).

Today, in the entire United States, only one or less of the approximately 500 transit systems operating in cities of 500,000 population operates vehicles other than motor buses; indeed, Dayton's Miami Valley Regional Transit Authority can truly be said to be unique. The tenacity of the other four U.S. trolley bus systems can be attributed largely, if not completely, to special circumstances. Certainly, topography and cheap power played an important role in Seattle and San Francisco, as did MBTA's Harvard Square subway in Cambridge. In Philadelphia, a pro-electric city policy led to retention of trolleys, albeit as a by-product of electric rail operations. But everywhere else in this country, the trolley bus has not reappeared on any of the dozens of systems it served 30 years ago. There has not yet been a single case in the United States or Canada since the 1950s where trolley buses have been introduced on a system that had completely abandoned them, or installed on a system that had never before benefited from their presence. Surely, if the mode is to be regarded as significant in national transit terms, much more must be accomplished in the way of electrification.

A reestablishment of the 11 percent fleet share of the early 1950s could be said to be a reasonable benchmark of significance. At today's level of national transit development, in itself perhaps not all that sufficient, this would mean something on the order of 6,600 coaches in operation in the United States alone, an eightfold increase. It would mean electrification on a vast scale, not just for unusual cities where topography or tunnel operation or cheap power makes trolleys especially attractive.

CAPITAL COST: MAJOR OBSTACLE

There appears to be widespread agreement that it is the high initial capital cost of a trolley bus installation that provides the major obstacle to greater use of the mode in North America. As UMTA's Electric Trolley Bus Feasibility Study emphasized, "Cost is by far the most significant barrier to trolley coach expansion" (3). Particularly in the case of the great majority of potential trolley bus systems, where unusual circumstances or policies do not exist, it is fundamentally the economic considerations that will govern consideration of trolley bus operations. The environmental advantages of the trolley and its ability to use alternative sources of power generation will probably not be sufficient in themselves to compel transit managements to embrace the mode in the face of significantly greater net costs. Only if the overall capital and operating costs are approximately equal to or lower than that of diesel operation is it likely that more transit systems in North America will feel justified in undertaking electrification projects. If the question of modal significance of the trolley bus is a question of expanded use, and if expansion is basically one of economics, it should be apparent that an enhanced role for the trolley bus in North America is largely dependent on setting the economic stage. The environmental benefits of the trolley bus represent a real public good, but they will in all likelihood have to be realized in most cases, particularly in view of the continuing high cost of capital, as the by-product of a fundamentally economic decision.

Many factors influence the capital cost of a trolley bus overhead installation, including the type of hardware and installation specified, the availability of existing support poles, the availability of existing power distribution facilities, the degree of utility relocation required, and the general complexity of the installation. An illustrative range of $0.5 to $1.0 million per mile of two-way (double track) overhead, plus substations, can be taken as representative. As noted earlier in this paper, average per-mile estimates in Portland for a four-line, 25 route-mile system range from $650,000 to $1,200,000 depending on the supplier and the degree of pessimism in construction assumptions (4). The Portland installation would include a reasonable amount of special work, new substations, and some utility relocation, and might be considered representative of the cost of installing a new overhead system of modest size in an average U.S. city. Complex trolley installations in high-cost cities under difficult circumstances, of course, can produce much higher costs. The San Francisco Municipal Railway's recent Sacramento Street electrification, for example, cost about $8 million for a 3 route-mile installation (5).

Another capital cost consideration is the price tag for rolling stock. The UMTA feasibility study's market analysis noted that trolley buses tend to have an initial cost on the order of 50 percent more than a comparable motor bus. However, when viewed in the context of a life-cycle costing analysis, the considerably greater life of the trolley bus in comparison with the diesel easily offsets its additional expense. Consequently, although it is obviously a factor in managerial decisionmaking, the capital cost of rolling stock can be considered to be generally favorable to an electrification decision.

Reduced operating expenditures are also among the benefits that can be expected from electrification. The operating cost differential between diesel and trolley buses is, and for some years has been, a hotly debated topic. It is not the intention of this paper to enter into that particular debate. However, it appears that once the infrastructure is in place, all other things being equal, trolley bus operating costs are slightly lower than diesel bus operating costs on the same line, perhaps on the order of 5 to 10 percent, provided that power costs are not extraordinarily unfavorable. In the Portland analysis discussed below, a 7 percent annual operating saving over diesel operation was estimated. Based on the 1985 opening of a four-line starter system using articulated vehicles, savings were calculated to be $398,000/year for 1,969,704 platform miles, or approximately 20 cents/mile (6).

A lot of longer-lived trolley buses and many more vehicle miles have to be run at a saving of perhaps 15 to 20 cents/mile to justify, on solely economic grounds, a capital investment of $0.5 to $1.0 million/mile. This is particularly true when capital itself costs 11 to 12 percent, even at municipal bond rates. Of course, other justifications for such an investment can be made; but judging from the status of the trolley bus in North America, it does not appear that these other reasons are overwhelming in most communities.

Transit systems are not rushing in droves to electrify their lines. Some of the general lack of transit industry enthusiasm can probably be put down to blind prejudice, but there can be little question that few systems have, on the basis of their current route structures, the density of service on a single route to justify electrification on economic grounds. UMTA suggested a "minimum service density requirement of 120 or 140 two-way vehicle trips per weekday." The 140-trip figure, or 70 round trips per day, is based on a theoretical service level of 10 min during the peak, 15 min during the base period, and 30 min at night. A 15-min base level of service is not all that intensive; yet, there are not many transit systems in the United States whose lines are characterized by service of that type. Certainly, there are not many in the medium-sized cities that were the trolley's stronghold 30 years ago. Even that level may not justify electrification on a solely economic basis. The UMTA analysis adds: "It appears unlikely that there are a significant number of routes and locations where trolley coaches can be justified on purely economic grounds. Thus, the minimum density level becomes a subjective decision point that is based on an implied value of environmental factors and the potential for use of energy sources other than diesel fuel."

Environmental factors and energy flexibility do have a real economic value, and transit management should take them into account in making investment decisions. However, under the stringent economic conditions that prevail in the industry today and are likely to continue, it appears unlikely that transit management can give significant weight to non-economic or, perhaps more correctly, external economic criteria in reaching investment decisions. The fate of the trolley bus--i.e., the degree to which it becomes once again a significant transit mode in North America--will depend on the degree to which it can be made a more economic choice than it largely is at present. To a great extent, this will depend on an intensification of service levels per unit of infrastructure (e.g., annual vehicle miles per route mile or daily trips). This, in turn, will depend on the structuring of the routes and service networks on which trolley operation is being considered. Without a structuring of routes to maximize service densities, it is unlikely that the pre-conditions for electrification can be met. Economically speaking, the trolley bus will not even be in the ballpark, and it will likely remain, even if fascinating and environmentally desirable, a rather insignificant transit oddity.

CREATING SERVICE DENSITY

An unfortunate service design policy appears to govern the provision of transit service to the central business districts (CBDs) of American cities. Even though the highest densities of urban development are generally found in the traditional central business district, the CBD accounts for a relatively small and often declining percentage of total regional trips (7). In order to serve this one focal point of activity, transit systems usually operate many routes, often of historic derivation, directly from surrounding areas to the CBD. The design principle relied on is ostensibly the maximization of patronage by provision of no-transfer service between the CBD and as many parts of its catchment area as possible. This strategy is intended to result in maximum patronage density on the transit lines in operation. The result, however, is often the opposite. The downtown market for public transportation, itself declining relatively or even absolutely, is split among many routes. The result is that, with the exception of quite densely populated cities, patronage is not very heavy on any one route. As a consequence, the service is not very intensive. Certainly, patronage is lower than it would be if it were concentrated on fewer routes. This is not to deny that there are in many instances routes with good service to downtown, particularly during the rush hour. However, rush-hour service also cannot provide sufficient daily bus trips to economically justify intensive capital structure development of the type required for electrification. Typical off-peak service--midday, evenings, and weekends--generally is too low to result in justification of this kind.

Furthermore, because most of the service is oriented to the CBD, little is designed to meet other transportation needs in the region, which may represent 90 percent of all the person-trips being made. As a consequence, the transit share of this large market is minuscule, often less than 5 percent. Portland's Tri-Met offers a typical example. In a city that Sunset magazine trumpeted as having "the best transit system of any city its size," Tri-Met has a 30 percent weekday modal split to downtown. Downtown Portland, however, attracts or produces fewer than 10 percent of the total weekday person-trips made in the metropolitan area. Of the other 90 percent of the trips, approximately 1 percent is made by transit. The net modal split is thus only about 4 percent (8).

This situation can also be viewed in reverse in the context of systems that have frequent service on downtown routes throughout the day. This can occur in cities where not all routes tapping a CBD's hinterland run directly downtown. In these cases, principal focal points such as the CBD are served by fewer routes carrying not only passengers generated along the routes themselves, but also passengers transferring from routes serving other parts of the urban area. The literature on transit network design and effectiveness has not always dealt with practical transit design strategies. However, some recent work has begun to lead to the conclusion that there are two fundamental systems, or transit system design strategies, that can be used more effectively to exploit both the downtown market and, in addition, the much larger market for potential transit use that exists with non-downtown trips. These two techniques are the timed transfer focal point system and the grid system.

Briefly, the timed transfer focal point system is one in which local routes serving neighborhoods in outlying areas focus on transit centers. These transit centers are linked with the CBD, and with one another, by trunk lines. Trunk line buses, and the buses serving local feeder routes, going in both directions on all lines, are scheduled to meet at the transit centers so that easy, quick, and predictable transfers can be made by passengers coming from any line and going to any other line in any direction. As a result, routes serve two purposes: (a) a local access function to the transit center, ideally located at an outlying activity center such as a shopping center or local business district, and (b) a feeder function to trunk routes serving the downtown. A main characteristic of a timed transfer focal point network is the concentration of downtown patronage on relatively few routes.

The grid system has similar properties. Classically, the grid consists of a network of east-west and north-south routes that are operated frequently. Passengers can travel between any two points on the system over a fairly direct path of travel, using lines that operate frequently and generally with no more than one transfer. Once again, the orientation of routes in non-downtown directions, performing instead a crosstown function in and between non-downtown areas, results in fewer routes going directly to the CBD. But because the CBD is usually the most intensively developed part of the urban area, it generates more ridership, and this patronage is concentrated on fewer routes. The routes can be operated more intensively.

The timed transfer focal point system is generally appropriate in suburban or low-density situations where base period service with headways of 15 min or less on most routes is not feasible. The grid network, which is based on the concept of random transferring and short headways, offers a high standard of service, but is only economically feasible in higher-density areas where many lines operating at 10- to 15-min base headways or less are justified (9). In either case, the principal characteristic of these techniques is diversification of public transportation to make it more useful for the majority of trips being made in contemporary American metropolitan areas--the non-downtown trips. This is done by deliberately not running all routes downtown. But, paradoxically, these techniques also result in fewer, well-served routes going to the CBD (10).

A usual objection to systems of this type made by the public and often agreed to by transit management is that it requires many people to transfer for downtown trips. This objection is raised even though such transfers would be between routes having scheduled transfer coordination at transit centers specifically designed for them, in the case of the timed transfer system, or between routes that are frequently operated, in the case of the grid system. The necessity of making passengers transfer between two routes, particularly where at present there is a direct route to the CBD, appears to scare away transit management. There is a great fear that the introduction of the transfer will result in passenger complaints and loss of patronage and that transferring is inherently evil.

Fortunately, there is a growing body of material available that indicates that properly designed transfers can be a positive element in system design. Transit systems based on the timed transfer principle, e.g., in Edmonton, in suburban Vancouver, and in the western suburbs of Portland, have proved to be remarkably successful. In these cases, the introduction of transfers has not inhibited the growth of transit ridership. To the contrary, the enhanced connectivity of the transit network and the increase in the number of potential destinations inherent in such a system have increased transit ridership. In the case of suburban Coquitlam, for example, east of Vancouver, British Columbia, a per capita ridership of approximately 45 riders per year was achieved within 3 months of startup of the system, even though for most passengers transferring was required (11). This level of transit use is similar to that found in some large American cities, but was achieved in a low-density suburban environment. In Edmonton, the timed transfer system has been the basis for a successful development of the entire city transit system. In the case of the Westside network in suburban Portland, the introduction of a timed transfer system, together with an improvement of service, resulted in a 40 percent increase in ridership within 1 year of startup. This can be contrasted with the 8 percent ridership growth that occurred outside the affected area (12).

In a similar manner, the operation of a grid network of frequently operated routes makes possible a desirable level of service to many possible destinations, resulting in a relatively high level of ridership. Far from being a barrier to transit ridership, the design of systems to enhance transfers, to make transfers possible, is a positive attribute. If transfers inhibit patronage, one would expect systems that require transferring to have low patronage. Although, of course, many variables are at work, it has been observed by Weisman that a positive, if modest, correlation exists between per capita ridership and the transfer ratio or percentage of all initial passengers who go on to transfer (13). Obviously, the introduction of unnecessary transfers is not desirable. However, it is fairly clear that systems designed to provide a service that is attractive for non-downtown trips, either through the timed transfer system or through the introduction of a grid route structure and crosstown service, will have higher patronage and will also have higher transfer ratios.

A result of the introduction of the multidestinational system is the creation of a higher level of service on fewer routes serving the CBD, and this higher level of service can justify capital development--either for rail service or for trolley bus systems. The fact that network orientation and capital development are intimately linked has been pointed out in a number of studies. Bakker, for example, makes this point in Advantages and Experiences of Timed Transfers (14). Thompson (15) points out the same thing in Planning Considerations for Alternative Transit Route Structure: "All transit-level travel to the downtown from the entire metropolitan area, therefore, is limited to this small number of routes. As a result extremely heavy passenger loads may occur on them and they may have to be highly developed in order to cope with the patronage thrust on them. The patronage may easily be of sufficient magnitude to warrant conversion to rail"--or, one might add, to trolley buses.

Analyses of the potential electrification of diesel routes are frequently made in terms of a more or less existing route structure. This was the case, for example, with the analysis of trolley buses conducted on the Tri-Met system in 1976. However, in light of the favorable system results of the grid and timed transfer focal point concepts, it appears that the trunking characteristics inherent in such concepts could more easily lead to the level of service that would justify electrification. If the advantages of trolley coach operation are seen to be desirable by a transit system, then it should also be desirable to reorient the system in such a way as to accomplish multidestination transportation objectives and at the same time set the stage for electrification. The UMTA State of the Art study hints at this (16). Configurations of routes involving branches that are only very lightly served are suggested for modification in order to bring the lines, as a whole, into the density required for trolley bus operation. However, instead of considering the trolley on an individual basis, it would probably be more productive to consider the introduction of the trolley bus as a part of a reorientation of the overall route structure. In this way, not only are trunklines created that justify electrification, but also systems are developed that can attract more patronage as a whole.

TROLLEY BUSES FOR PORTLAND: THE CASE OF TRI-MET

The Tri-County Metropolitan Transportation District of Oregon (Tri-Met) is the agency that provides public transportation service in and around the Portland metropolitan area. The system operates approximately 625 diesel buses, of which 87 are articulated. It provides service over an area of approximately 1,000 miles in Multnomah, Clackamas, and Washington counties in Oregon. It provides approximately 5,700 hr of platform service per weekday and some 22 million miles of service per year.

Historically, Portland had a moderate-sized trolley bus system consisting of 10 of the principal city routes, requiring at peak strength 191 trolleys for operation. The zenith of the trolley bus system was reached in the early 1950s; the entire transit system declined thereafter and electric operations ended in 1958. Tri-Met was formed in 1969 in order to take over the operations of the faltering Rose City Transit Company that had operated the trolley bus system in its final years, which then carried on with motor coaches alone.

Tri-Met embarked on a program of service improvement and extensive building of patronage, largely through education of the public concerning fares, expansion of service, and diesel fleet modernization. This strategy was generally successful in meeting its objective. Tri-Met was able, in the next 10 years, to almost triple patronage, so that, in comparison with the approximately 15 million passengers carried in 1969-1970, by 1982 approximately 42 million passengers were being carried annually. It was in the context of this improvement of service and growth of the system that the issue of a new trolley bus system began to be raised. In part, the issue arose because of the strong environmental awareness in Oregon, in part because of the specific interests of a number of citizen groups. The call was heard for the introduction of electrified service on at least some of Tri-Met's principal urban lines. At the same time, Tri-Met was also embarking on analyses of possible regional, light rail lines, so that, far from being contrary to the direction of system development that had been established, trolley buses were viewed as a possible complement to a light rail operation (17).

An early staff report, which looked at trolley buses in a general way in 1973, reported favorably on the possible introduction of this mode to the Tri-Met system. Subsequently, in 1976, largely as a result of citizen pressure on the district to pursue a possible electrification strategy, a more detailed study was conducted for Tri-Met by DeLeuw Cather and Company. This evaluation study specifically examined electrification of four lines (Sandy Boulevard, Hawthorne-Foster, 23rd Avenue, and Jackson Park) and rather thoroughly looked into the economic, operational, and environmental issues related to possible trolley operation. At that time, Tri-Met was 5 or 6 years into its program for developing patronage and improving service, but had not yet committed itself to a program of network restructuring. A profusion of duplicative routes and compound branches was in operation. As a result, service on the individual city routes was not very young. Although environmental advantages were real and the operating costs of the coaches themselves were lower, the study concluded that the introduction of trolley buses would have resulted in net additional capital and operating costs of \$1.0 to \$2.5 million/year over the cost of diesel operation. The trolley bus issue was put aside for the moment, and the district's energies focused on light rail evaluation and bus system expansion.

In the meantime, restructuring and growth continued on the city system. Gradual rationalization of the historically evolved city network began, and trunk development started. In 1979 and 1980, as part of the preparation of Tri-Met's first 5-year transit development program (TDP), another general staff analysis of trolley bus introduction was conducted. The TDP analysis indicated that for a five-line starter system, annualized operating costs could range from \$183,000 more to \$134,000 less than an equivalent diesel bus system. However, the total annualized capital costs would range from \$400,000 to \$800,000. It was pointed out that, conceived from Tri-Met's own point of view, the potential operating savings might offset the local match for construction. In this case, then, for the first time, specific calculation of costs and benefits of operation led to a favorable staff response. Further work would be needed, though, in order to come to a firmer conclusion. In the 1980-1982 period, significant staff effort went into the redesign of the entire city bus system serving Northwest, North, and Eastside Portland to form what is essentially a grid route structure, concentrating service on trunk routes serving downtown Portland. The final version of these improvements was adopted by the Tri-Met Board in May 1982, with introduction of service scheduled for September 5, 1982.

It is at this point that the most recent analysis of electrification possibilities took place. It is useful to look at the transit development milestones in the Portland region that were reached in the late 1970s in order to understand the context of the current trolley bus project in Portland. To begin with, it was in this period that Tri-Met and the Portland region resolved to undertake the first of a series of regional light rail transit lines--the 15-mile Banfield line connecting Portland with East Multnomah County and the city of Gresham. The regional commitment to such a strategy and the availability of interstate transfer funds have led to the reintroduction of electrified transit service to Portland after a lapse of some 25 years. The line is now under construction. In the sphere of network development, Tri-Met moved into a deliberately planned multidimensional strategy with the inauguration in June 1979 of a timed-transfer service based on Canadian models of Edmonton and Vancouver. This strategy, which establishes outlying transit centers on the Westside suburban network at Beaverton and Cedar Hills, led to the trunking of transit routes between those transit centers and downtown Portland, and has been an outstanding success in terms of patronage development. That success encouraged the agency to go ahead with the development of a grid network in Portland involving not only the addition of bus hours and the creation of new crosstown routes, but also the discontinuance of many of the weaker secondary radial services, which were descendants of lines that, in some cases, had been in operation for many years. Remaining downtown routes are, in the main, being given a much more intensive level of service, not only making it possible for people to transfer on a random basis between urban trunk and crosstown routes, but also setting the stage for effective capital investment in modes other than the diesel bus (see Figures 1 and 2).

The 1976 evaluation looked at four lines of approximately 54.9 wire-miles. At that time, these lines required 1,044,500 annual revenue bus-miles using standard coaches, so that the number of annual trips per route mile was approximately 19,026. On a daily basis, using 300 as an annualizing figure for weekday service, this would represent 63 trips in each direction per day or approximately 126 trips total per day. Thus, the 1976 evaluation, even though it was performed on what were at that time the heaviest lines in the system, could produce only 128 trips/day per two-way route mile of trolley system. This was at the lower end of what was later developed in the UMTA Feasibility Study as the range for potential electrification.

By comparison, the 1982 evaluation, looking forward to 1985, similarly looks at a system of 55.9 wire-miles but an annual revenue mileage figure of 1,758,537 vehicle-miles. This is the equivalent of 31,458 annual trips/mile or approximately 105 trips/one-way mile, or 210 trips/double-track system/year. In comparison with the 1976 figure, this is approximately two-thirds again as dense a system as was evaluated only 6 years ago. Comparing this with the UMTA figure, the transit improvement program embarked on by Tri-Met has set the stage for potential trolley bus application. However, the post-1982 projections are based on the use of articulated coaches. If this is compared with the standard coaches in the 1976 study, it would be necessary to compensate by an additional capacity factor of 40 to 50 percent over the capacity for an equivalent num-

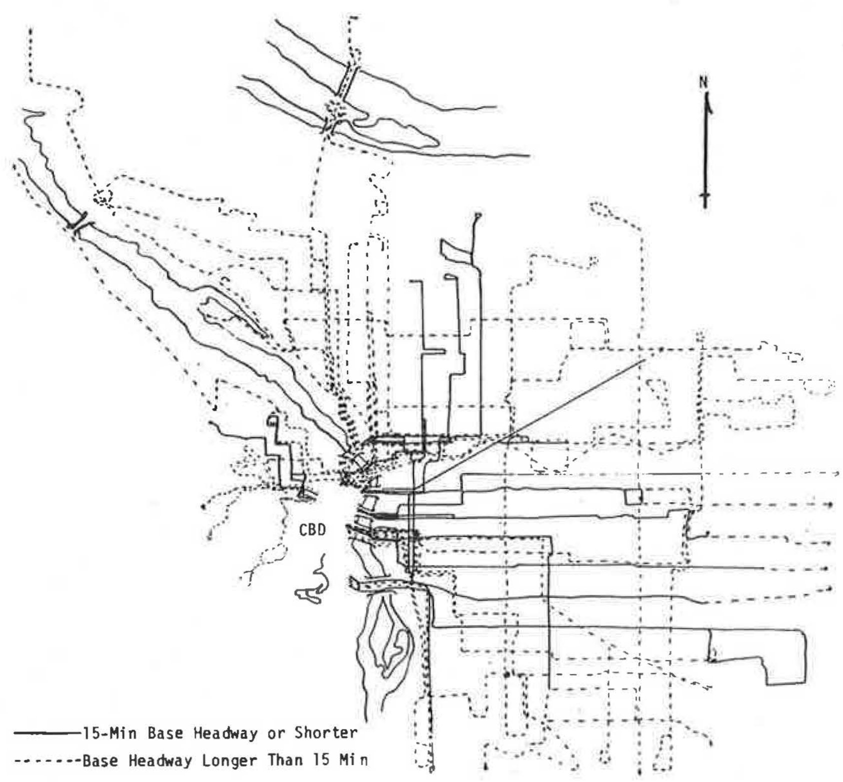


Figure 1. Tri-Met: Portland city transit routes, Spring 1982.

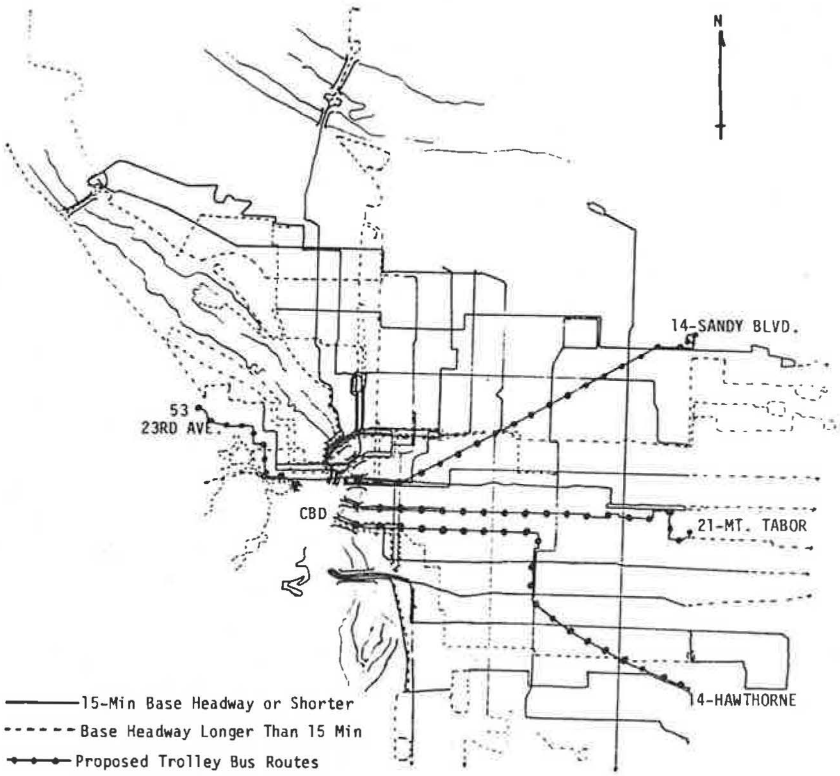


Figure 2. Tri-Met: Portland city transit routes, Fall 1982.

ber of standard buses. In terms of scheduled capacity, this means that the post-1985 trunk route system is 2.3 times as densely served as was the system of 1976. It is this density of service, created by the network restructuring program, that makes it possible to consider favorably for the first time the electrification of major urban routes in the Tri-Met system. (As a final note, it should be recognized that the 1976 system included branches and off-lying loops for many of the trips and that the number of trips operated over the common section of route was diluted on the other sections of lines where branches existed. Under the 1982 system and beyond, all branches and off-lying loops have been eliminated and the full intensity of service is operated over the full length of line.)

The result of the Tri-Met feasibility study is that under moderate to pessimistic assumptions, on a life-cycle costing basis, the trolley bus approach to operation of these four lines will be no more expensive from an overall economic point of view (capital plus operating cost) than the operation of diesel articulated buses on these four lines, offering a comparable level of service. Under moderate to optimistic assumptions, there would be a slight saving in total cost. Looking at the question from the point of view of Tri-Met as the operator, the opportunity to substitute federal capital funds for local operating costs could be a temptation almost too overwhelming to resist (17).

A word about articulated trolley bus operation in Portland is in order at this point. The trolley bus is usually identified as a potential candidate for densely operated inner-city routes characterized by frequent stops and starts, heavy passenger loadings, and a high rate of passenger turnover. It is on densely operated service that articulated buses can be used to maximize the productivity of labor without sacrificing attractive service frequencies. The through-routed 14-Sandy Boulevard/Hawthorne Boulevard line, even with articulated coach operation, will offer frequent rush-hour service, 12-min weekday bus service, and 15-min service on nights and weekends.

At the same time that Tri-Met is reorganizing its urban route structure, it is adopting European self-service fare-collection techniques that permit passenger loading and unloading at all doors. In the case of the articulated diesel coach, which will be phased into operation before electrification, this will mean three double-width doors. At the time this paper was prepared, the service was not yet in operation; however, it is expected that with a great number of passengers either using transfers, prepaid tickets, or passes (the system is already nearing the 50 percent passenger usage rate for passes), dwell times on heavy urban lines should be minimized, and the ubiquitous passenger on-and-off movement will be handled without unduly sacrificing overall schedule speed and performance. Under these circumstances, Tri-Met believes that the trolley bus could offer the optimum in operating efficiency for medium- to heavy-density urban lines operating on surface streets. The key elements in efficient operation are high-capacity trolley coach operation, the ability to take advantage of an investment in electric infrastructure by maximizing service densities, and the use of self-service fare-collection techniques to maximize efficiency and economy of operation.

SUMMARY

This paper views the design of the transit network as the basis for successful introduction of trolley coach operation in most American cities. There will always be cases where steep hills, tunnels, or other unique circumstances will make trolley buses a favored mode. However, these circumstances alone do not lead to significant use of the trolley bus in overall U.S. transit operations. A more universal application of the trolley bus appears to require a level of operation denser than is found on typical American transit systems. American systems can be redesigned to maximize operating service densities and bring the level of operation into the sphere of economic consideration of trolley bus application. If properly done, through the use of either timed transfer focal point or grid network techniques, urban trunk routes can be developed that will be strong enough to justify electrification without economic grounds, or at least to permit the consideration of electrification without economic penalty. Further refinements to optimize trunkline economies could include articulated trolley bus deployment and adoption of self-service fare-collection techniques. Such a combination of techniques is now being pursued as a transit development strategy by Tri-Met.

REFERENCES

1. Transit Fact Book. American Public Transit Association, Washington, DC, 1981, p. 40, Table 1.
2. Transit Fact Book. American Public Transit Association, Washington, DC, 1981, p. 14, Tables 18 and 19.
3. Chase, Rosen, and Wallace, Inc. The Trolley Coach: Potential Market, Capital and Operating Costs, Impacts and Barriers (Electric Trolley Bus Feasibility Study Task 2 Report). UMTA, June 1980, p. 59.
4. Tri-Met Transit Development Department Trolley Bus Project, Technical Memorandum 16: Capital Cost Estimates. Tri-Met, Portland, OR, July 1982, p. 12.
5. Interview with Carl Natvig, San Francisco Municipal Railway Planning Division.
6. Tri-Met Transit Development Department Trolley Bus Project, Technical Memorandum: Operating Costs. Tri-Met, Portland, OR, June 1982, Table 5, p. 9.
7. J.R. Meyer, J.F. Kain, and M. Wohl. The Urban Transportation Problem. Harvard Univ. Press, Cambridge, MA, 1965, pp. 35-39, 84-87.
8. Summary of the Regional Transportation Plan: Draft Two. Metropolitan Service District, Portland, OR, Aug. 1980, pp. I-39, I-40, I-45.
9. B.E. Sullivan. The Timed Transfer Focal Point: A Refinement in Public Transport Service Design. UITP Revue, Vol. 25, No. 1, 1976, pp. 43-48.
10. J.B. Schneider and others. Planning and Designing a Transit Center-Based Transit System: Guidelines and Examples from Case Studies in 22 Cities. UMTA, Sept. 1980, pp. 19 and 29.
11. The Impact of New Bus Services in the Coquitlam Area. British Columbia Bureau of Transit Services, Vancouver, Oct. 1974, p. 3.
12. M. Kyte, K. Stanley, and E. Gleason. Planning, Implementation, and Evaluation of a Timed-Transfer System in Portland, Oregon's Suburban Westside. Tri-Met Service Planning Department, Portland, OR, Jan. 1982.
13. M. Weisman. Variables Influencing Transit Use. Traffic Quarterly, Vol. 35, No. 3, July 1981, p. 381.
14. J.J. Bakker. Advantages and Experiences with Timed Transfers. Presented at TRB Annual Meeting, Jan. 1981, p. 89.
15. G.L. Thompson. Planning Considerations for Alternative Transit Route Structures. AIP Journal, Vol. 43, No. 2, April 1977, p. 165.
16. Chase, Rosen, and Wallace, Inc. The Trolley Coach: Development and State of the Art (Electric Trolley Bus Feasibility Study Task 1 Report). UMTA, Oct. 1979, p. 220.
17. Trolley Bus Project--Phase I, Summary Report and Staff Recommendations. Tri-Met Transit Development Department, Portland, OR, July 1982, pp. 18-21.

CHAPTER 5

Vehicles and Propulsion Systems

With some exceptions, trolley buses in the United States and Canada have been completely dependent on external electricity. But in Europe the practice has been to provide some form of auxiliary drive system. European trolley buses built before 1970 usually had a battery-powered auxiliary drive, adequate for maneuvering within the garage or moving out of an intersection in case of power failure. Speed was a walking pace, and the battery would be exhausted after only 100 yards or so. The new trolley buses built for the Vancouver system have such an auxiliary drive unit. A system that uses a chopper to convert the battery power to a higher voltage and thus obtain greater speed will be tested in Dayton as noted earlier.

Most European trolley buses made in the last decade use a small gasoline-engine generator. Small diesel engines are also used, notably in the newer French trolley buses that have an air-cooled unit rated at about 60 kW. The greater power and the durability of the diesel enable these buses to be used for some regular off-wire service.

Without these special provisions, trolley buses can only operate on power from electrification. Because the vehicle can be driven away from the overhead wires, the question posed is: Should a trolley bus be able to operate at all away from the electrification and, if so, to what extent? Different users, as well as manufacturers, have developed different answers. Some of them are highlighted here in a consideration of modern propulsion systems, of specific off-wire operations, and of procurement, maintenance, and design. The Selected Materials section of this chapter includes both specially prepared papers and summaries of slide-only presentations.

PROPULSION SYSTEMS

Four representatives of manufacturing companies in the United States and abroad joined in a panel discussion of propulsion systems with proven track records. The participants were George Swartz, Swartz Engineering Company, Lynnwood, California; Kurt Vollenwyder, Brown Boveri (Canada), Ltd., Quebec; Jacques Soffer, Alsthom Atlantique, New York City; and Thomas C. Matty, Westinghouse Electric Corporation, West Mifflin, Pennsylvania.

The companies all had recently manufactured DC chopper propulsion systems for trolley bus fleets in Seattle, Philadelphia, Edmonton, Vancouver, St. Etienne, and Nancy. Brown Boveri produced the first chopper for a North American trolley bus, supplying a prototype to Vancouver in 1977. Although the design philosophies of the four companies (systems) are different, the fact that all focus on choppers suggests that this technology has become well accepted.

A DC chopper is electronic in nature and regulates the power delivered to the DC traction motor by rapidly switching line power on and off. The pulses are produced at a rate of about 200 to 400/sec. By varying the width of the pulses, the average "on" time can be controlled from a few percent to nearly 100 percent. The circuit is arranged so that the current in the motor builds up or decays slowly, requiring the time of several pulses to approach steady state. Therefore, the current can be regulated to a reasonable approximation of DC at any desired value within wide limits.

Three-axle trolley bus of Solingen, West Germany, under the Wuppertal Monorail, was built in 1972 and has axuiliary propulsion via a VW engine (photograph by J.P. Aurelius)

The chopper is theoretically lossless, so the system is more efficient than older rheostatic designs that dissipate power in resistors while the vehicle is accelerating to running speed. Varying claims for energy savings have been made, but it is reasonable to expect savings of about 25 percent compared with rheostatic control on heavy in-city routes with schedule speeds of about 10 miles/hr. Electrical propulsion systems usually do much of the vehicle's braking, with the energy of motion dissipated in a resistor instead of in friction elements. With chopper systems it is possible to regenerate much of this energy back into the overhead wires so that another coach can use it, thus reducing overall energy consumption still further. Both the Westinghouse and the Alsthom-Atlantique choppers are equipped for regenerative braking

The duration of the chopper pulses is regulated in a stepless fashion. In contrast, the mechanical switches in a rheostatic control vary the resistance in discrete steps, typically with about 15 to 20 levels. The smoother control and reduced jerk rate improve ride quality and reduce driver effort. The improvement is especially noticeable at low speeds.

Last, the chopper does its heavy-current switching with electronic devices (thyristors) rather than with mechanical contactors. Contactors, when operating under high loads, draw arcs that erode and pit the contact tips. They must be inspected regularly and the tips must be dressed or replaced as necessary. Conventional controls have mechanical parts such as relays, cams, and drums that require adjustment to function properly. The chopper saves maintenance cost by eliminating much of this frequent inspection, minor repair, and adjustment.

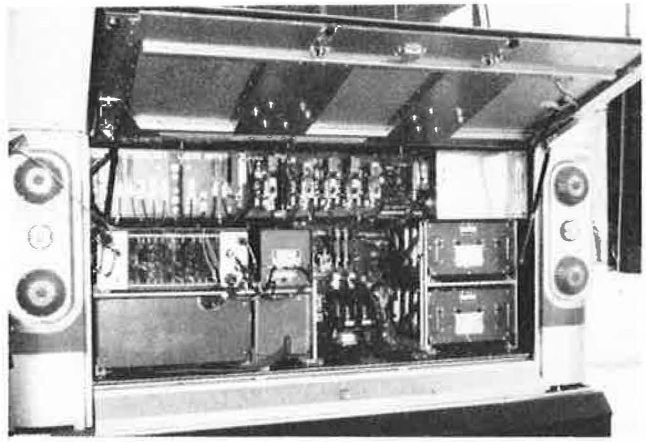
A critical item in designing chopper systems is cooling the power semiconductors. In some early designs the power used by low-voltage fans was underestimated and the vehicle battery would run down. Fans move a lot of air, which inevitably involves a considerable amount of dirt. It is a serious design challenge to first minimize ingestion of dirt, road salt, and water, and then to remove the remainder with a filtering system that is effective and easy to maintain. The four chopper systems discussed handle cooling in different ways.

The Randtronics unit (described by Swartz) and the Brown Boveri unit use fan cooling. Some 219 trolley buses were built with Randtronics systems and have been in service for about 3 years. Despite considerable care in design, there has been some trouble with ingested salt, and there are signs of gradual dirt buildup on the heat sinks. The fans also require maintenance. The Brown Boveri trolley buses for Edmonton have not been in service as long, but the firm's European arm has been building trolley bus chopper systems since 1968.

The Westinghouse chopper is cooled by natural convection. The heat sinks are massive, with large passageways for slower-moving air. This approach avoids the energy consumption of the fans and provides surfaces that can be cleaned when necessary. It is more difficult, however, to filter the air when it is not moved by fans. The Vancouver fleet is just entering service, so it will be a while before the success of this approach is proven.

Alsthom-Atlantique places the power semiconductors in a sealed vessel filled with R 113 freon. The vessel is fanned and cooled by natural convection, with no filters needed. The vessel is costly, but it is compact, provides full insulation for the power components, and avoids contamination of the electronic devices. The liquid is in intimate contact with the surfaces of the semiconductors and allows higher current ratings at acceptable junction temperatures, compared with metal heat sinks. The freon-cooled vessel has been used on rapid transit and railroad equipment as well as on trolley buses.

Advances in electronics have enabled reductions in the size and component count of chopper circuits. Comparison of choppers designed to fit the space of an engine cradle shows the Brown Boveri and Westinghouse units (designed in 1980-1981) to be simpler and less crowded than the Randtronics unit (designed in 1977-1978). Lower costs for power semiconductors make it practical to use thyristors for the power/brake transition (Alsthom and Westinghouse) and the reverser (Westinghouse). Much of the logic in the Westinghouse unit is software-driven using a microprocessor. This approach simplifies the hardware and makes it easier to debug and optimize the system. Software changes can be retrofitted in an existing fleet by replacing read-only memory chips, which are inexpensive plug-in components. Chopper propulsion systems can, and should, be of modular design with diagnostic features so that in the event of a failure the subassembly containing the fault can be isolated and quickly replaced.



Electronic chopper equipment appears in a Philadelphia trolley bus (photograph by J.P. Aurelius).

In the future the trend to better cooling, lower component count, and replacement of mechanical parts with semiconductors will continue. Choppers will operate at higher frequencies, allowing the use of smaller inductors and capacitors in the input filter. Microprocessor logic and regenerative braking will probably become more common. Fault memory would be a useful feature so that intermittent-type failures can be detected and located when the bus gets back to the garage.

Thyristors start the flow of current on command but cannot stop it; a separate "commutating" circuit using another thyristor does this. The gate turn-off thyristor, just becoming available, can both start the current and stop it. This greatly simplifies chopper circuits. In fact, the gate turn-off thyristor may make three-phase inverter systems practical for trolley buses, supplanting the chopper. This circuit is more complete but it drives an induction motor, which is lighter and less costly than the DC traction motor and has no commutator or brushes to maintain.

OFF-WIRE PROPULSION

Tom E. Parkinson of Vancouver, representing BC Transit, and Charles Weinstein, Garrett AiResearch Manufacturing Company, joined to explore off-wire propulsion systems. The former presented his views in a paper and the latter in a slide presentation. Both are summarized here.

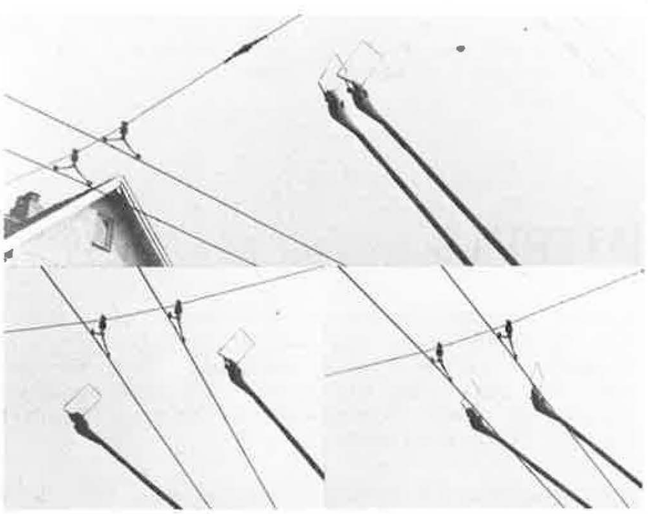
Most North American trolley buses have no off-wire propulsion capability; without 600-V overhead power they cannot move at all. This minimizes weight, complexity, and cost, but creates operational problems when a street is blocked or a bus stops on an insulator. Off-wire capability minimizes these difficulties, and some overhead wiring can be eliminated in maintenance areas, some short-term loops, and emergency routings.

The question was asked: Is it worthwhile to put batteries or an engine-generator on every trolley bus to gain these advantages? Auxiliary propulsion adds 0.25 or 0.50 ton to the weight of the bus and costs perhaps $4,000 to $10,000. These are low-performance systems with a top speed of 6 miles/hr for a simple battery and 18 miles/hr for Garrett's battery system with chopper or a smaller gasoline-engine unit. The speed is much less uphill with these systems, decreasing to about one-third on a 5 percent grade.

The dual-mode vehicle operates in regular service both on the wire and off-wire. A large fleet of "all-service vehicles" was operated in New Jersey in the 1930s and 1940s. They had an engine and generator, traction motor(s), trolley poles, and a control system. They were also equipped with motorized retrievers and mechanical latches so that the driver could raise and lower the poles without leaving the driver's seat. Special guiding funnels were placed in the overhead at locations where the buses came back to the wire. Both elements are necessary if buses are to operate on and off the wire in regular service.

Dual-power buses can use diesel propulsion or stored energy when off-wire; batteries and flywheels are the principal means for storing energy. A second full-performance propulsion system is both heavy and costly. For diesel propulsion an engine of at least 150 kW output is needed, plus a hydraulic transmission, drivelines, clutches, and at least 60 gal of fuel capacity.

The flywheel system developed by Garrett adds about 1 ton to the weight of the bus and stores 16 kWh of energy. A battery of similar storage capacity will weigh as much or somewhat more, in addition to the weight of the charging equipment. Equipment to raise and lower the poles is additional. Operating characteristics of the two systems differ, but in gross terms they can perform a similar mission. This amount of energy will give full performance for about 5 miles without heating or air conditioning.



This series of three pictures shows the automatic rewiring sequence on the German Duo-Bus developed by Mercedes-Benz and Dornier under a West German federal research program (photograph by J. P. Aurelius).

The lifetime requirements for a successful energy storage dual power vehicle are stringent. Trolley buses average about 25,000 miles/year or nearly 100 miles/weekday. With a 16-kWh energy storage system, about 20 charge-discharge cycles would be needed for an average daily mission. If the route is half wired so that the storage system is charged while the bus continues in service, the number of cycles is cut in half. Each dual-power vehicle must disconnect from and connect to the overhead wires about 10 times daily in all kinds of weather. Thus, the rewiring system and the energy storage system need a lifetime on the order of 50,000 cycles (with perhaps one or two renewals) if the bus lasts 20 years.

The speakers asked: Is there a future for dual-power buses? Is it reasonable to carry around a diesel system and an electric system--and keep both maintained or will an energy storage system with constant transitions on and off the wire and constant cycling of the storage element work well and deliver attractive cost savings? To these questions there are no universal or easy answers. As the technology and applications of trolley buses advance, answers may evolve. At the moment, though, dual-power applications may be site-specific; i.e., specific area transit needs may necessitate vehicles designed specifically for those needs.

PROCUREMENT AND MAINTENANCE

The types of auxiliary propulsion available and the limited number of manufacturers and suppliers are among the hurdles to be cleared by transit operations considering trolley bus purchases. With this in mind, Michael W. Voris of Seattle Metro outlined some considerations in the procurement and maintenance of a new trolley bus fleet.

The market for trolley buses in North America is different than in the past. In 1950 a transit property in the United States and Canada had a choice of six vehicle manufacturers and two propulsion suppliers. Until the mid-1970s transit agencies still did not have much of a choice--a fact exacerbated by the decline in the trolley bus mode during those preceding 20 years. With the renewal of interest in the trolley bus, however, the situation has changed.

About a dozen fleet orders of trolley buses have been built in North America in the last 15 years. There is some continuity and progression in their procurement--from a new body with rehabilitated electrical gear, to an all-new trolley bus with a 1940 propulsion system design, to the chopper-controlled vehicles built since 1978. The early vehicles in the group had special structures added for the propulsion equipment, and all were made by one supplier (Flyer Industries).

The later buses with chopper controls have less modification to the motor bus body, with the propulsion system in a cradle structure as used in the diesel version. Bodies by Flyer, AM General, and GM Diesel Division have been used. This approach separates the task of building a bus from that of building the propulsion system--a factor that should have as much attention as any other when considering procurement and subsequent maintenance. One of the existing chopper fleets has air conditioning, and the complete heating and air-conditioning subsystem was supplied as a module that can easily be removed in its entirety and then replaced.

The hypothetical property, for example, purchasing in 1970, 1980, and 1990 could be looking at switched resistors, DC chopper, and AC drive, respectively, but with no procurement continuity, no usable maintenance history, and probably no propulsion supplier of long standing. Because trolley bus purchases are made much less frequently than standard diesel buses, procurement requires a much longer time frame due to the many considerations involved and the new design plans that may be required.

Some of the procurement criteria that should be examined are compatibility with the planned or existing characteristics of the DC distribution system, including overhead hardware; electromagnetic interference and noise; safety for drivers, passengers, and maintenance personnel; performance for the duty cycle; a propulsion system that is maintainable at a reasonable cost; an attractive and functional design comfortable for drivers and passengers; economy of power use; and off-wire capability. Throughout the procurement process it must be remembered that purchasing a trolley bus is not the same as purchasing a motor bus, because the trolley bus has a number of elements (propulsion system, construction of insulated doors, and battery storage, for example) that must be viewed as a system before purchase is feasible and practical.

The goal of a propulsion system that is maintainable at a minimal cost includes a variety of items; such a system requires input from all parties--transit operators, designers, planners, manufacturers, and suppliers. Some of these items are reasonable performance-oriented specifications, a good, tested design from the propulsion supplier, cooperation between the propulsion supplier and the body builder in the all-important component integration phase, and high standards of quality control by all suppliers and assemblers.

After vehicles are purchased and delivered to the transit agency, a maintenance shop must be staffed and equipped. Documentation for proper maintenance of the propulsion system is critical, and it should be supplied by the manufacturer. The same applies to spare parts, chassis components, and other power distribution elements.

DESIGNING AND DEVELOPING TROLLEY BUSES

Arthur J. Deane of AM General Corporation explored different aspects of the construction and design of trolley buses in a slide presentation, which is summarized here. In 1972 the renewed and revived trolley industry started with 1930 technology. Manufacturers and suppliers were not spending much time or financial resources in trolley bus technology; they were concentrating instead on the development of motor buses for public transit. However, gradually they became interested in the technology necessary to convert motor buses to electric fleets as well as to design entirely new coaches.

It was concluded that conversion of diesel buses to electric traction would minimize development and manufacturing costs. It was further concluded that designers could draw from an existing technical data base for a product configuration already recognized by operators and passengers, and that the commonality of service parts and maintenance requirements would introduce considerable cost reductions for municipalities.

A single prime contractor, preferably the body supplier, should be responsible for the work of conversion. Essential is the presence of 100 percent propulsion supplier service support in the body builder's plant and at the transit property to check out and correct propulsion defects.

High-quality vehicles can be delivered fully serviceable and ready to operate provided that all vehicles are tested on an in-plant dynamometer and that strong in-house quality control programs exist. The use of a separate propulsion module pretested at the propulsion supplier's plant results in significant reduction in trolley bus manufacturing start-up costs.

Design considerations must place special emphasis on roof structure, rear end, heaters, driver controls, pedal controls, and hot coach detectors.

Air compressors that are already commercially available, as well as air-conditioning systems and propulsion systems, have been proven effective in the conversion process. Chopper propulsion systems have also been proven effective. A reliability factor in excess of 7,500 miles between failures was achieved within 12 months of putting an AM General system into service. This compares with approximately 3,500 miles between failures for a cam system trolley bus.

Finally, there is a need to develop and establish industry-accepted standards for the next generation of trolley buses. Various features, however, must be developed and tested before becoming a part of these standards or specifications.

SELECTED MATERIALS

Freon-Cooled Choppers for Trolley Bus Applications

J. Soffer

The first trolley buses were built 60 years ago by VETRA with Alsthom electrical equipment. Production continued up to 1950 with the VA 3 B2, which is still in service today in certain French cities. However, three reasons contributed to the collapse of the French and the world markets for this type of equipment: the drop in the price of oil, the dependence of the trolley bus on overhead equipment, and the proved reliability of the internal combustion engine. In 1974 two factors arose that led to renewed interest in the trolley bus: the increase of oil prices and the increased awakening of public attitudes about pollution and the environment.

After detailed market research Alsthom-Atlantique decided to revive the electric vehicle projects. Due to the newly developed technologies the following improvements over the earlier trolley buses with rheostatic equipment were obtained: improved comfort for passengers and driver, improved equipment reliability, reduced energy per kilometer costs, and reduced maintenance costs.

CHARACTERISTICS OF ALSTHOM-ATLANTIQUE TROLLEY BUS EQUIPMENT

To improve passenger comfort the chopper technique was chosen. Stepless rates of acceleration and deceleration are thus obtained even in heavy traffic areas, and the abrupt stop-start movement associated with the power notching and resistances incorporated in conventional trolley buses is avoided.

To reduce noise, mechanical vibration, weight, and volume, it was decided to place all main chopper components inside a freon-filled container. In the same way the rotating converter was replaced by a solid-state converter. To obtain a vehicle flexible in operation in heavy traffic, a solid-state traction-braking switching device functioning in milliseconds was chosen with the driver obtaining rapid braking response. The chopper equipment allows maintaining a steady rate of acceleration on starting even when the driver wishes to go faster.

In braking, the equipment allows recuperating to the maximum the inertia forces of the vehicle. The circuit chosen allows regenerative braking from the higher to the lower speeds practically down to the halt by operating the chopper to increase the voltage sent into the line. With the chopper equipment eliminating the resistances for starting and regenerative braking not requiring resistances, the consumption of energy is considerably reduced and the vehicle equipment is lightened.

The liquid cooling system efficiently protects the components against aggressive external elements while maintaining the semiconductors at a more constant average temperature. Concerning the circuit adopted, only those contactors necessary for security reasons and having a clean mechanical cut-out function are retained.

ELECTRICAL EQUIPMENT AND CHOPPER SYSTEM

The trolley bus power circuits are shown in Figures 1 and 2. Immediately after the trolley-poles A1 and A2 are the lightning arrester or surge diverter PF, fuses F1-F2, and the circuit breaker DJ. The circuit breaker in addition to its power circuit switching role also protects the propulsion power electronics by means of a high-speed tripping circuit.

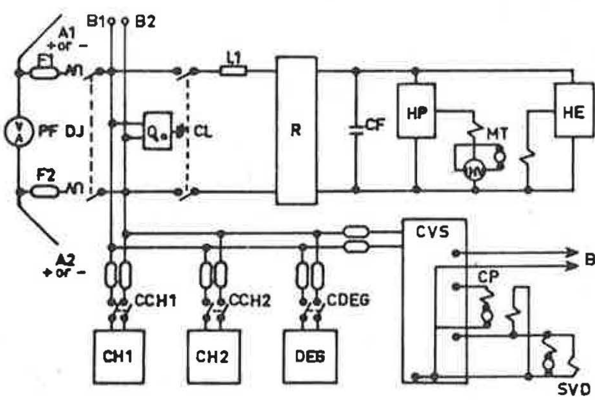


Figure 1. Trolley bus power circuit.

Immediately after the circuit breaker is a control relay circuit (Qo), which monitors the leakage current of the high-voltage circuits. A tapping is also brought out at this point for supplying the auxiliaries, which are the heaters CH1-CH2, defrosting system DEG, and the solid-state converter CVS. Each of these subsystems is protected by two fuses.

In the event that the trolley bus has to circulate without line voltage supply, the replacement energy supply must also be entered at this point at the terminals B1-B2. This replacement supply can be from any electrical source such as batteries, DC generators, or alternator/rectifier group.

The compound traction motor is fed through the intermediary of the main chopper (HP) for the armature and series fields and by the excitation chopper (HE) for separate excitation. Change of running direction is made by reversing either the armature connections or the separate excitation connections by means of the selector switch (INV).

TRACTION

Figure 2a details the propulsion circuit for traction. In traction the input filter (CF, LF). is supplied at line voltage through the intermediary of the line contactors (CL) and the rectifier bridge (R) - (D1 to D4).

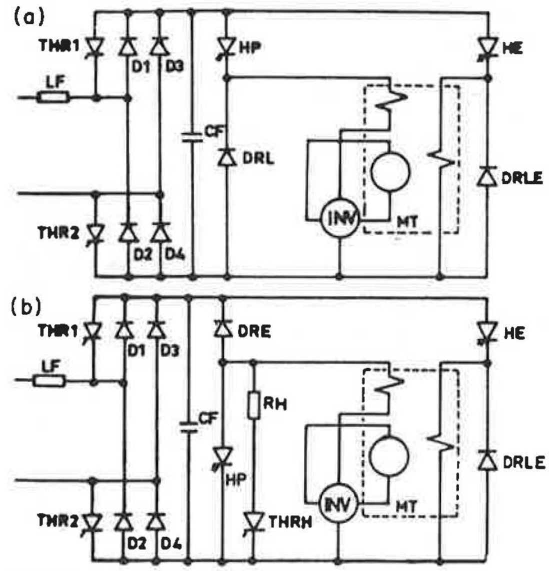


Figure 2. Traction schematic circuit (top) and braking schematic circuit (bottom).

The main chopper (HP) maintains the motor current (armature and series field) at the required value. Throughout the starting period the excitation chopper (HE) is in permanent conduction so as to ensure maximum motor excitation. When sufficient vehicle speed has been reached, the motor current is controlled with the aid of the excitation chopper.

BRAKING

As the vehicle moves, if the driver wants to brake, the kinetic energy has to be transformed either into electric energy or directly into heat by means of the mechanical brake. Electric braking has priority because it allows regeneration of the energy and, at the same time, prevents the mechanical brakes from becoming worn. If the power line cannot recuperate a part or the whole braking energy, this energy can be wasted into a resistance. Our equipment blends automatically the two types of electrical braking. Nevertheless, it should be mentioned that some customers consider the supplementary cost of price and weight of dynamic braking not to have any worth, because the feeding line is almost always able to recuperate the energy.

Regenerative braking is rendered possible by the regenerating thyristors THR1-THR2. If regenerating is becoming impossible, thyristor THRH is switched on and the energy is dissipated in resistance RH. Blending of dynamic and regenerative braking is made by regulating the relative switching phases between thyristors THR1, THR2, and THRH. The motor excitation is controlled by the excitation chopper and the armature current returned to the input bridge across the regenerative diode (DRE). When the motor speed is no longer sufficient, the excitation chopper is placed in permanent conduction and motor current is adjusted by the main chopper functioning as a voltage increaser. This arrangement allows maintaining the electric braking effort constant down to speeds around 4 km/h.

Traction to braking switching is entirely solid state and is thus both silent and extremely rapid because switching takes place in a few milliseconds. The only two electromechanical units retained for the propulsion system are the reverser and the line contactors, and because these always work on zero loads, there is practically no wear effect on their contacts.

In braking, if the deceleration desired cannot be obtained by electric braking alone, the driver can amplify the braking effort by operating the foot pedal of the mechanical brake. In the traction mode the line contactors are automatically closed by depressing the accelerating pedal; in the braking mode automatic opening occurs at the threshold of 3 km/h where the electric braking is no longer efficient. The driver also has at his disposal an overriding manual control for opening the line contactors.

Automatic operation of the trolley-pole is provided as optional equipment. This arrangement allows the driver to operate the poles without leaving his seat.

LIQUID COOLING OF SEMICONDUCTORS

The advantages of a cooling system with boiling R 113 are briefly outlined here.

Improved Cooling

A comparison test was carried out with a diode already commercially available. The results obtained showed that for a same rise in junction temperature the direct cooling of the bare pellet by boiling R 113 allowed the dissipation of double the power compared to that obtained by conventional cooling methods and heat sinks cooled by forced air.

Using Bare Pellets

The semiconductors now available are always supplied encapsulated or sealed off from the outside atmosphere by welded hermetic seals in order to provide environmental protection. The high dielectric strength of R 113 allows the elimination of the casing structure and thus reduces the volume of the semiconductors.

Thermal Inertia

In the case of direct cooling by air the junction/case inertia and the heat sink/air inertia must be considered. The former is of the order of a few seconds and the other is several tens of seconds. The time constant of the semiconductor assembly, case plus heat sink, is comparable with the duration of the function sequency of the equipment. It thus follows that each semiconductor assembly must be dimensioned for the peak power that is to be dissipated. Forced ventilation is thus imperative in order to avoid overdimensioning of the equipment.

In the latter case, the junction/R 113 inertia and R 113/air inertia must be considered. The first is of the order of seconds with the R 113/air inertia on the order of 1 hr. This is greater than the duration of the function cycle of the equipment.

With R 113 added, the cooling common to all the semiconductors housed in the same container need only be dimensioned for the average power dissipated by the assembly of semiconductors. This helps to reduce the volume. Due to the high R 113/air inertia value, the natural ventilation provided by the vehicle movement is sufficient.

Increased Compactness

Cooling by R 113 allows deleting the semiconductor individual heat sink and permits compact power components, which are light and easy to handle.

Good Environmental Protection

The electrical circuits immersed in the R 113 cooling liquid are most effectively protected against water, snow, dust, and short circuits. The container holding the R 113 is connected to the vehicle ground. The components under voltage are not accessible when functioning, thus guaranteeing the protection of operating personnel. The container cooling fans are at the ground electric potential and so do not attract dust; fouling of the cooling fans is thus eliminated.

Absence of Annexed Equipment

The container in which the equipment is housed immersed in R 113 is in the form of a sealed vessel, which only requires a slight renewal of the air for cooling purposes. For this, natural ventilation is sufficient. There is no requirement for a cooling fan and thus no noise or maintenance; air filters are also eliminated.

Ease of Maintenance

If repairs are necessary, they can be carried out most rapidly, which significantly reduces the downtime of the vehicle. Locating the fault and replacing the semiconductors involved is an easy operation in the workshop. The assembling pressures and associated tolerances for the semiconductors are much less rigorous than for the semiconductors mounted on heat sinks. A standard replacement operation in the workshop for a semiconductor requires approximately 15 min, including the opening and closing of the container.

Security

The R 113 presents no chemical danger at ambient temperatures and can be handled easily by nonspecialist personnel. The sealing of the container is excellent; this has been proved by numerous checks with an electronic leak detector.

No conditioning operations are required on a container that has just been closed and it can be placed directly in service on the vehicle. Two tests of behavior under fire conditions were carried out, one at the Aeronautical Test Centre in Toulouse and the other at the National Fire Laboratory at Champs sur Marne.

For each of these tests a container in working order was suspended over a tray containing raw alcohol that was then ignited. After approximately 10 min, a coupler failed with a subsequent leakage of R 113. The analysis operations that followed showed that no toxic gas was present.

During these tests the flames were controlled by trichlorotrifluorethane fire extinguishers of the type used in aviation; R 113 belongs to the same family.

A Look at Chopper Systems

George Swartz

I started with Randtronics Transit in 1977. I designed the two-phase armature chopper, which is used on the trolley fleets in Seattle and in Philadelphia. Some 109 trolleys were delivered to Seattle in 1979 and 1980, and 110 were delivered to Philadelphia in 1980. I followed the trolleys to Seattle and took over the warranty maintenance there; over the last 3 years we have gained quite a bit of experience. The Seattle system is running well at this point, and we are approaching 10 million miles of chopper operation in the two trolley fleets.

The energy saving of a chopper system of 15 to 20 percent compared with a cam controller is justification alone for using a chopper system, despite expectations of some maintenance headaches or extra effort required for an electronic or solid-state system. The extra maintenance has not materialized; the system in Seattle is running well at a low maintenance cost. The smooth control of a chopper system improves ride and reduces stress on the drive train.

The Randtronics system uses the GE 1213 compound motor at 165 hp. The AMG trolley in Seattle will go up the 18 percent Queen Anne hill at between 15 and 20 miles/hr. The current limit on the chopper is 475 amps and the chopper will work as low as 200 V line voltage and as high as 750 V; the Seattle system is 700 V nominal.

Because the 1213 is a compound motor, there is also a field chopper in the system rated at 5 amps. In the propulsion package Randtronics also provided a static converter for battery charging, which is rated at 350 amps and 13.7 V.

The system uses a two-phase chopper, essentially two single-phase choppers operating in parallel like a two-cylinder gasoline engine; this has the advantage that if one side of the system fails, the bus can continue to run on the remaining chopper. When one of the two phases fails, the current limit is reduced, so the bus cannot negotiate the hills in Seattle with a crush load. In Philadelphia, when one side of the chopper historically has failed, the bus has continued to run for weeks or months until the chopper is repaired. In addition, the two-phase chopper reduces ripple current in the motor and is a convenient way to share current between two main SCRs.

The chopper is configured with an H-type commutator and a pulse commutation so that the voltage across each device in the chopper is approximately one time the line voltage. Thus, if the line voltage is 700 V, the devices typically see about 800 to 900 V with transients on top of the line. The advantage of this configuration is that only one device has to be used in each position in the chopper rather than using several SCRs in series.

The next feature is the full-on or bypass mode of the chopper. When the vehicle reaches the base speed of the motor, the main chopper turns on fully and the commutator turns off. The advantage to running in this mode is reduced electromagnetic interference (EMI); there is also reduced noise and heat generation. Because of this full-on mode the only time the chopper is operating is during initial acceleration. The duty cycle on chopper operation is probably 10 to 15 percent of the operating time of the bus.

We also designed the logic with discrete integrated circuit CMOS logic. We had a choice to make: we could have gone to microprocessor logic. The only reason we stayed with discrete logic was that we felt that it would be easier for the properties to maintain in the field. In fact, microprocessor logic would have been cheaper for the manufacturer.

Much of the expense of the Randtronics system is related to the modular design. The chopper, the convertor, and all other modules can be pulled out in a matter of minutes and replaced with new modules to get a bus back on the road. In Seattle there is a 97-bus signout. With 109 buses in the fleet and a portion of buses scheduled for routine preventive maintenance, we were allowed a maximum of four buses down for propulsion-related problems. In the last 3 years we have never missed a signout in Seattle. In fact, typically, there is either none or one bus down at any given time.

The modular design allowed us to work in the bus yard and not in the barn. For example, we could pull out a chopper or a logic rack or some other module that had a problem. Without bringing the bus into the barn we could replace the most difficult module in 1 hour at the most.

In addition, Randtronics built in diagnostic test channels and status indicators, which proved invaluable in the maintenance program. Something that any property should consider in procurement is a fault memory in the logic, i.e., circuits built into the logic that will diagnose what happened after an event, because the most difficult problems in chopper propulsion are intermittent--those that stop a bus, but disappear by the time the technicians arrive. Thermal problems especially are of this nature; by the time somebody arrives to look at the bus, things have cooled off. This is a factor that should be written into specifications.

The propulsion systems have to be viewed in a systems approach. A propulsion system is not a unit apart from the bus. Both EMI or "hot coach" problems, the trolley bus, the chassis, the overhead lines, the substations--i.e., the complete system--must be considered.

We solved problems with hot coach bodies that were caused by diodes in the hot coach detector and, to some degree, by the overall design of the coach. Randtronics did not build the hot coach detector; it was built by a firm in Canada. The hot coach detector connected the shell of the coach to the negative line through resistance and a diode network. The negative line in the Seattle and Philadelphia systems is a quasiearth ground and the coach body typically runs 20 to 25 V from earth ground, which is considered safe. The hot coach detector diodes interacted with the noise or spikes in the negative line; the diodes rectified the spikes and caused the coach body to go 75 to 100 V negative with respect to earth ground and presented a shock hazard. This is a lethal shock hazard, but because the bus chassis has capacitance to earth ground one could contact the bus, get a shock, and maybe jump back into a hazard. This was solved by adding resistance without diode networks between the coach body and the negative line.

In Philadelphia we found that static buildup due to the tires running on the road surface alone would cause the coach body to go negative 5,000 V with respect to the propulsion system. Again, the diodes in the hot coach detector were in a blocking direction and as soon as we got up to 4,000 to 5,000 V, there would be an arc in the propulsion system and our logic would fault. We determined that this was solely due to tires running on the road surface, by instrumenting and engaging only to the negative trolley line (one pole up) and coasting the coach down a hill. Again this was solved by adding resistance between the negative line and the coach body to make sure we could bleed off a static buildup. We unsuccessfully tried a ground strap to the road surface.

Another problem in the hot coach category is AC voltage coupled onto the coach body through capacitance of the motor windings to the motor frame and inductor windings to inductor frames. What this amounts to is very narrow pulses of fairly high voltage. This was solved by providing capacitance between the negative line and the coach body. This was also instrumental in reducing radio frequency interference (RFI).

Another problem occurred when driving on streets in Seattle that have overhanging trees with wet leaves. Because the coach body was referenced to the negative line, the hot coach detector would go off if the negative line was 25 to 30 V above earth ground and the detector was set at a too-sensitive position.

Radio frequency interference has been a nagging problem and I believe it plagues all trolley systems. The Randtronics system found effective ways to reduce interference to a level that is not too detrimental. The RFI problem is difficult because in the Randtronics system the coach body is part of the RFI shield. Because of 600-V isolation, creep, and strike for voltage isolation, much of the system is built in a fiberglass cradle and with fiberglass insulation components that do not shield RFI. So the coach body becomes part of the RFI shield.

In addition the overhead lines are an effective antenna system that distributes RFI and amplifies it. The overhead line actually has some of the characteristics of an antenna system. RFI exists in standing waves on the overhead lines and couples directly into automotive AM radio antennas. This has been a difficult problem; it is difficult to even measure the broadband RFI from the trolleys. We started out by using a spectrum analyzer; however, it was found that a spectrum analyzer is the wrong kind of equipment to use for measuring low-level broadband interference. We found that a car radio is the best monitor for interference, which has been confirmed by the experts in the RFI field.

In addition, we experienced noise and radio frequency susceptibility in Seattle. Under the TV towers on Queen Anne Hill our converter and our dynamic brakes would quit; these problems have been solved simply. People riding in the bus have operated CB radios and ham 2-m transceivers in the back seat, near the propulsion system. This is a design problem that has to be considered; in the presence of high-level radio frequency it must be at least fail-safe. If the propulsion system has been well shielded with, for example, a zinc metal spray on the outside of the fiberglass cradle or a completely metal-enclosed propulsion package, operations would not have been affected.

We experienced arcing on aluminum heat sinks, in spite of the fact that they are milled flat, and we used Penetrox and correct clamping pressure on pressure-pack-type devices. I have concluded that the most reliable heat sink material, at least at the interface to SCRs and diodes, is nickel-plated copper.

We have had problems at crosswalks with plastic stripes; as the bus accelerated across them, the rear axle would break traction, speed up to a high speed, come across the crosswalk, and then grab hold of the pavement. We had initial problems with the speed loop in getting stability.

In conclusion, I would like to emphasize that no matter what system is being considered or installed, there will most likely be problems; I believe patience is the key to solving them.

Advanced Technology for Trolley Bus Systems

Thomas C. Matty

During the 1960s Westinghouse began a program to advance the state of the art of technology used in the transportation industry. This effort successfully bore fruit when the contract of the BART System in San Francisco was awarded to Westinghouse in 1969, which resulted in development of a completely new form and generation of automatic train signaling equipment. This same technology was later applied to the Sao Paulo Metro as well as to a number of people mover systems throughout the United States and Great Britain.

Also during this period, Westinghouse had prototype choppers in operation at BART, New York, and Chicago. The first production contracts for Westinghouse chopper propulsion were BART and Sao Paulo. Since then, Westinghouse has more than 1,700 units of advanced chopper propulsion in revenue service and on order for both heavy and light rail applications, including 250 sets for the new trolley buses in Vancouver. Now that the last lingering question of the technical applicability of choppers, i.e., electromagnetic interference, has been successfully resolved at the Washington Metro, it appears that chopper technology has finally come of age in the transit industry.

Through the 1970s, Westinghouse continued to advance transit technology state of the art. In 1976 Westinghouse started a new technology development to allow the use of convection cooled semiconductor equipment for propulsion systems. Another program developed solid-state motor control circuits, which were applied in a prototype trolley bus in operation in Mexico City. Its power circuit is completely convection cooled and uses all solid-state devices to perform the mode switching and circuit configurations for a trolley bus. This circuit resulted from the development of two- and four-motor circuits for heavier transit equipment.

WESTINGHOUSE CHOPPER PROPULSION FOR VANCOUVER TROLLEY BUSES

The new trolley buses for Vancouver represent another developmental step in the state of the art for traction equipment (Figure 1).

The propulsion systems are fully solid-state, controlled by a microprocessor with only a minimum number of mechanical switches to assure high reliability and minimum maintenance cost. Although the Vancouver bus propulsion may appear to be complex, it is, in fact, simpler and easier to maintain than previous trolley bus equipment designs (Figure 2). All components are mounted in a single-layer, sealed package so that only the components that need to be changed are removed. Because the semiconductor package is sealed, heat is transferred through a cold plate. Cooling occurs by natural convection assisted by motor inlet cooling air, thus eliminating the need for an expensive fan and high-maintenance filters.

Figure 1. New bus for Vancouver trolley fleet.

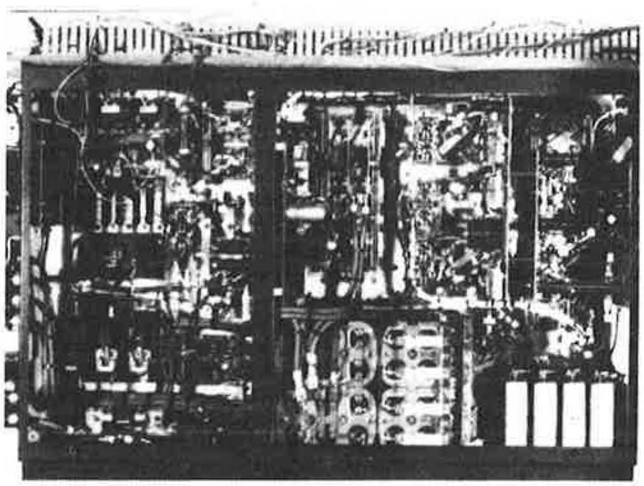


Figure 2. Propulsion system in Vancouver vehicles.

Before any device is removed, the unit can be fully tested using a three-mode test automatically controlled by the microprocessor. Each mode performs a complete series of tests to verify every component in the propulsion system, including semiconductor devices, fuses, and capacitors.

The bus carries an auxiliary propulsion battery, maintained by a dual output converter, which allows for off-wire capability to change routes and avoid obstacles. It also has electric dynamic and regenerative braking capability from top speed down to 3 km/h. This provides for smooth but efficient operation at minimum energy costs.

MICROPROCESSOR DEVELOPMENTS

The Vancouver bus microprocessor is the Westinghouse standard unit used on heavy and light rail transit systems, including the Rio de Janeiro Metro, SEPTA, WMATA, and the Baltimore and Miami Metros. It is maintained using a "black box" replacement concept. After the unit is removed from the bus, it is checked by using a programmable simulator unit that checks and verifies all functions of the microprocessor package. A test unit is also provided for the converter package that automatically tests all converter functions.

But the development of even more efficient and reliable transit propulsion technology must and will continue. Once again, Westinghouse is developing a new advanced cooling concept for semiconductors used in chopper propulsion gear to eliminate many maintenance problems now associated with previous applications of semiconductor technology. This new cooling concept will be completely solid-state in nature, without the application and maintenance problems of coolants such as freon. The operator's maintenance personnel will be able to maintain and service the solid-state drives easily by using conventional tools and equipment (Figure 3).

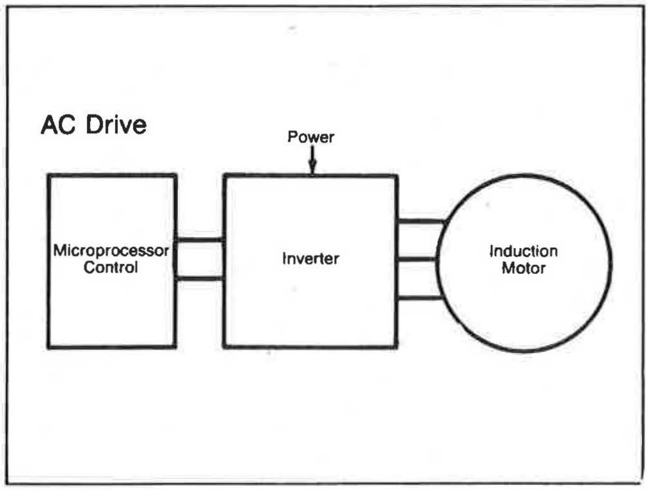


Figure 3. Systems to be maintained.

AC DRIVE PROPULSION

Another key propulsion technology development area for Westinghouse is the AC drive. Propulsion technology developments at Westinghouse are not confined to the power circuit, although that is the most costly component and one of the most critical maintenance items in the total propulsion system. Westinghouse is also working on a new electronics control to enable much more simplified maintenance philosophies for system operators. The new control incorporates both on-board diagnostics and sophisticated external diagnostics, which Westinghouse calls prognostic capability. Prognostics is similar to diagnostics except that the former has additional intelligence to predict impending failures before they cause service disruption.

For example, determination that a semiconductor device in the power circuit is exceeding certain temperature limits under certain operating conditions may signal that another problem exists somewhere in the equipment, which is causing the overtemperature condition. The importance of prognostics is the ability to recognize an impending failure so that the operator can take corrective action. This may involve removing the equipment from service or some other kind of strategic action to minimize or avoid disruption of normal operating service.

OTHER NEW TECHNOLOGY OPPORTUNITIES

Westinghouse is also investigating other new technologies that could prove applicable and beneficial to trolley bus use. Automatic rewiring capability should offer significant benefits on new systems by eliminating much of the special work associated with street intersections and by increasing the operating flexibility of the system. With the development of limited off-wire capability at Vancouver, the next step in trolley bus system technology advancement is automatic rewiring capability to enable a bus operator to drive through an intersection or divert around an obstacle without ever having to leave his position to reconnect the trolley poles with the catenary.

There are also a number of other strategies using off-wire alternative energy that could be employed to improve trolley bus operation. However, implementation of these strategies requires additional development in the application of existing microprocessor capabilities. For example, if battery off-wire capability exists onboard the bus, it would be useful to maintain the charge on that battery so that maximum regenerative energy recovery could always be obtained. With the microprocessor today, it is possible that each trolley bus operation can be adjusted to the normal route followed in service, including the complete grade profile. This would allow the bus propulsion system to use part of its energy from the battery and less energy from the line when climbing grades. Energy can then be returned to the battery on downgrades instead of burning it either in brake shoes or resistor heat.

MAINTENANCE IMPLICATIONS

Arguments continue today about the trade-offs associated with advanced technology and the increased labor and technical skills required to maintain more sophisticated equipment. In the 1940s and 1950s electrical engineers were basically power circuit specialists. Starting in the 1960s they became more electronics oriented. Today, it is difficult to hire a DC motor designer or a power circuit engineer or a power systems engineer. Young engineers now believe that electrical engineering should be focused on developing applications for microprocessors.

What is the base of knowledge that new maintenance and service people will bring to transit operators in the future? The answer is microprocessors, solid-state devices, and some of the new concepts that have been presented here.

Westinghouse believes in advancing technology for all forms of electrified transit, and has seized the opportunity to do so again for a reemerging transit mode--the trolley bus. The necessary maintenance and technical support capability will be there, from operators and suppliers like Westinghouse, so that the significant benefits of advanced technology can be realized by current and future trolley bus system operators in North America and around the world.

Off-Wire Operation

Tom E. Parkinson

Off-wire propulsion can fill several needs, including the short-term need to avoid delays when stuck on an insulator or to get around a defective switch or broken wire. These minor problems occur every day but do not always appear in the records. They need little stored energy capacity. This small capacity would also permit running through an intersection with a wire down, detouring over a block to avoid a fire, or short turning where there is no wire. This is the biggest need for off-wire capability. To run around the block, about 0.5 mile of off-wire capability is needed.

Another need involves a branch where wiring cannot be justified. Ideally, it is level and there are no air conditioning or heating requirements because auxiliaries put a severe constraint on off-wire operation. This is the type of service of which many European buses, equipped with small diesel or gasoline engines, are capable. It is also a need that can be met with current battery technology.

There is also a need to have a full-service capability off-wire; that is, the full performance of 200 or more hp. This is not currently available; however, when available it will probably produce disadvantages for both the diesel bus and the trolley bus. It is difficult to see any economic viability in this area.

In all off-wire needs the poles have to be taken off the wires. To do this automatically is not a problem, even while moving. However, putting the poles back up without having the driver get out of the bus is much more difficult. There are different ways to accomplish this by using quite sophisticated electronic servomechanisms, but lack of reliability in all types of weather and the rigors of transit operation strongly suggest that the procedure is not realistic. The idea that it is possible to avoid all the overhead and intersections and get rid of the switches and the visual pollution by having to pull down the poles and cross the intersection and put them up again is, in my opinion, absurd--now or in the future. To pull down the poles to run over an unused branch, or for an emergency short turn, once or twice every round trip, is realistic. In a short-term emergency the driver can rewire by getting out and using the ropes to put the poles back up. In a regular, off-wire operation to service a branch, there are various competing means to reliably put the poles back up on the wires at a predetermined location when the coach is stopped.

Off-wire requirements can be achieved with batteries, with reciprocating engines, and with flywheels. These all have limitations, which are related to weight, cost, and reliability. The short-distance need is met easily, cheaply, and reliably by batteries. The medium-distance reduced-performance need can be met by all three. Only the reciprocating engine is here at the present time. Batteries that provide the capability to run 2 miles off the wire (and 2 miles back) are available, but the weight or the cost of some of the new, high-energy-density batteries is high. The flywheel has not yet been developed to an acceptable cost or weight.

My view, knowing the packaging and the weight problems and that off-wire trolley buses will always be a small production item, is that it is difficult to see the cost of these units going down. I doubt that flywheels on buses will become economically viable.

I also do not believe in using reciprocating engines on trolley buses. The advantage of a trolley bus is that it is an all-electric vehicle. It is stored out of doors in the coldest weather; it does not have to be filled with fluids; oil does not drip out nor do vibrations reduce its life. The use of a reciprocating engine on the trolley bus provides the equivalent of the diesel bus. A diesel or gasoline engine on a bus also reduces reliability, despite figures to the contrary from European properties where there is a considerably higher maintenance standard. The capability of a property to maintain new designs of vehicles must always be considered. Some properties are not capable of operating standard trolley buses because despite their many advantages they need more management and more street supervision. The operation of trolley buses requires extra effort in order to get the benefits; a property that is not able to or is not prepared to put in that extra effort is well advised to keep to diesels. Dual-mode vehicles compound this situation. Vancouver chose the limited-range battery because most delay incidents are minor, relating to broken insulators, stalls on insulators, short sections of wire down, or defective switches.

The original specification called for an option of a reciprocating engine; the cost ($10,000 to $20,000) appeared quite reasonable. The weight was something else. The current designs of trolley buses are converted diesel buses and are too heavy. In the future as we move to better coaches and better propulsion systems, particularly AC motors with inverters, it should become possible to include the added weight of batteries or flywheels.

The limited-range battery cannot power the compressor. Consequently, the travel of the bus off-wire is limited not only to the capability of the battery, but also to the amount of air that can be stored. Assuming that the air system would be fully charged before the poles are pulled, the bus can make eight full stops. An additional air tank could be fitted if necessary to expand this capability. There is no danger of losing braking capability as the buses have the maxi-brake system, which applies an emergency brake from a separate air reservoir when the main air pressure has reached a preset level. The driver has no control over this application but can release the emergency brake to make one move of the bus and then reapply it.

The new trolley buses in Vancouver are currently being equipped with standard bus batteries for limited off-wire use. These batteries are not optimized for traction applications and add some 400 kg to the vehicle weight. Such batteries typically deliver about 20 kWh/kg. When experience has been accumulated on the actual duties of these off-wire batteries, state-of-the-art lead acid batteries could be used to deliver some 35 kWh/kg, provided that these more expensive batteries are cost effective. Development in lead acid batteries is still continuing; it is expected that the battery capability could be extended to 50 kWh/kg. Advances in battery technology have been slow in moving from the laboratory to the production stage. Several new battery technologies offer the opportunity of 100 or more kWh/kg, which within the space and weight capabilities of full-sized buses would permit substantial off-wire operation in the range of 5 to 10 km of wire that would correspond to a branch of 5 km with the batteries recharging under wire on the main trunk or downtown section of a route. Among the advanced batteries, sodium sulfur has been under extensive development, but it has the liability of requiring an operating temperature of 300°C.

Nickel iron batteries are now being used extensively in railway applications in Europe and have the potential for development into higher energy-density levels. Nickel zinc and the more expensive silver zinc batteries also offer high energy densities and are being developed in robust configurations for traction service. The latest development with longer-term potential is the application of semiconductor physics to battery technologies in the form of the polyacetylene battery. Organic polymer batteries, although at an early stage of development, appear to have particular attraction for electric vehicle applications.

Apart from certain specific applications, reciprocating engines and flywheels are not a desirable addition to the trolley coach. However, traction batteries now capable of providing limited off-wire operation will be the way to provide more extensive off-wire operations in the medium-term future.

CHAPTER 6

Infrastructure

During the last 30 years, a significant amount of innovation and modernization of transit buses has occurred. However, during this same period, little attention was given to the modernization of other elements necessary to the successful operation of a trolley bus system--especially those pertaining to power distribution hardware. Emphasis to date has been on diesel propulsion rather than on electric propulsion, but with the recent reemergence of interest in the latter, work is under way to develop trolley overhead hardware that will contribute to higher speeds and greater system reliability. As a result, the presentations made on system infrastructure dealt primarily with power distribution, power rectification, and supervisory control systems to support trolley bus operation.

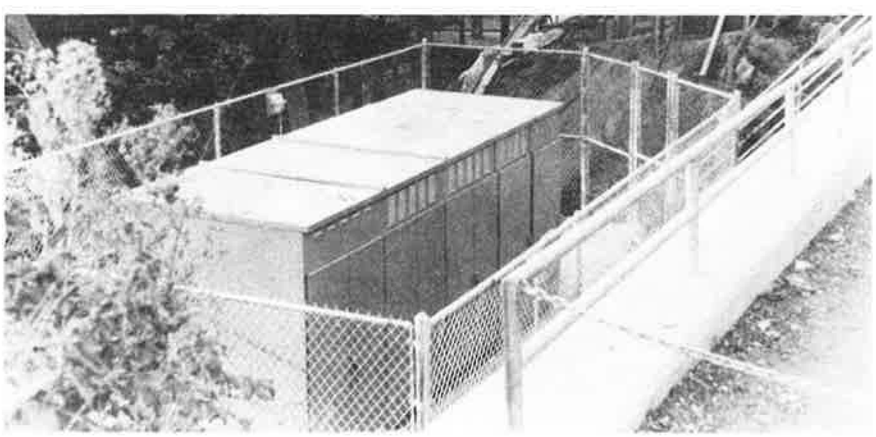
A prime requirement for a successful trolley bus operation is an understanding of the correlation and impact of each element on the total system. For instance, if a feederless system is contemplated, the power requirement of the propulsion unit in the buses and the headways on each route will tend to dictate the size and spacing of rectifier substations. These considerations, in turn, will affect the decision on the weight and type of wire used in the overhead distribution. Also, operational requirements must be considered in the decision to use a rigid, semielastic, or elastic suspension system. Similarly, terrain and local street use ordinances will heavily impact the design and construction of the power distribution system. Consideration of pole placement criteria and joint use of poles with other utilities is absolutely essential. Greater visibility for these sometimes overlooked elements was stressed by all of the speakers.

TYPICAL OVERHEAD SYSTEMS

Galen Sarno of the City and County of San Francisco Public Utilities Commission gave a slide presentation on the trolley buses and overhead distribution systems currently in use in China. All of the equipment is manufactured there. The trolleys are generally older vehicles, and the system is generally of the catenary type. Furthermore, the overhead distribution system is patterned after those in use in Europe and in the Soviet Union.

In other slide presentations, examples of rigid and semielastic systems were shown. In one presentation prepared by Daniel J. Ferrante of the Ohio Brass Company and given by David Thompson, these systems were shown to have some site-specific advantages and lower cost advantages. In another, Gilbert de Steffani of Kummler and Matter in Switzerland illustrated the advantages of an elastic overhead system.

Some of the lessons learned and experiences in the rebuilding and the expansion of the Seattle system were also discussed by Robert Powell, supervising engineer for Seattle Metro. As this was the first U.S. undertaking of its kind in 40 years, there were problems in adapting new control technology to old design hardware. The application of computer control and solid-state overcurrent protective devices should be carefully thought out before designing them into a system to ensure that incompatibility problems do not occur. This means that a total system approach must be taken in which the major components are the vehicles, the power supply, and the overhead.



This compact substation to supply 660V dc to Seattle trolley buses has a rated capacity of 500 kW.

DC POWER RECTIFICATION

Thomas H. Young of the Ohio Brass Company discussed DC power rectification systems. The evolution of power rectifier equipment includes added safety features designed to deenergize the overhead system in the event of faults. It was pointed out that rate-of-rise detection was difficult and not totally reliable when applied to a two-wire trolley overhead system. It was strongly recommended that a backup system be provided if the rate-of-rise approach was taken.

SUPERVISORY CONTROL

Thomas Margro of the Southeastern Pennsylvania Transportation Authority outlined some supervisory control systems. Systems to obtain supervisory control of the power distribution network range from one-on-one in which each substation has an individual master control to more sophisticated systems (either controlled by computers or microprocessors) in which one master control can handle up to 60 or 70 substations. It was emphasized that cost is usually the controlling factor in the selection of a supervisory control system.

OTHER FACTORS

Relating back to the Seattle experience, it was pointed out that one innovation not seen in other U.S. systems but used in Seattle was the feederless power distribution system. Rather than large substations feeding out to the overhead in heavy cable through long runs, Seattle has small 500-kW substations 1.25 miles apart that directly feed the overhead. The overhead wires are 4/0 hard-drawn, high-conductivity copper and serve as their own feeders.

Conflicts, too, with other utilities are likely to be myriad. The requirement for close coordination and accepted ground rules for the solution of these problems must be worked out and understood by all parties early in the design stage.

An important part of the system approach is early input from the maintenance organization. It is then up to the design team to keep the degree of maintainability decided on in the detailed design. Performance specifications are an effective tool to ensure system maintainability.

The construction of an overhead system has a broad impact on all the citizens in the area served. It is ideally suited to a turnkey contract, a type of contract that is not seen in public works in the United States. The advantages, though, of a single contractor who designs, builds, and starts up the system point toward lower costs and closer adherence to the construction schedule.

SELECTED MATERIALS

Modern Trolley Bus Overhead Contact Lines

Gilbert de Steffani

In general, construction of overhead contact lines for trolley buses is a little-noticed technical field. Vehicles are built for high speeds, and there are slow and quick overhead contact lines. The quality of the overhead contact line depends on the uninterrupted receipt of electric current. The resultant static and dynamic problems are discussed here.

Most overhead contact lines used for urban mass transit have not kept pace with the development and technical progress related to the higher speeds associated with other forms of mass transit. The old rigid overhead contact line not only causes greater wear and tear but also extensive sparking at high speeds. This, in turn, produces radio disturbances. In the case of trolley buses, dewirement of the current receiver is a frequent result.

Kummler and Matter developed a fully elastic overhead contact line that meets the requirements of rapid transit for electric vehicles and eliminates the disadvantages of the old, rigid suspension system.

If a contact wire is suspended from two points, it produces an approximately parabolic line. In the middle, between the two points of suspension, the line is horizontal and then climbs on either side toward these points at an increasing angle. The deviation from the horizontal is therefore greatest in the immediate vicinity of the suspension points. This ascent of the contact wire depends on the distance between the suspension points and the specific tension of the wire.

If a trolley shoe slides along the wire, the pressure of this sliding contact displaces the wire from its basic position into its so-called working position. The working position is greatest in the middle of the span and slightest at the suspension points. The curve of the working position is of the same order as that of the basic position, i.e., horizontal in the middle of the span and steepest at the suspension points.

ELASTIC OVERHEAD CONTACT LINE

Another type of suspension system involves the choice of a slanting pendulum. This allows for speeds in excess of 50 mph, minimizes dewirement potential and radio disturbances, decreases wire wear, and results in lower maintenance costs (see Figure 1).

It should be noted that if the vertical component is changed ever so slightly by the pressure of the sliding contact, the obliquity of the pendulum is changed immediately. As a result, the height of the contact wire at the suspension point is affected.

To economically build a trolley bus overhead contact line, as few suspension points as possible should be used. To accomplish this, the angle of the contact wire at the suspension points must be as great as possible.

To prevent detrimental side hits of the trolley shoe on the contact wire, this angle is rounded off. The head of the contact wire is clamped between two elastic rails, the length of which depends on the angle of the contact wire. These curve rails are attached to the cross suspension by a parallelogram pendulum (see Figure 2). Depending on the angle of the curve, the curve rail can have one, two, or three oscillating pull-offs. The curve rails are mounted so that the curve of the contact wire at the suspension point is a parabola. This curve form ensures the proper augmentation and diminution of the centrifugal powers of the current receiver shoe, eliminating sudden moves to the side, which cause dewirements.

Comparison of the rigid and elastic trolley bus

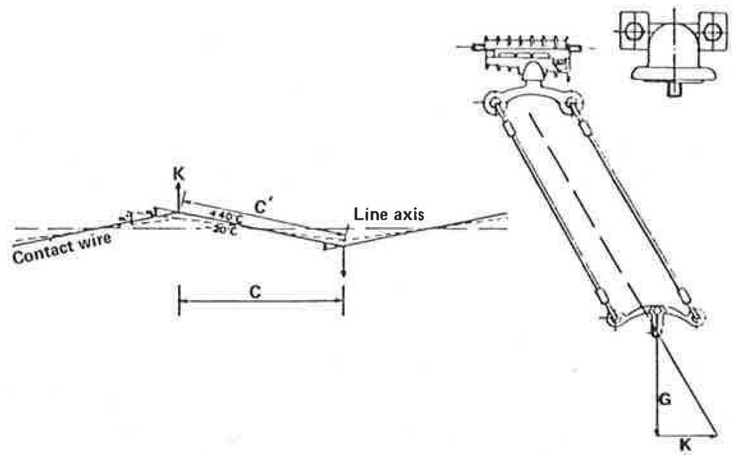


Figure 1. Suspension system that involves slanting pendulum.

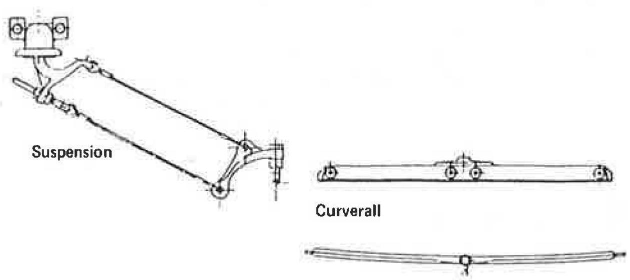


Figure 2. Parallelogram pendulum.

overhead contact lines has shown that dewirements are fewer with the elastic type than with the rigid type. On the straight angle and on curves, considerably greater speeds are possible with the elastic system. In view of the technical advantages of the elastic system, the life cycle of the sliding contact carbon is considerably longer. This cycle varies depending on supplier and time of the year, but sliding contact carbons have been known to last 2,500 miles or more.

Supervisory Control Systems

Thomas E. Margo

The traction power substation is one of the vital elements in an electrified transit system because it must provide power in an efficient, safe, and reliable manner. These features are provided in the design of the power conversion equipment installed in the substation. However, a key element in any transit system operation is the ability to know what is going on and to effectively respond to that situation.

For traction power substations, this information and control function can be provided efficiently by a supervisory control system--generally referred to as a supervisory control and data acquisition (SCADA) system. A SCADA system provides three basic functions: (a) control (e.g., trip or close a circuit breaker or other controllable device), (b) indication (e.g., report of the status of a device or function), and (c) telemetry (e.g., reporting the quantitative measurement of an item such as voltage or current). With this capability, efficiency and flexibility in traction power substation operation can be achieved.

BACKGROUND

Almost all electrified transit systems have adopted the principle of automatic traction power substations. This includes the newer transit systems designed and constructed over the past several years as well as the older transit systems that date back to the early 1900s. An automatic substation can be defined as an unmanned substation in which the equipment is designed with automatic features (protective circuits, load-measuring circuits, etc.) that provide for safe operation of the substation in response to the demands of the electrified traction power system.

The Southeastern Pennsylvania Transportation Authority (SEPTA), the transit operator in Philadelphia and the surrounding counties, has had an ongoing program of renovating old traction power substations and adding new substations where system changes or expansion dictate. All such substations become automatic substations and SEPTA has adopted the policy that all automatic substations will incorporate supervisory control. The supervisory control system concept provides complete optional, overriding control of the automatic substations from a centralized location. The advantages offered by this centralized supervisory control system concept include economy of operation (because the substations are unmanned); continuous real-time update and display of electrical system status; prompt operation of equipment in response to dispatcher's commands; and greatly increased flexibility of operations in response to operational problems (accidents, electrical faults, etc.). These items are all of vital importance to the transit system operators.

Many years ago, SEPTA had used electromechanical supervisory control systems at several substations. These were of the single-master, single-remote type; the master was installed in an existing manned substation and one other substation via the supervisory set. This afforded some economy of operation and provided some of the other advantages noted above.

To realize more fully the benefits and advantages of the substation supervisory control system, a centralized supervisory control facility was established at SEPTA's operation headquarters for all new substations that were added or existing ones that were modernized. It was decided at the time (about 1970) that the SCADA system to be used would be the one-on-one type with a master control unit and a corresponding remote terminal unit for each substation. Thus, each substation essentially had its own SCADA system that operated entirely independent of the other systems. The independent one-on-one SCADA system was chosen for reliability purposes, because all the substations being converted to supervisory control primarily served the rapid transit portion of SEPTA's electrified transit system.

Since 1970 SEPTA has installed an electronic one-on-one SCADA system for each substation added or modernized. SEPTA has had successful experience with this equipment and is satisfied with its operation. However, there are two major items that must be contended with--cost and technology. The one-on-one SCADA system is the most expensive way to provide supervisory control, especially if done in a piecemeal fashion. Also, electronic technology is making advances at such a pace that the electronic technology of the 1960s and the 1970s is practically obsolete. It is becoming increasingly difficult to obtain electronic components for 10-year-old equipment. Therefore it was necessary for SEPTA to reexamine its commitment to the one-on-one SCADA system.

SCADA SYSTEMS

Generic Types

In its investigation of the various systems available, SEPTA found that the systems could be grouped into two basic types: one-on-one, which has a master control unit and a remote control unit for each substation; and the single master, which provides one master control unit for all substations and a remote control unit in each substation. The latter type can also be configured in a dual-redundant scheme for enhanced reliability (see Figures 1-3). Furthermore, the single-master system can be broken down into two other categories: microprocessor-based master station and computer-based master station. Both categories are available in dual-redundant configurations.

It should be noted that many transit operators want the SCADA system to do more than just operate substations. Features such as system reports, cal-

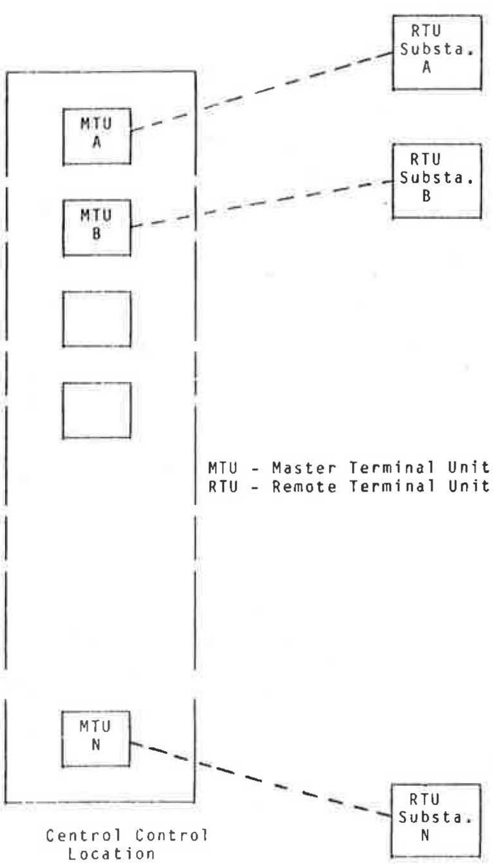


Figure 1. One-on-one SCADA system.

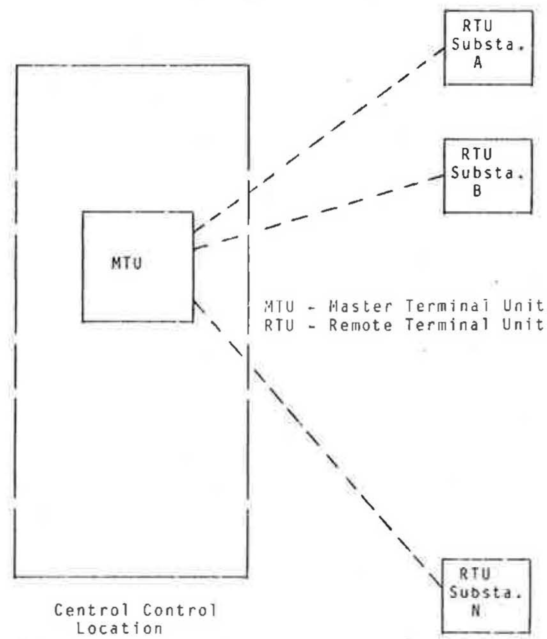


Figure 2. Single-master SCADA system.

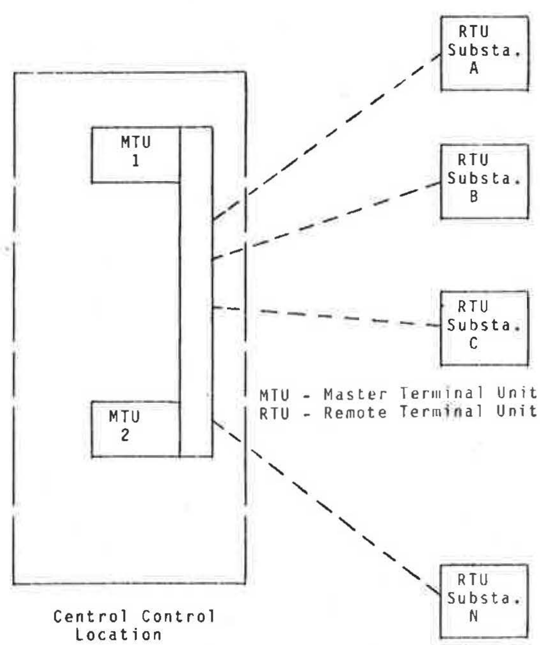


Figure 3. Single-master SCADA system, dual-redundant configuration.

culation capability, system data storage, data trending, passenger facilities supervision, and so forth, may be desired. Such requirements will likely result in the selection of the single master system and, depending on the size of the system to be operated, will usually result in the choice of a computer-based master station.

Reliability

It is difficult to compare quantitatively the reliability of the one-on-one system to the single master type. The former is likely to be much better than the latter when viewed from an overall system basis. However, it is questionable whether the reliability of the one-on-one type is significantly greater than that of a single master type with dual-redundant configuration to warrant the greater expense of the one-on-one system. This evaluation is system specific and must consider many other facets of operation that the transit operator may wish to incorporate into the SCADA system.

Cost

The transit system operator must always consider the costs, both operating and capital, associated with the purchase, installation, and operation of equipment. This is especially important in evaluating electronic equipment when the technology is constantly undergoing dramatic changes. The system purchased today may be obsolete 10 years from now.

General comparisons can be made of the costs associated with the three types of SCADA systems likely to be considered: one-on-one, single master (microprocessor based), and single master (computer based).

Operational Features

Regardless of the system chosen, several key features that are highly recommended by SEPTA should be incorporated into the SCADA system design. These include an error-detecting code, a select/check-back operation, an audio and visual alarm indication, logging, a means to secure communications, and a man-machine interface. Other features that depend on operational and other specific system needs should also be given consideration.

Support Considerations

In order to implement effectively a SCADA system, a number of items should be provided as part of the system's purchase. These include the following: system documentation, training, maintenance/warranty contract, spare parts, and test equipment. It is recommended that these areas be given close attention to ensure that the items are adequately defined and determined.

CONCLUSION

To date SEPTA has had a positive experience with the operating one-on-one SCADA system. It will shortly put into operation a dual-redundant computer-based single-master type system. This new system will handle not only substation control but will also have the capability for single system supervision and fixed-facility supervision. SEPTA is convinced that the use of the SCADA concept has produced significant benefits in the operation of its transit system.

Rebuilding Seattle's Trolley Overhead System

Stuart Maxin (presented by Robert Powell)

Seattle Metro has been responsible for public mass transportation in the metropolitan Seattle-King County area since January 1973. Before that time, public transportation was provided by several smaller organizations. One of these, the Seattle Transit System, had been operated by the city of Seattle. A part of that system was a trolley coach overhead network covering some 32 route-miles that were in operation when Metro took over. Thus, the overhead system inherited by Metro was old and in many areas had been worn to the limit of its service life.

On December 1, 1972, the city of Seattle and Metro signed an agreement (Transit Transfer Agreement), which described how Metro would take over the Seattle transit system. Metro would continue to operate the existing trolley system. The agreement also provided for a future expansion of the trolley system at the request of the city. A complete rehabilitation of the old 32-mile system was included in a transit improvement project outlined by Metro in early 1973. In 1974, at the request of the city, the transit improvement project was amended to include an expansion of the overhead system. How much expansion was to be effected was to be defined at a later date. But this lack of definition on specific routes and degree of expansion led to some of the problems that were encountered during the design phase.

During the planning phase, a number of decisions were made that later were to have significant impact on the design and during the construction stages. Even though a planning effort was made, a number of unforeseen problems were encountered during design and construction. Essentially these stemmed from the fact that this was the first major construction on a trolley bus overhead system in the United States in some 30 years, and experience was in extremely short supply. As a learning curve was established and overcome, the problems began to diminish.

Early in the planning phase, a detailed study of power distribution alternatives was undertaken by Metro staff. This study had to consider a city policy that required the eventual elimination of all overhead wiring except, of course, the trolley contact wires. The alternatives to be considered were thus reduced to (a) place the existing feeders underground; (b) place reduced-sized feeders underground and add small rectifier substations; or (c) construct a feederless system that uses small rectifier substations. After a comprehensive research and study effort, alternatives a and b were found to be much more expensive when compared with the feederless system due to the high cost of installing underground feeders. In recommending a feederless system, the study concluded that "to avoid the expense of feeder cables, it is necessary to eliminate them and let the trolley contact wires carry all the current required. To minimize voltage drop, the trolley contact wires need to have as high a conductance as can be practically attained and the current handled by each feeder circuit needs to be reduced. This requires that distances between power feed points to the trolley contact wire system be made small."

To obtain a maximum conductivity in the outlying areas, it was decided to use 4/0 hard-drawn copper trolley wire. Several other decisions were made during the planning phase. These played significant roles later on. First, it was decided to handle the rehabilitation and expansion projects as separate entities. Second, it was decided to reuse the poles and building eye bolts that had supported the old wire in the rehabilitation area. This decision was to have far-reaching effects during the design and construction phases. Finally, it was decided to contract for the design and construction separately rather than to enter into a design-build or turnkey contract.

In April 1975, a design consultant firm was selected, and the design phase began in early October 1975. The first task for the firm was to work on a system configuration study. This was completed in April 1976 and generally confirmed that the feederless system favored earlier by Metro staff was the way to go. However, it was recommended that the feeder system in the CBD be retained and rehabilitated because of the existing underground duct system.

A preliminary design was developed that established the required size, number, and spacing of the rectifier substations. For the outlying areas, the feederless system selected was designed as a network of discrete sections of wire powered by the adjacent substations sharing the load. The system would thus provide continued service in the event of rectifier or primary power failure at any one substation. Dependent on the type of substation power failure, power would either feed through the DC bus from an adjacent substation, or feed the wire section up the DC switch gear in the failed substation. The 500-kW capacity (not a standard traction size) was accepted to provide a balance between substation spacing, forecast loads, and voltage regulation. The specifications called for 26 units consisting of 26.5 KV primary feed switch, a transformer, an AC circuit breaker, a solid-state rectifier, and DC switch gear. All associated hardware, buses, and wiring were to be enclosed in dead front cabinets for indoor use. The specifications for both the 500-kW and the 1,500-kW rectifiers became a mix of performance and hardware requirements. The specifications for both these rectifiers were not as strong as might be desired. However, because of predicted lead times, it was decided to attempt to refine the specifications on the rectifiers as soon as possible and proceed to advertise for bids.

In April 1976, a blanket notice to proceed was given to the design consultant firm for the remainder of design tasks with priority on rehabilitation work. In August 1977, the city agreed on the expansion routes that were to be electrified.

With the signing of the first supplement to the Transit Transfer Agreement, the final wire map was established. At this point, it was found that through routing could be accomplished. That is, new routes in the expansion area could be tied to existing routes in the rehabilitation area. This, in turn, raised several problems. First, it appeared that some of the routes in the rehabilitation area would not be used until the expansion routes had been constructed. Second, it meant that certain intersections that had already been final-designed in the rehabilitation area would have to be redesigned to accomplish the through routing of expansion routes. After all of the through routing had been decided on, the design effort was reprioritized. This effort placed the remaining design work in a holding pattern. These delays added to the cost of the design and later to the construction. Even then, there followed an almost continuous flow of requests for minor route revisions, revised intersections, turnback locations, and so forth, for practically the duration of the project. In every case, there was sound reasoning for making the revisions. However, the lack of timeliness was often detrimental to the schedule and to the budget of the project. Some revisions will be inevitable, but must be kept to a minimum if the project is to be completed within the time frame assigned and within budget.

Like any public works project, the trolley overhead program required a number of permits and approvals from a variety of agencies and organizations, including several city departments. As the project entered the final design and construction phases, it became apparent that the Seattle Engineering Department would have to play an active role. One of the major reasons was that the city was proceeding with several street improvement and utility underground projects, some of which were on the streets where the trolley overhead wire was to be installed. To minimize construction impact and also a proliferation of utility poles, detailed coordination among the projects was required. This resulted in a series of memoranda of agreement. Implementing the Transit Transfer Agreement, memoranda of agreement, permits, reviews, and schedule coordination activities soon became a complicated task.

Shortly after construction of the rehabilitation area began, it became evident that the support structure was posing the major problem for the project. As noted earlier, it had been decided to reuse the old support structure in the rehabilitation area and to use 4/0 hard-drawn copper wire in the outlying areas. Before this, the old wire had been 2/0 bronze and it soon became evident that the wood poles would require extensive guying to support the heavier weight of the new contact wire.

For years, a number of poles in the rehabilitation area had been shared by three different utilities. The uppermost area of the pole was occupied by Seattle City Light's transmission lines. Below these lines was the telephone company equipment that shared space with cable television lines. Finally, below the telephone company equipment were the attachments that held up the trolley overhead wire. To comply with Washington State Code, which required the contact wire be maintained at a height of 18 ft 6 in. above the street, it became evident that span wire and pull-off attachments would have to be raised on practically every pole. Innumerable instances were encountered where power and telephone line drops serving residences on the opposite side of the street came in conflict with the new trolley contact wire. City Light and the telephone company were reluctant to allow Metro's contractor to handle their equipment. This forced a detailed scheduling activity to resolve conflicts between the utility crews and Metro contractors. A comprehensive three-party agreement stipulating responsibilities and costs had to be negotiated. Even with such an agreement, each time a conflict arose, additional project costs and construction delays resulted.

In the CBD, the support system problems were different in nature. It was not anticipated that problems would arise regarding the installation of a new building eye bolt where one had existed for years. However, in early 1978, some of the building owners declined Metro permission to install the eye bolts. Although condemnation action through the right of eminent domain was possible, the delay due to such actions was considered unacceptable. This unanticipated situation resulted in adding poles, and, in some cases, redesigning the support system and negotiating change orders with the contractors. Underground problems also began to appear. In some cases, obstacles such as high-pressure natural gas lines and electrical conduit were not accurately reflected on city base maps. When such an obstacle forced relocation of an intersection pole by as much as several feet, recalculation of pull-off tensions and, in some cases, re-engineering of intersections were required.

In addition, the need for special foundations was not fully recognized in the plans and specifications. Bidders were indirectly advised in the specifications of the presence of areaways or storage space under sidewalks, but not all of these were specifically located. The contractor proceeded with the work apparently without conducting a thorough investigation of these situations. In March 1978 the contractor began to discover undisclosed areaways the hard way--by drilling into basements and underground parking garages. In each case, special foundations had to be designed and change orders negotiated with the contractor. Again, redesigns and construction delays added significant costs to the project.

In mid-1978, the contractors constructing the overhead system informed Metro that a shortage of journeymen-linemen was threatening progress. Construction of the overhead system was competing with high-voltage transmission line construction in the eastern part of the state. Work on the overhead subjected crews to heavy street traffic, city requirements that limited working hours to between 9:00 a.m. and 4:00 p.m., and construction tolerances measured in inches. The linemen were much more willing to work in more remote areas where differential pay was available, overtime was encouraged, and construction tolerances were not nearly as rigid. After negotiations with the union, it was agreed that as long as the overhead system was not energized, certain union personnel could be upgraded to work on the overhead provided that they were supervised by a journeyman-lineman. In addition, in some instances, overtime was authorized. Although this action had some negative impact on the budget, it did allow work to continue.

There are a multitude of factors that must be considered in designing and building a trolley bus overhead system. This paper has briefly outlined some of them. It is hoped that the Seattle experience will serve as a guide to other cities.

CHAPTER 7

What the Future Holds

Improved reliability, good looks, and economy have given the trolley bus a new lease on life, and its future is promising. Although no one in the transportation community expects the trolley bus to replace an existing public transit mode, it is believed that the trolley system can provide a viable alternative in high-density metropolitan areas.

SOME PERSPECTIVES

The relative attractiveness of the trolley bus has been increasing since the early 1970s. This development is due in large measure to the parallel increases in diesel fuel. Operators of existing systems in North America and other parts of the world now find it more cost effective to stay with electric power. Their decisions have been accompanied by the emergence of new trolley coach manufacturing capabilities in North America and Western Europe.

Advances in bus design and related technology also tend to enhance the future prospects of trolley bus application. The conversion potential of diesel buses to electrified trolley vehicles is one aspect that is receiving increased attention from both manufacturers and transit operators. That the trolley bus is just a regular bus with an electric motor instead of a diesel engine is both an advantage to users and a challenge to designers. The design challenge is rooted in the ability to address this subject and the vehicle's relationship to its infrastructure.

There is a kind of continuity and progression in the types of trolley buses ordered in the last 15 to 20 years that bespeak the durability not only of design but also of utility that can be attributed to the trolley bus. These vehicles have ranged from those with a new body and rehabilitated electrical gear, to an all-new bus with a 1940 design propulsion system, to the chopper-controlled vehicles built since 1978. The later buses with chopper controls have less modification to the motor bus body, and the propulsion system in a cradle structure is comparable to that used in the diesel version. This approach separates the task of building a bus from that of building the propulsion system.

Selected technologies can also be used by trolley bus operators to improve the performance and energy efficiency being obtained. Although the trolley bus already operates with low energy costs, further energy efficiencies appear possible. Electric vehicles also have the potential for recovering and reusing the energy involved in braking.

In addition, studies of the flywheel energy storage system for urban transit vehicles indicate that a flywheel can result in a dramatic reduction in the amount of overhead wire needed for trolley bus operation. Such a development could do a great deal to eliminate the unsightliness, maintenance, and capital costs of overhead wires. Furthermore, it would make deployment of new trolley bus systems attractive to many more cities.

Further study of the electrically floating body, i.e., insulation that performs better when wet and coated with dirt, control of static, and detection of a hot body condition without continual nuisance alarms is warranted as is an evaluation of fiberglass trolley poles. To date these have not been successful enough to displace the metal pole in use. The mechanical behavior of the current collection system merits the attention of manufacturers. Better current collectors would dewire less frequently, would be less likely to catch in the overhead, and would break off at a determined place and at a determined stress to minimize damage to the vehicle and the overhead system.

SUMMARY

In those cities that have trolley buses, public perception and support are favorable for improving and expanding the system. Cities such as Seattle and Dayton have experienced this public backing and with the support of community and professional organizations have involved elected officials in supporting system improvement and extension. This is not to say that there has not been opposition from those along the routes or those concerned with the aesthetics of the overhead, but rather that the public discussion resulted in a choice of the trolley bus. If and how this attitude can be transferred to non-trolley bus cities is worthy of consideration.

Few people are likely to claim that trolley buses are a panacea to urban transit ills. But there are applications that appear economically and operationally attractive. Economic, environmental, operational, and technological considerations must be examined for each application.

Economics

There is little disagreement that the operating and maintenance costs of trolley buses are lower than diesels because of the longer life of the equipment, reduced maintenance needs, and lower energy costs. On the other hand, the initial investment for vehicles and electrification can wash out these savings unless careful design is instituted to reduce both cost categories. The electrification of current bus designs appears to be one such cost saving. The economic results appear to be sensitive to local electrical costs and the kind of deal the operating agency can swing with the local utility.

Many people have observed that replacement of diesels with trolley buses appears to increase patronage. Factoring this aspect into the analysis and a close look at the operation strategy, such as timed transfers, which can improve patronage, also need to be included in an assessment of the economics.

Environment and Energy

All of the data presented at the workshop indicate that the trolley bus is less energy-intensive than diesels on a seat basis. This factor becomes even more attractive if the electricity is generated from non-petroleum sources. Environmentally, the trolley bus is quieter and free of diesel emissions, which increases its attractiveness in high-density areas and especially in restricted areas such as transit malls. The overhead system is a visual problem, although that effect can be reduced by good design and the use of feederless systems. This visual intrusion appears to be more of a concern in cities unfamiliar with trolley buses than in those that have them.

Technology

The most exciting aspect of modern trolley bus systems is that of the technological innovations. Chopper control that can improve performance and reduce power consumption, AC propulsion systems that can be less expensive and lighter, automatic pole raising and lowering, improved methods to reduce dewiring, and off-wire operational capabilities all increase the attractiveness of the mode.

This is not to say that there are not technical problems to be resolved. Vehicle weights appear to be getting out of hand. A better understanding is needed of the various technologies for off-wire operation--batteries, flywheels, and internal combustion engines. Procurement procedures for vehicles and systems need to be improved. Formal knowledge of trolley buses and the overhead system needs to be increased. Adequate means to provide standards, specifications, and product documentation are needed.

Research is needed on insulation, EMI, detection of electrically hot bodies without continual false alarms, fiberglass poles, and the mechanical behavior of the current collection system. These problems are more in the nature of hindrances than obstacles and all are solvable with a modest amount of research support.

CONCLUSION

If there is one single message from the workshop, it is that the trolley bus can provide a useful transit function and that any city considering the improvement of its transit capabilities should look closely at this mode.

Much work and progress have occurred already, contributing to the reemergence and reawakening of interest in the trolley bus since the early 1970s; but it is recognized by operators, manufacturers, and suppliers that more must be accomplished if the current momentum is to be maintained. Herein rest the challenge and the future for the trolley bus.

APPENDIX A

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APPENDIX B

Committee Members

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